AECOM

AECOM 314 429 0100 tel
1001 Highlands Plaza Drive West 314 429 0462 fax
Suite 300
St. Louis, MO 63110-1337
www.aecom.com

April 6, 2017

Ms. Joyce Munie, P.E.
Manager, Permit Section
Illinois Environmental Protection Agency
Bureau of Land
1021 North Grand Avenue East
Springfield, Illinois 62794

TACO Tier 3 Demonstration
Roxana, Illinois
1191150002 – Madison County
Equilon Enterprises, LLC d/b/a Shell Oil Products US

Dear Ms. Munie:

On behalf of Equilon Enterprises, LLC d/b/a Shell Oil Products US (SOPUS), AECOM is submitting the enclosed TACO Tier 3 Demonstration (Report). SOPUS' goal with this submittal is to present and obtain approval from the Illinois Environmental Protection Agency (IEPA) for site-specific Tier 3 remediation objectives (ROs) for soil gas. Based on a comparison of site data to the calculated Tier 3 soil gas ROs, it is SOPUS's opinion that the site data meets the proposed RO's. However, in order to determine this compliance, rebound monitoring must be completed with the Regenerative Thermal Oxidizer (RTO) turned off. Once the RTO Soil Vapor Extraction (SVE) system operations are turned off, a rebound monitoring program will be initiated to assess compliance with the soil gas ROs in the Village of Roxana and the Public Works Yard. This rebound monitoring program along with the ROs are proposed within this submittal.

The Report is presented in two parts for ease of review:

<u>Part 1</u>- Site Characterization Summary, presents an overview of site history and past investigations, site geology and hydrogeology, the nature and extent of petroleum hydrocarbons in soil, soil gas and indoor air, as well as temporal changes in soil gas since the startup of the SVE system. Part 1 also presents a conceptual site model (CSM) for both pre-SVE and conditions based on soil gas data through 4th quarter 2016 (4Q16) presented in the Site Characterization Summary. The presentation of temporal data provides strong evidence supporting the effectiveness of the SVE system in remediating soil gas which supports the development of Tier 3 ROs and for establishing a path forward to permanent SVE system shutdown and dismantlement.

<u>Part 2</u>- Tier 3 Proposal, begins with a summary of the key site characterization conclusions from Part 1, then presents an introduction to the Johnson & Ettinger (J&E) and Little, Daisy, Nazaroff (LDN) models and the overall mass flux model approach to calculating soil gas concentration end points that are protective of indoor air. Part 2 discusses the inputs used to calculate the LDN model values and presents the modeling results. Based on the results of the LDN modeling, Tier 3 ROs are presented. Using the proposed remediation objectives, Part 2 outlines suggested system shutdown and a rebound monitoring program.

AECOM and SOPUS would like to schedule a meeting to discuss the contents of the TACO Tier 3 Demonstration. If you have any questions during your review, please contact Kevin Dyer, SOPUS Senior Principal Program Manager, at kevin.dyer@shell.com (618-288-7237), or Robert Mooshegian at robert.mooshegian@aecom.com (314-743-4106).

Sincerely,

AECOM, on behalf of Shell Oil Products US

Claire Mitchell

Claire Mitchell, P.E.
Senior Engineer

Robert B Billman

Robert Billman, P.G.
Senior Project Manager

Robert E. Mooshegian, CHMM
Senior Program Manager

Enclosures: TACO Tier 3 Demonstration (Part 1 and Part 2)
Illinois EPA RCRA Corrective Action Certification Form (2 copies)

cc: James Moore, IEPA, Springfield
Gina Search, IEPA, Collinsville
Yuping Ding, IDPH
Kevin Dyer, SOPUS
Eric Petersen, Phillips 66
Shannon Haney, Greensfelder, Hemker & Gale, P.C.
Robert Ettinger, Geosyntec Consultants, Inc.
Repositories – Roxana Village Hall, Roxana Public Library, website
Project Central File

AECOM

AECOM
1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110-1337
www.aecom.com

314 429 0100 tel
314 429 0462 fax

April 27, 2017

Ms. Joyce Munie, P.E.
Manager, Permit Section
Illinois Environmental Protection Agency
Bureau of Land
1021 North Grand Avenue East
Springfield, Illinois 62794

TACO Tier 3 Demonstration – Corrections to Part 1, Table 3-4 and Appendix 3-E
Roxana, Illinois
1191150002 – Madison County
Equilon Enterprises, LLC d/b/a Shell Oil Products US

Dear Ms. Munie:

On behalf of Equilon Enterprises, LLC d/b/a Shell Oil Products US (SOPUS), AECOM is submitting a corrected version of Part 1 Table 3-4, Summary of Soil Gas Analytical Detections and Screening Results – VOCs, and Part 1 Appendix 3-E, Cumulative Summary of Soil Gas Analytical Detections and Screening Results – VOCs, as well as a corrected Part 1 Table of Contents. Data associated with certain vapor monitoring points were inadvertently not included in the aforementioned Table and Appendix in the TACO Tier 3 Demonstration transmitted to you on April 6, 2017. Paper copies of the corrected Table of Contents and Table 3-4, and a DVD containing the revised TACO Tier 3 Demonstration are included. Replacement pages are noted as “Revision 1”.

If you have any questions, please contact Kevin Dyer, SOPUS Senior Principal Program Manager, at kevin.dyer@shell.com (618-288-7237), or Robert Mooshegian at robert.mooshegian@aecom.com (314-743-4106).

Sincerely,

AECOM, on behalf of Shell Oil Products US

Claire Mitchell

Claire Mitchell, P.E.
Senior Engineer

Robert B Billman

Robert Billman, P.G.
Senior Project Manager

Robert E Mooshegian

Robert E. Mooshegian, CHMM
Senior Program Manager

Enclosures: TACO Tier 3 Demonstration (Revised Part 1 Table of Contents and Table 3-4 (hard copy) and DVD (TACO Tier 3 Demonstration package)

cc: James Moore, IEPA, Springfield
Gina Search, IEPA, Collinsville
Yuping Ding, IDPH
Kevin Dyer, SOPUS
Eric Petersen, Phillips 66
Shannon Haney, Greensfelder, Hemker & Gale, P.C.
Robert Ettinger, Geosyntec Consultants, Inc.
Repositories – Roxana Village Hall, Roxana Public Library, website
Project Central File

Illinois Environmental Protection Agency

Bureau of Land • 1021 North Grand Avenue East • P.O. Box 19276 • Springfield • Illinois • 62794-9276

ILLINOIS EPA RCRA CORRECTIVE ACTION CERTIFICATION

This certification must accompany any document submitted to Illinois EPA in accordance with the corrective action requirements set forth in a facility's RCRA permit. The original and two copies of all documents submitted must be provided.

1.0 Facility Identification

Name WRB Refining LP Wood River Refinery
County Madison
Street Address 900 South Central Avenue
Site No. (IEPA) 1191150002
City Roxana
Site No. (USEPA) ILD080012305

2.0 Owner Information

Name Not Applicable
Mail Address
City
State Zip Code
Contact Name
Contact Title
Phone

3.0 Operator Information

Name Equilon Enterprises LLC dba SOPUS
Mail Address 17 Junction Drive, PMB #399
City Glen Carbon
State IL Zip Code 62034
Contact Name Kevin Dyer
Contact Title Senior Principal Program Manager
Phone 618-288-7237

4.0 Type of Submission (check applicable item and provide requested information, as applicable)

☐ RFI Phase I Workplan/Report
☐ RFI Phase II Workplan/Report
☐ CMP Report;
☑ Other (describe):
TACO Tier 3 Demonstration: Parts 1 and 2

IEPA Permit Log No. B-43R
Date of Last IEPA Letter on Project Jan 18, 2017
Log No. of Last IEPA Letter on Project B-43R-CA-59, -60, -69
Does this submittal include groundwater information: ☐ Yes ☑ No

Date of Submittal April 6, 2017

5.0 Description of Submittal: (briefly describe what is being submitted and its purpose)

Site Characterization Summary (Part 1) and Tier 3 Proposal (Part 2) related to the SVE System for the project area in Roxana, Illinois. Copies separately sent to Jim Moore and Gina Search.

6.0 Documents Submitted (identify all documents in submittal, including cover letter; give dates of all documents)

Cover Letter dated April 6, 2017, RCRA Corrective Action Certification, TACO Tier 3 Demonstration Part 1: Site Characterization Summary, and TACO Tier 3 Demonstration Part 2: Tier 3 Proposal (2 copies submitted)

7.0 Certification Statement

(This statement is part of the overall certification being provided by the owner/operator, professional and laboratory in Items 7.1, 7.2 and 7.3 below). The activities described in the subject submittals have been carried out in accordance with procedures approved by Illinois EPA. I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

IEPA RCRA Corrective Action Certification

For: TACO Tier3Demonstration Pts 1 & 2

Date of Submission: April 6, 2017

7.1 Owner/Operator Certification

(Must be completed for all submittals. Certification and signature requirements are set forth in 35 IAC 702.126.) All submittals pertaining to the corrective action requirements set forth in a RCRA Permit must be signed by the person designated below (or by a duly authorized representative of that person):

1. For a Corporation, by a principal executive officer of at least the level of vice president.
2. For a Partnership or Sole Proprietorship, by a general partner or the proprietor, respectively.
3. For a Governmental Entity, by either a principal executive officer or a ranking elected official.

A person is a duly authorized representative only if:

1. the authorization is made in writing by a person described above; and
2. the written authorization is provided with this submittal (a copy of a previously submitted authorization can be used).

Owner Signature: ______________________ Date: ____________

Title: ______________________

Operator Signature: Kevin E Dyer Date: 3/29/17

Title: Senior Principal Program Manager

7.2 Professional Certification (if necessary)

Work carried out in this submittal or the regulations may also be subject to other laws governing professional services, such as the Illinois Professional Land Surveyor Act of 1989, the Professional Engineering Practice Act of 1989, the Professional Geologist Licensing Act, and the Structural Engineering Licensing Act of 1989. No one is relieved from compliance with these laws and the regulations adopted pursuant to these laws. All work that falls within the scope and definitions of these laws must be performed in compliance with them. The Illinois EPA may refer any discovered violation of these laws to the appropriate regulating authority.

Any person who knowingly makes a false, fictitious, or fraudulent material statement, orally or in writing, to the Illinois EPA commits a Class 4 felony. A second or subsequent offense after conviction is a Class 3 felony. (415 ILCS 5/44 (h))

Professional's Signature: Robert Billman Date: 4/5/17

Professional's Name Robert B. Billman

Address 1001 Highlands Plaza Dr West, Suite 300

City St. Louis

State MO Zip Code 63110

Phone 314-429-0100

Professional's Seal:

ROBERT B. BILLMAN
196-000646

7.3 Laboratory Certification (if necessary)

The sample collection, handling, preservation, preparation and analysis efforts for which this laboratory was responsible were carried out in accordance with procedures approved by Illinois EPA.

Name of Laboratory Not Applicable

______________________ Date: ____________

Signature of Laboratory Responsible Officer

Mailing Address of Laboratory

Address ______________________

City ______________________

State _____ Zip Code ____________

____

Name and Title of Laboratory Responsible Officer

Design and
Consulting Services
Environmental

Submitted to:
Illinois Environmental
Protection Agency-
Bureau of Land
1021 North Grand Ave. East
Springfield, IL 62794

Submitted by:
AECOM
1001 Highlands Plaza Drive West,
Suite 300
St. Louis, MO 63110

TACO Tier 3 Demonstration Part 2: Tier 3 Proposal

Equilon Enterprises LLC d/b/a Shell Oil Products US Roxana, Illinois

April 2017
Project Number: 60527968

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Executive Summary

On behalf of Equilon Enterprises LLC, d/b/a Shell Oil Products US (SOPUS), AECOM Technical Services, Inc. (AECOM) is submitting this Tiered Approach to Corrective Action Objectives (TACO) Tier 3 Demonstration ("Report"). The Report has been reviewed by Robert Ettinger of Geosyntec Consultants, Inc.

Since 2006, SOPUS, at the direction of the Illinois Environmental Protection Agency (IEPA), has been conducting subsurface investigations in the Village of Roxana in the area generally bounded by the alley north of East 1st Street (1st Street), the Roxana Public Works Yard, Illinois Route 111 (a/k/a South Central Avenue), and the property boundary ("West Fenceline") of the WRB Refining, LP (WRB)[1] Wood River Refinery (WRR) ("Investigation Area" or "the Site") and has operated soil vapor extraction (SVE) remediation in the vicinity of Chaffer Avenue along the West Fenceline since May 10, 2011. SOPUS' goal with this submittal is to present and obtain approval from the IEPA for site-specific Tier 3 remediation objectives (ROs) for soil gas. Based on a comparison of site data to the Tier 3 soil gas ROs, SOPUS recommends that the Regenerative Thermal Oxidizer (RTO) SVE system (SVE system) be turned off and a rebound monitoring program will be initiated. The results of the rebound monitoring will be used to assess if SOPUS' remedial efforts related to soil gas in this area are complete.

The IEPA's TACO rules (35 Illinois Administrative Code [IAC] 742) present procedures for developing soil gas remediation objectives under Tier 2 including using the Johnson & Ettinger (J&E) model. Under the Tier 2 assessment, TACO requires that institutional controls be implemented requiring future buildings are constructed with "*a full concrete slab-on-grade or a full concrete basement floor and walls*" (Section 742.1000(a)(9)). The Tier 3 ROs developed have been calculated assuming that a concrete slab-on-grade or full-concrete basement floor and walls are not present so that the institutional controls required under a Tier 2 assessment are not needed. The Little, Daisey, Nazaroff model (Little, et al., 1992) was used to develop the Tier 3 ROs. This model, hereafter referred to as LDN, is applied to buildings without concrete slabs or concrete basements.

Data presented in Part 1 of this Report support the conclusion that biodegradation of hydrocarbon vapors is occurring at the Site. However, the proposed Tier 3 ROs do not account for the effects of biodegradation on the migration of petroleum compounds in the vadose zone which incorporates added conservatism to the assessment.

Data presented in this Report demonstrate that soil gas has been remediated through the intermediate zone (e.g., to a depth of 20 feet below ground surface (bgs)). Soil gas data were compared to the proposed Tier 3 ROs within the shallow zone (e.g., to a depth of 10 feet bgs) and current soil gas concentrations meet the proposed ROs in the residential and construction worker areas[2]. Higher concentrations have been detected in samples collected at depth (e.g., below 20 feet) in certain areas; however, shallow data collected at these locations show that attenuation mechanisms decrease concentrations to below the objectives at shallow depths and the vapor intrusion (VI) pathway is not complete.

Since the site data meet the Tier 3 ROs, SOPUS proposes to shut down active SVE operations and begin a one year rebound monitoring demonstration period. The rebound monitoring program includes triggers for increased monitoring and restart of the SVE system should conditions change.

This document is presented in two parts for ease of review:

Part 1- Site Characterization Summary, presents an overview of site history and past investigations, site geology and hydrogeology, the nature and extent of petroleum hydrocarbons (PHC) in soil, soil gas and indoor air, as well as temporal changes in soil gas since the startup of the SVE system. Part 1 also presents a conceptual site model (CSM) for both pre-SVE and conditions based on data through 4th quarter 2016 (4Q16) presented in the Site Characterization Summary. The

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[1] WRB, formed January 1, 2007, is a 50/50 joint venture between ConocoPhillips (COP) and EnCana US Refineries, LLC (now known as Cenovus Energy, Inc.). ConocoPhillips Company announced the separation of the Refining and Marketing business from the Exploration and Production business on July 14, 2011. The separation included an ownership change as well as a name change that became effective May 1, 2012. Phillips 66 is now the operator of the WRB WRR.

[2] With two outliers which are discussed in **Section 2.2.1**.

presentation of temporal data presents evidence of the effectiveness of the SVE system in remediating soil gas and supports the development of a path forward to permanent SVE system shutdown and dismantlement. Supporting tables, figures, and appendices are included.

Part 2- Tier 3 Proposal, begins with a summary of the key site characterization conclusions from Part 1, then introduces the J&E and LDN models and the overall mass flux model approach to calculating soil gas concentration end points that are protective of indoor and trench air. Part 2 discusses the inputs used to calculate the LDN model values and presents the modeling results. Based on the results of the LDN modeling, Tier 3 remediation objectives are proposed. Using the proposed remediation objectives, Part 2 outlines suggested system shutdown and a rebound monitoring program.

1 Introduction to Tier 3 Proposal

1.1 Key Site Characterization Conclusions

SOPUS has been conducting investigations and performing active remediation at the Site under the oversight of IEPA and Illinois Department of Public Health (IDPH) for approximately 10 years. Both Agencies have provided technical input and approvals on an ongoing basis and, in coordination with SOPUS, have kept the community informed throughout the various investigations and remedial activities. The data collected through investigations and monitoring events were used to create an extensive database that has been used to characterize the Site and document reductions in soil gas concentrations over time.

The following bullets summarize key points and conclusions that have been presented in Part 1 of this Report:

- Soil gas data collected over the past 6 years of SVE system operation demonstrate a significant reduction in hydrocarbon concentration in the subsurface, particularly in the shallow and intermediate zones.
- Site soil conditions have been assessed at over 190 soil boring locations. The information derived from the borings has demonstrated subsurface materials are primarily sands, along with the presence of relatively thin, discontinuous layers of finer-grained, lower permeability soils (silts and clays) located sporadically throughout the Site, typically at depths between approximately 20 to 30 feet bgs. Petroleum impacts were more apparent in the finer-grained materials.
- Over 330 soil samples have been collected for laboratory testing for compounds characteristic of petroleum hydrocarbons. These compounds were more pronounced in the discontinuous lower permeability soil zones prior to remediation and at depth (influenced by groundwater conditions).
- Over 3,300 soil gas samples have been collected and analyzed and over 17,000 soil gas samples have been collected and field-screened. Collectively, the nature and extent of petroleum impacts in soil gas and the reductions in concentrations that have occurred since startup of the SVE system are well defined.
- Indoor air and sub-slab conditions were evaluated at over 50 structures, with no instances of vapor intrusion. Most of the indoor air and sub-slab sampling occurred prior to construction of the SVE system. Petroleum vapors were elevated in soil gas beneath five homes, and even though indoor air was not affected, a conservative approach was adopted, and interim measures were taken to mitigate sub-slab vapors until the SVE system was operational.
- Groundwater is being managed through the current groundwater monitoring program including the groundwater containment and treatment system. A Groundwater Management Zone (GMZ) proposal was submitted to the IEPA on May 19, 2016, and is pending as of the date of this Report (AECOM, 2016). The GMZ was prepared as requested by the IEPA in their letter to SOPUS dated February 23, 2016 in which the IEPA agreed with the conclusion that groundwater within the Village of Roxana has been delineated (IEPA, 2016).
- The Interim SVE system operated from May 10, 2011 until the RTO SVE System began operation on January 31, 2012. The RTO SVE System was extended in 2013 and 2014, and consists of 45 SVE wells, over 50% of which have been closed over the past 3 years as soil gas data demonstrates the shallow and intermediate zones have been remediated.

1.2 Overview of Tier 3 Proposal

As discussed in Part 1 of this report, under Tier 1 and Tier 2 of TACO, the J&E model is used to calculate acceptable soil gas concentrations. Since intact concrete foundations are a premise of J&E as interpreted within TACO, TACO requires institutional controls to address future building construction when Tier 1 or Tier 2 assessments are conducted. Under the current TACO regulations, there is not a clear path to site closure without the implementation of institutional controls. From a long term site management perspective, this creates an issue whereby soil gas can be remediated to conditions that are protective, yet ongoing management would still be necessary. For the Site, this outcome is not practicable. However, in TACO, a Tier 3 assessment allows for site specific modeling that could enable closure of a site without institutional controls (Section 742.900(c)). As a result, this proposal uses the Little, Daisey, Nazaroff model (1992), to develop Tier 3 ROs. The LDN model provides for calculation of target soil gas concentrations without assuming the presence of concrete foundations, which allows for ROs that do not require long-term institutional controls.

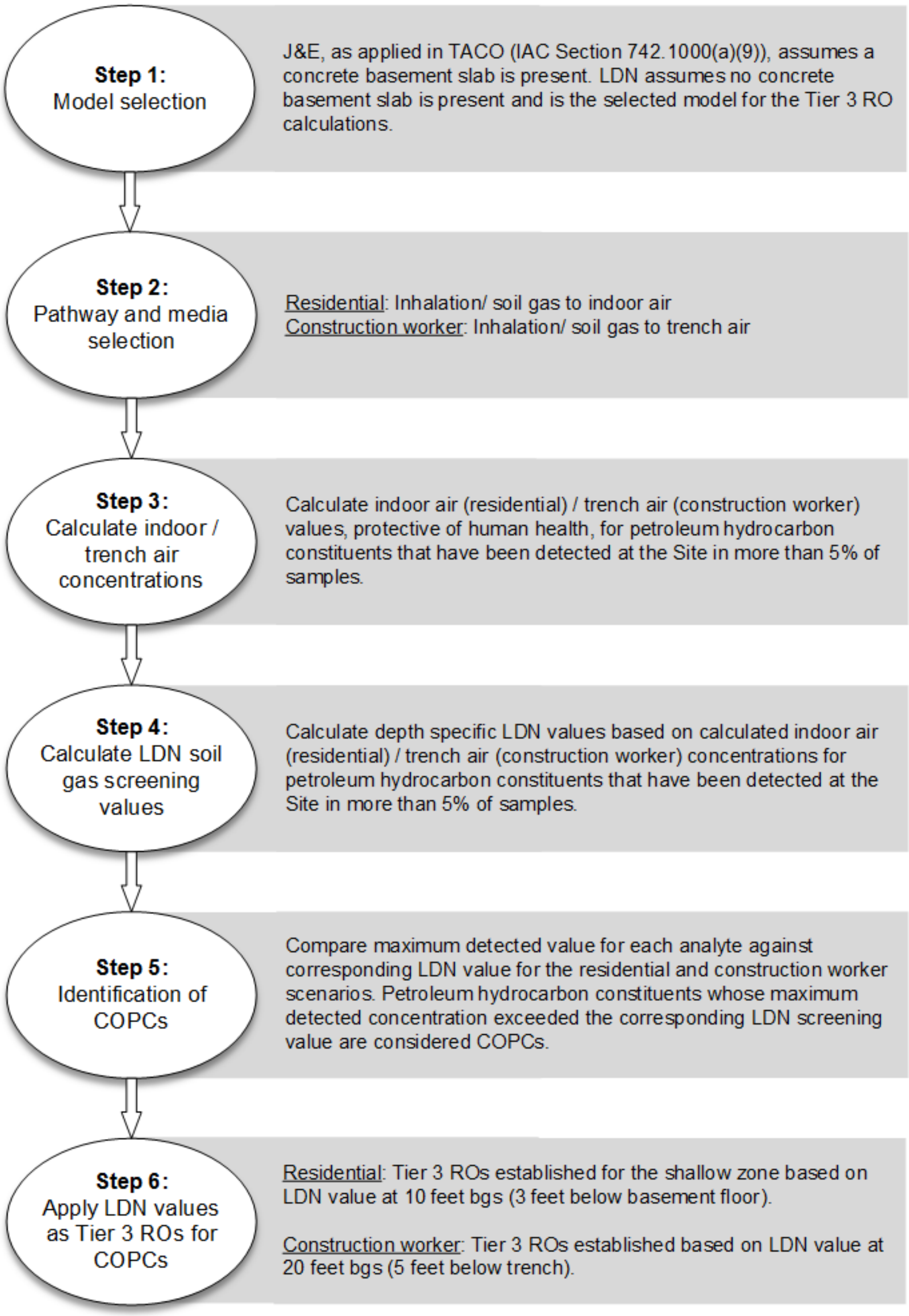
The subsequent sections of Part 2 of this report include the following:

- **Section 2** describes the LDN modeling effort, including: (1) the process to identify constituents of potential concern (COPCs); (2) comparison of J&E and LDN models; (3) model inputs and modeled results (i.e., Tier 3 ROs); and (4) comparison of Site data to the ROs.
- **Section 3** presents the proposed rebound monitoring program to be implemented following shut down of the system during an established demonstration period. Potential rebound can only be assessed during a shutdown of the system in the absence of SVE system vacuum. **Section 3** describes the basis for the rebound monitoring program, the details of the monitoring program and triggers for enhanced monitoring and potential restart of the system.
- **Section 4** presents the conclusions of the Tier 3 Demonstration, summarizing key points described in Part 1, the process for the development of the proposed Tier 3 ROs (**Section 2**) and the proposed rebound monitoring program (**Section 3**).

2 Development of Tier 3 Remediation Objectives

The fate and transport of benzene and other VOCs was evaluated using mathematical models. The primary purpose was to determine soil gas concentrations at specific depths for constituents that have been detected at the site that would be protective of human health. The calculated soil gas concentrations are proposed Tier 3 ROs and represent a concentration that would not lead to an exceedance of risk-based air concentrations for vapor intrusion (VI) into residential structures or vapor transport to a trench for a construction worker scenario. **Exhibit 2-1** below summarizes the process for development of the Tier 3 ROs which is described in detail in subsequent sections.

Exhibit 2-1: Tier 3 RO Development Process



Step 1: Model selection

J&E, as applied in TACO (IAC Section 742.1000(a)(9)), assumes a concrete basement slab is present. LDN assumes no concrete basement slab is present and is the selected model for the Tier 3 RO calculations.

Step 2: Pathway and media selection

Residential: Inhalation/ soil gas to indoor air
Construction worker: Inhalation/ soil gas to trench air

Step 3: Calculate indoor / trench air concentrations

Calculate indoor air (residential) / trench air (construction worker) values, protective of human health, for petroleum hydrocarbon constituents that have been detected at the Site in more than 5% of samples.

Step 4: Calculate LDN soil gas screening values

Calculate depth specific LDN values based on calculated indoor air (residential) / trench air (construction worker) concentrations for petroleum hydrocarbon constituents that have been detected at the Site in more than 5% of samples.

Step 5: Identification of COPCs

Compare maximum detected value for each analyte against corresponding LDN value for the residential and construction worker scenarios. Petroleum hydrocarbon constituents whose maximum detected concentration exceeded the corresponding LDN screening value are considered COPCs.

Step 6: Apply LDN values as Tier 3 ROs for COPCs

Residential: Tier 3 ROs established for the shallow zone based on LDN value at 10 feet bgs (3 feet below basement floor).

Construction worker: Tier 3 ROs established based on LDN value at 20 feet bgs (5 feet below trench).

2.1 Tier 3 Remediation Objectives

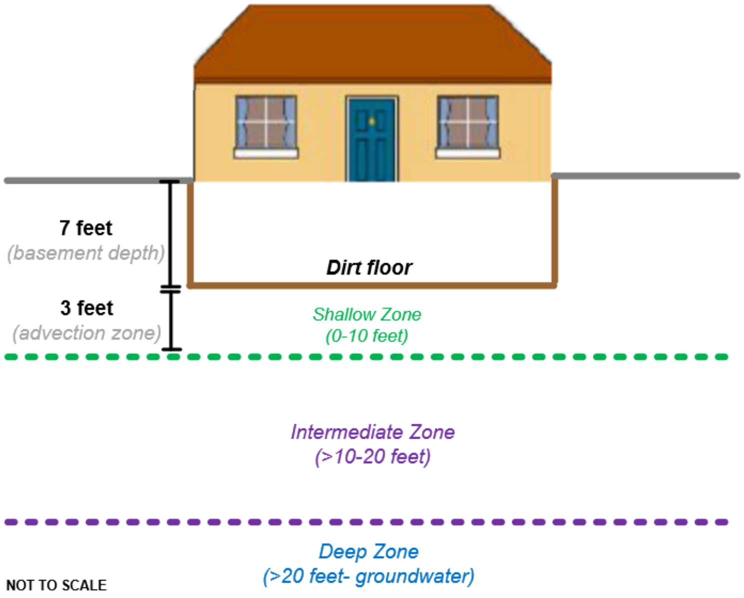
Given the characterized impact at the Site is primarily VOCs as discussed in **Section 1**, for modeling purposes, the inhalation via indoor air was considered primary exposure pathway for residents; therefore, considered for evaluation for soil gas concentrations that are protective of human health. For the construction worker scenario, the ingestion and dermal contact exposure pathways are managed through controls such as safe work plans. As such, inhalation via air in a trench was considered for evaluation for soil gas concentrations that are protective of human health for a construction worker scenario. The LDN model is used to evaluate the inhalation exposure pathway for the residential and construction worker scenarios.

The IEPA TACO rules lay out procedures for developing soil gas ROs using the J&E model under Tier 2. The J&E model has been incorporated into Microsoft Excel® (Excel) spreadsheets by the United States Environmental Protection Agency (USEPA), and these spreadsheets are the default regulatory tool for VI modeling. Under Tier 3, the option of using an alternative model is also allowable (35 IAC 742.110d, 35 IAC 742.300c, and 35 IAC 742.900).

When developing Tier 3 ROs, the selected model assumes no building slab is present (i.e., assumes a basement or crawl space with a dirt floor). For the purposes of this Tier 3 Demonstration, the LDN (1992) model was used (**Appendix 2-A**). The LDN model can be applied to buildings without slabs/concrete basements as well as excavation trenches with dirt walls and bottom. This concept was used for development of Tier 3 ROs for both residential and construction worker scenarios. The approach of deriving Tier 3 ROs using the LDN model will not require the use of restrictions on property because the ROs are not conditioned on intact concrete foundations.

A schematic demonstrating the proposed application of Tier 3 ROs under the residential scenario is shown in **Exhibit 2-2**.

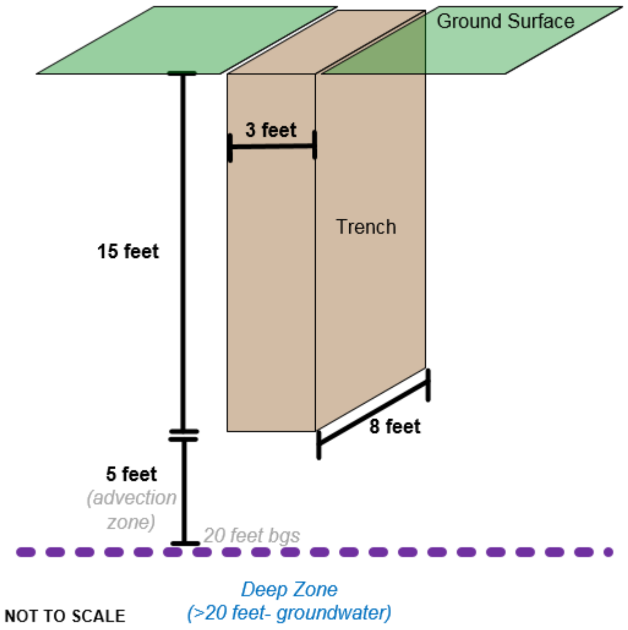
Exhibit 2-2: Application of Tier 3 ROs in Residential Scenario



For the construction worker scenario, even though a trench is not fully enclosed like a building, the air circulation and wind velocity within the trench may be lower than values on ground surface depending upon its depth and alignment. If the trench is of sufficient depth, a construction worker breathing zone may be located below the ground surface. Estimating air concentrations within an excavation trench is akin to using a box (or room) model where the box represents the construction worker's breathing zone while standing in a trench.

A schematic demonstrating the proposed application of Tier 3 ROs under the construction worker scenario is shown in **Exhibit 2-3** below.

Exhibit 2-3: Application of Tier 3 ROs in Construction Worker Scenario



2.1.1 Introduction to Johnson & Ettinger and Little, Daisey, Nazaroff Models

The J&E model is the selected vapor intrusion model in TACO, thus a brief summary of J&E is provided below followed by a discussion on how the LDN model compares. Both are mass flux models based on Fickian diffusion through soil and include advective flux (pressure-driven flow) into the building; therefore, there are more similarities than there are differences. Neither model takes into account biodegradation or other transformations during transport.

2.1.1.1 Johnson & Ettinger

The J&E model calculates the following:

- Transport rate of soil gas through the vadose zone;
- Transport rate of contaminants from soil gas into structures; and
- Transport rate of indoor air out of the building.

The J&E model combines the equations for each of these transport components to calculate the indoor air concentration based on a soil vapor concentration.

The transport rate of soil gas through the vadose zone is assumed to be due to diffusion only. The rate of diffusion is calculated using Fick's First Law and depends on the concentration gradient, diffusivity, and distance. The diffusive transport rates for VOCs are largely dependent on the air-filled porosity of the soil, which in turn is dependent on the type of soil, its degree of compaction, and its moisture content. The effective diffusivity is calculated using the Millington-Quirk relationship.

The J&E model can be used to evaluate the vapor intrusion pathway for buildings with either basements or slab-on-grade construction. In both cases, it is assumed that cracks are present and serve as pathways for vapor transport as opposed to permeation through the building materials themselves. The J&E model assumes that advection is the dominant transport mechanism across the building foundation and that all vapors from underlying media will eventually enter the building. Similarly, the default assumptions in TACO (i.e., assumed soil gas convection rate) assume that soil vapor beneath the basement will be pulled into the building. Additonal assumptions are that vapors from the underlying media will all enter the building and will not migrate laterally or otherwise by-pass the building. The rate of transport into the buildings is not specified in the J&E model and is largely dependent on the pressure differential between the soil and the basement or structure and the area of any cracks or openings.

The concentration of the contaminant in the indoor space is calculated using a steady-state mass balance approach that assumes no other contaminant sources or sinks and a well-mixed building atmosphere. For a given rate of vapor intrusion, the resulting concentration within the building depends on the rate of building ventilation, which is expressed in terms of air changes per hour (ACH). The rate of vapor intrusion (Q_{soil}) is usually conservatively assumed to be 5 Liter (L)/min for a residential size building over coarse-grained soils. This value takes into account the advective flow present due to pressure differentials.

Overall, J&E is a mass flux model; it describes mass flow per unit area. The rate of mass flow depends on the concentration gradient, so the higher the starting soil gas concentration, the higher the rate of mass flow. If there are multiple soil layers present, the overall mass transport rate can be no higher than the rate through the soil layer with the lowest effective diffusivity.

In VI studies, the use of an attenuation factor or coefficient (α) is frequently employed. It is the ratio of indoor air concentration to soil gas concentration. If the attenuation factor is known or estimated, soil gas data can be used to predict indoor air quality impacts. A comparison of the J&E model to the LDN model is described in **Section 2.1.1.3**.

2.1.1.2 Little, Daisey, Nazaroff

Little, Daisey, Nazaroff published equations to predict the transport of subsurface contaminants into buildings for various scenarios, including diffusion through unsaturated porous media from a planar source of contamination some distance from a building. The areal extent of the source is assumed to be substantially greater than the footprint of the building. The effective diffusion is calculated using the diffusion coefficient of the VOC in air and soil porosity information. The entire flux of VOC arriving at the zone of influence near the basement floor is assumed to be swept into the building via advection.

The flux of VOCs through the soil is multiplied by the appropriate cross-sectional area to calculate the mass flow of VOCs that enters the building. The indoor air concentration (C_{indoor}) is estimated as the rate of VOC mass entering the building divided by the volumetric flow rate of air through the building (Q_b). A transient solution for the attenuation coefficient (α) is (**Appendix 2-A, Equation 5**):

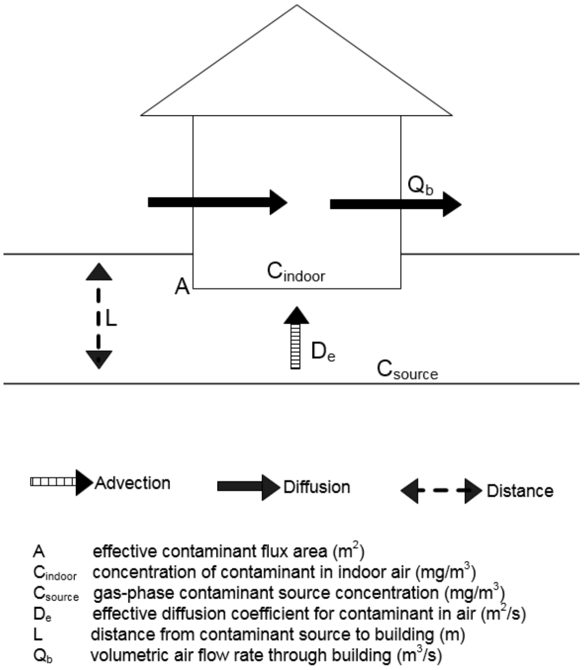
$$\alpha = \frac{C_{\text{indoor}}}{C_{\text{source}}} = \left(\frac{D_e A}{L Q_b}\right)(1 + 2\sum_{n=1}^{\infty} (\cos(n\pi)\exp(-D_e n^2 \pi^2 t / R\epsilon_a L^2)))$$

At infinite time, the summation term reduces to zero, yielding the steady-state solution as defined below.

$$\alpha = \frac{C_{indoor}}{C_{source}} = \frac{D_e\, A}{L\, Q_b}$$

A schematic demonstrating this concept is provided in **Exhibit 2-4** below.

Exhibit 2-4: Schematic representation of the subsurface transport of VOCs from a planar source (Little, et al., 1992)



2.1.1.3 Comparison of J&E to LDN

The LDN model is very similar to the J&E model. The J&E model, as described in IEPA and USEPA documents, and the LDN model as applied in this Tier 3 Demonstration are compared in **Exhibit 2-5** below with differences shaded grey.

Exhibit 2-5: Comparison of J&E to LDN Model

Concept	J&E Model	LDN Model
Basis of model	Mass flux	Mass flux
Starting contaminant input	Soil gas concentration	Soil gas concentration
Soil description	Single soil layer	Single soil layer
Transport through soil	Diffusion	Diffusion
Rate of diffusion	Fick's First Law	Fick's First Law
Effective diffusivity	Millington-Quirk relationship	Millington-Quirk relationship
Aerobic biodegradation	Not taken into account	Not taken into account
Presence of building slab	Yes	No
Transport across building slab	Assumed resistance	Assumed no resistance
Advective flow into building	Yes	Assumed to take place
Indoor space	One compartment, well-mixed	One compartment, well-mixed
Building ventilation	Q_b = Volume x ACH	Q_b = Volume x ACH

As indicated above, the only difference between the J&E model and the LDN model as used in this Tier 3 Demonstration is the absence of a building slab/concrete basement in the LDN model.

The two models will yield very similar results when comparing equivalent (to the extent possible) input parameters: 99% crack in J&E and no slab in LDN (e.g., soil). For a given soil gas concentration at depth, the transport through the soil will be essentially identical. In other words, the amount of attenuation in soil gas concentration for a given distance will be comparable. The main difference is that the J&E model incorporates attenuation or resistance across a building slab, whereas this is not taken into account in the LDN model. Therefore, the J&E model is less conservative and will always predict somewhat lower indoor air concentrations than the LDN model for a given soil gas concentration and set of input values.

The LDN model includes an advective component, whereby it is assumed that vapors are swept into the building by a pressure differential. The LDN model calculates a flux into the building (i.e., an emission rate per area) that essentially assumes a large value for Q_{soil}. The absence of a slab would tend to reduce the pressure differential and the rate of advective flow would be reduced, so the model predictions for indoor air impacts and sub-basement floor soil-gas concentrations are both biased conservative.

2.1.2 LDN Model Inputs

The LDN model calculations and inputs are provided in **Appendix 2-B: Tables 1** through **4** and are summarized below for both the residential and construction worker scenarios.

Residential

Input parameters for the residential scenario were TACO default values as provided in TACO, 35 IAC Part 742, Appendix C, Table M (Illinois Pollution Control Board [IPCB], 2013). It is important to note the J&E and LDN models' input parameters are generally the same; it is the treatment of the building foundation that is different, not other VI modeling input parameters that differ.

Construction Worker

Chemical and soil properties were the only TACO parameters used in the construction worker scenario. Trench dimensions and air changes per hour input parameters for a construction worker scenario are not provided in TACO; therefore, default values (e.g., trench dimensions and air changes per hour) from a commonly referenced trench model established through Virginia Department of Environmental Quality's (VDEQ) Voluntary Remediation Program[3] were utilized in lieu of TACO default values. VDEQ provides modeling equations; however, trench width, length, and air changes per hour input parameters were all that were used for our purposes (VDEQ, 2015). A combination of the VDEQ trench dimensions and the LDN model were used to model ROs under the construction worker scenario.

A summary of modeled input values is provided in **Exhibit 2-6** below.

Exhibit 2-6: Summary of Input Parameters for Residential and Construction Worker Scenarios used for LDN Modeling Efforts

Category	Parameter	Residential Input	Construction Worker Input	Comment
Chemical Properties	Molecular weight	Chemical specific	Chemical specific	TACO values or USEPA Chemical Specific Parameters Table values if TACO values not available
	Diffusivity in air (D_a)	Chemical specific	Chemical specific	
Soil Properties	Temperature	286 °K	286 °K	TACO default value, (= 13 °C)
	Total porosity (θ_t)	0.43	0.43	TACO default values, unitless
	Water-filled porosity	0.15	0.15	
	Air-filled porosity (θ_a)	0.28	0.28	
Building/Trench Inputs	Length	1000 cm	244 cm	TACO residential default values (= 10 m); For construction workers, Virginia DEQ Trench model (also = 8 ft x 3 ft = 2.44 m x 0.91 m)
	Width	1000 cm	91 cm	
	Ceiling height	244 cm	457 cm	TACO residential default value (= 2.44 m); For construction workers, site-specific utilities approximate deepest depth (= 15 ft or 4.57 m)

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[3] VDEQ's Voluntary Remediation Program - Risk Assessment Guidance, Section 3.2.2 Exposure of Workers to Volatiles in a Construction/ Utility Trench.

Exhibit 2-6 (continued)

Category	Parameter	Residential Input	Construction Worker Input	Comment
	Ventilation rate	0.53 ACH	2.0 ACH	TACO residential default value (= 0.53 ACH) For construction workers, Virginia DEQ Trench model (= 2.0 ACH)
	Basement/ Trench depth	7 ft	15 ft	
Advective Flow	Q_{soil}			LDN assumes that all vapors beneath the floor are swept into the building (no value used)
Calculated Values	Effective diffusivity	Chemical specific	Chemical specific	$D_i^{eff} = D_i\left(\frac{\theta_{a,i}^{3.33}}{\theta_{T,i}^{2}}\right) + \left(\frac{D_w}{H'_{TS}}\right)\left(\frac{\theta_{w,i}^{3.33}}{\theta_{T,i}^{2}}\right)$
	Floor footprint	100 m^2	2.22 m^2	length x width
	Internal volume	244 m^3	10.15 m^3	length x width x height
	Air flow rate ($Q_{building}$)	129 m^3/hr	20.3 m^3/hr	Volume x ACH
	Attenuation factor (α)	Depth dependent (3 ft transport/ 10 ft bgs)	Depth dependent (5 ft transport/ 20 ft bgs)	

It is important to note the attenuation factor within Equation 5 of the LDN model (**Appenedix 2-A**) is chemical and depth dependent. Additionally, target indoor/ trench air concentrations are chemical specific. For example, a benzene soil gas value in a residential setting was calculated based on the 0.31 µg/m^3 value (the calculated target indoor air concentration for a resident based on J&E1 and J&E2 equations). This is equivalent to how IEPA developed the published soil gas screening levels given in TACO, using a 1E-06 risk level and an assumed exposure scenario of 24 hours/day and 350 days/year over 30 years. Note that the benzene value of 0.31 µg/m^3 used in this demonstration is less than the USEPA's current Residential Air Regional Screening Level (RSL) for benzene of 0.36 µg/m^3.

2.1.3 LDN Model Results

The LDN model was used to calculate Tier 3 ROs by rearranging Equation 5 of the LDN model (**Appendix 2-A**) to solve for "C_{source}" as shown below.

$$C_{source} = C_{indoor\ air\ (or\ trench\ air)} / \alpha$$

The LDN modeling was performed for petroleum hydrocarbon constituents whose detection frequencies (ratio between detected samples and total samples collected) were greater than 5% (USEPA, 1994). Seventeen petroleum hydrocarbon constituents were detected at frequencies greater than 5%, and target soil gas concentrations were calculated using the LDN model for all constituents where toxicity and chemical data were available. A LDN value was also calculated to naphthalene, based on review of a limited dataset from 1st Quarter 2013 (1Q13) and 4th Quarter 2016 (4Q16). Target indoor air screening levels were calculated using TACO J&E equations 1 and 2 (**Appendix 2-B: Table 2**).

The LDN results for residential and construction worker scenarios are shown in **Appendix 2-B: Table-1** and **Table-3** and in **Exhibit 2-7** below.

Exhibit 2-7: LDN Modeling Results for Residential and Construction Worker Scenarios

Chemical	Residential (mg/m^3) 3 ft transport	Construction Worker (mg/m^3) 5 ft transport
Benzene	0.15	1800
Carbon Disulfide	300	120000
Cyclohexane	3300	440000[a]
Ethylbenzene	0.55	6700
Hexane	420	500000

Exhibit 2-7 (continued)

Chemical	Residential (mg/m^3) 3 ft transport	Construction Worker (mg/m^3) 5 ft transport
2-Hexanone	19	7700
Isopropylbenzene (Cumene)	290	27000
Naphthalene	0.05	620[a]
4-Methyl-2-pentanone	1900	110000
n-Propyl- benzene	730	22000
Propylene	1200	500000
Styrene	620	34000[a]
Tetrahydrofuran	880	360000
Toluene	2800	140000[a]
1,2,4-Trimethylbenzene	5.1	21000
1,3,5-Trimethylbenzene	7.3	3000
m,p-Xylenes[b]	57	24000
o-Xylenes	64	26000

a Calculated LDN value exceeds the C_v^{sat} value and was adjusted to equal C_v^{sat} value.

b m,p-xylenes screening value based on p-xylene LDN calculations.

The LDN modeling results can also be applied to a building with slab-on-grade construction. The separation distance or advection zone between the soil gas measurement depth and the building/trench is the same for each type of construction, but the depth bgs differs by the ceiling height of the basement or depth of the trench.

The LDN model, as used in this demonstration, yields a lower soil gas result than the TACO Tier 1 residential values for the proposed Tier 3 ROs. For example, the Tier 3 RO for benzene is 0.15 mg/m^3 versus a Tier 1 RO of 0.37 mg/m^3. Though different modeling assumptions are considered for J&E and LDN models (as previously discussed in **Section 2.1.2**), the calculated LDN value for this 3-foot separation distance is less than that of the TACO Tier 1.

In addition, the LDN model yields roughly comparable results for a construction worker scenario. For example, for a 5-foot separation distance between the soil gas measurement location and the bottom of a trench, LDN outputs a target concentration of approximately 1,800 mg/m^3 for benzene versus a concentration of 1,100 mg/m^3 for the Soil Screening Level (SSL) model (as presented in TACO, Appendix B, Table G). Calculated residential and construction worker ROs for select constituents and for vapor monitoring points (VMPs) port depths are included in **Table 2-1**. A discussion on COPC selection is described in **Section 2.1.4**. See **Table 2-2** for a comparison of calculated Tier 3 ROs to Tier 1 ROs.

Petroleum hydrocarbons such as benzene are generally considered to be readily biodegraded in the presence of oxygen. If aerobic biodegradation were taken into account, the calculated LDN value would be expected to be at least two orders magnitude higher (i.e., a larger soil gas concentration could be present at a given depth without resulting in unacceptable indoor air impacts). If aerobic degradation were occurring, the rate of oxygen transport into the subsurface would be at a maximum for a dirt floor compared with a concrete slab. The concentration of oxygen in indoor air far exceeds the concentration of any petroleum hydrocarbon vapors in soil gas, so the net effect of no slab being present is to enhance any aerobic degradation (DeVaull, 2007).

2.1.4 Constituents of Potential Concern Selection

This section describes the process of identifying COPCs under the residential and construction worker scenarios.

Residential

Modeling was performed for selected constituents as described in **Section 2.1.3** which calculated LDN values at a specific depth based on an indoor air concentrations that are protective of human health (**Appendix 2-B, Table 1** and **Table 2**). Site data collected between 4th Quarter 2009 (4Q09) and 4Q16 were then compared to the calculated LDN screening values. Those constituents whose maximum historic detected concentrations (MDCs) that were greater than the calculated LDN screening values were considered COPCs (**Appendix 2-C**). Based on additional assessment of naphthalene independent of the Quarterly Soil Vapor Monitoring Program, naphthalene is also included as a COPC for an added level of conservatism.

A total of ten[4] constituents were identified as COPCs based on the process described above. The COPCs are:

- Benzene
- Ethylbenzene
- Cyclohexane
- Hexane
- Naphthalene
- Toluene
- 1,2,4-Trimethylbenzene
- 1,3,5-Trimethylbenzene
- [†]m,p -Xylenes
- o-Xylenes

[†] m-Xylenes and p-Xylenes have different chemical data; however, analytically these compounds cannot be resolved.

Construction Worker

The same process for developing the COPCs for the residential scenario was applied to the construction worker scenario with appropriate LDN modeling assumption changes (e.g., “building” [a/k/a trench] dimensions), as identified in **Section 2.1.2**. USEPA’s on-line calculator was used to derive target trench air screening levels (USEPA, 2016) to be protective of a construction worker in an excavation trench (**Appendix 2-B, Table 3** and **Table 4**). The TACO construction worker default exposure frequency of 30 days per year and exposure duration of 1 year as well as sub-chronic toxicity values were used in the calculations. The LDN screening values were then compared to Site data collected between 4Q09 and 4Q16. Benzene was the only chemical determined to be a COPC for construction workers based on the MDCs in historical concentration data (**Appendix 2-C**).

As discussed under the residential scenario above, naphthalene is included as a COPC for an added level of conservatism.

2.2 Application of Soil Gas Tier 3 Remediation Objectives

Site data were evaluated for residentially located VMPs and those located within the Village of Roxana rights-of-way (excluding VMPs located within the WRR). Residential and construction worker VMPs are located in the Investigation Area within the Village of Roxana. VMPs considered only under the construction worker scenario are located in the rights-of-way of Illinios Route 111 and Rand Avenue.

VMPs within WRR were excluded from consideration because any intrusive activity within the refinery requires activity-specific controls specified by Phillips 66. The construction worker model in this demonstration captures utilities as deep as 15 feet. One utility has been identified at 16 feet bgs however, it is a Phillips 66 maintained utility; therefore, any intrusive work would require activity-specific controls specified by Phillips 66. When intrusive work is planned, Phillips 66 conducts an evaluation of the work with respect to potential hazards and controls are established to monitor and mitigate the potential hazards. Commonly, the following controls are established:

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[4] 11 if m,p-Xylenes considered two separate constituents.

- An activity specific Health and Safety Plan is developed, which, among other things, describes the potential hazards and mitigation and monitoring methods;
- Work permits are issued, which specify hazard controls such as notification procedures and personal protective equipment (PPE).

Additionally, workers are required to have refinery-specific awareness training and, depending on the work, may also need Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) training.

2.2.1 Application of Tier 3 ROs in the Village of Roxana and Public Works Yard

Tier 3 ROs for the ten COPCs listed in **Section 2.1.4** were calculated for VMP ports at 10 feet bgs in the Village and Public Works Yard. Ten feet bgs is considered the “action depth” representative of a 3 foot transport distance from the assumed basement floor (7 feet bgs). The existing vapor monitoring network has the highest density of ports within the shallow zone (below the assumed basement floor) at 10 feet bgs, with 28 of 39 VMPs in the proposed vapor monitoring program having ports at 10 feet bgs. Therefore, 10 feet bgs has been chosen as the action depth where the Tier 3 ROs are applied.

For the Tier 3 model, benzene has a soil gas RO of 0.15 mg/m^3 for VMP ports 3 feet below the assumed basement depth of 7 feet bgs, or 10 feet bgs. This value is applied for VMP ports between 7 feet bgs (basement floor) and 10 feet bgs (action depth). Tier 3 ROs were not applied to shallower VMP ports because the site data reflects remaining concentrations are at depth; therefore, if rebound were to occur, it is critical to identify that at a depth below the assumed basement floor. Additionally, because the LDN values are calculated based on depth and the assumed basement depth (7 feet bgs) is the “0” datum, any values between 0 and 7 feet bgs cannot be calculated because the depth would be less than “0”.

As described in **Section 2.1.4**, ten constituents[5] have been identified as COPCs (**Appendix 2-C**). Those constituents were then compared to more recent Site data (1st Quarter 2015 (1Q15) through 4th Quarter 2016 (4Q16))[6]. This time frame was chosen because the most recent extension of the SVE system (Blue Line extension) was started in December 2014. Comparisons of the recent Site data to the Tier 3 ROs for the residential scenario are shown in **Chart 1** through **Chart 9.** These charts show the detected concentrations to a depth of 20 feet bgs and the residential Tier 3 ROs. The figures show that no samples collected at depths less than 10 feet bgs had concentrations exceeding Tier 3 ROs with two exceptions that are considered outliers (see **Chart 3** (ethylbenzene) and **Chart 6** (1,2,4-trimethylbenzene) and discussed below).

In 1Q15, the sample from VMP-2-5 (5 foot port) had ethylbenzene and 1,2,4-trimethylbenzne concentrations of 0.79 mg/m^3 and 5.8 mg/m^3, respectively. In 2nd Quarter 2016 (2Q16), the sample from VMP-4-5 (5 foot port) had an ethylbenzene concentration of 0.63 mg/m^3. These results are considered outliers based on the following information:

- In both cases, the deeper ports at each VMP location had results that were non-detect or were one to three orders of magnitude lower than what was observed in the 5 foot port. If vapors were migrating from a deeper source, higher concentrations would have been observed in the deeper ports.

- When compared against data collected from 2012 through 2016, the values observed in 1Q15 and 2Q16 at VMP-2-5 and VMP-4-5, respectively, were outside of the range of values typically detected at these locations. Typical ranges of values observed are described in **Exhibit 2-8** below.

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[5] 11 if m,p-xylenes are counted as two constituents.

[6] With the exception of naphthalene.

Exhibit 2-8: Typical Values at VMP-2-5 and VMP-4-4

Location	Ethylbenzene (mg/m^3)	1,2,4-Trimethylbenzene (mg/m^3)
VMP-2-5	ND – 0.058	ND – 0.01
VMP-4-5	ND – 0.061	

Analytical data is provided in **Table 3-4** and **Appendix 3-E** of Part 1 of this Tier 3 Demonstration.

Those constituents with elevated concentrations at depth are not considered a human health concern because shallower depths at the same VMP locations do not demonstrate exceedances. If the contaminant were migrating to shallower depths, the shallower ports would serve as an indication to detect contaminant migration. For example, benzene concentrations in soil gas at VMP- 50-20 (20 feet bgs) and VMP-50-30 (30 feet bgs) during the 3rd Quarter 2016 (3Q16) Quarterly Soil Vapor Monitoring event were 0.00053 mg/m^3 and 0.420 mg/m^3, respectively. A predicted concentration can be estimated using the ratio of calculated LDN values for benzene relative to the target indoor air concentration used to develop the Tier 3 ROs as shown in **Exhibit 2-9** below.

Exhibit 2-9: Predicted Benzene Concentration at VMP-50-20

VMP-50 Port Depth	Actual Benzene Concentrations (3Q16) (mg/m^3)	Calculated LDN Values for Benzene Relative to Target Indoor Air Concentrations (mg/m^3)	Predicted Benzene Concentration at 20 ft bgs Based on Actual 30 ft bgs Concentration (mg/m^3)
20 ft bgs	0.00053	0.63	***0.238 =*** **(0.63 / 1.11) * 0.420**
30 ft bgs	0.420	1.11	N/A

Using the ratio of LDN values calculated for benzene at 20 feet and 30 feet depths, the theoretical concentration at the 20 ft port (VMP-50-20) would be 0.238mg/m^3 based on the actual concentration at the 30 ft port (VMP-50-30). This comparison assumes a diffusion-only based environment; however, the actual concentration was three orders of magnitude lower. This occurrence is typical of data collected at the Site and serves as one line of evidence that the calculated Tier 3 ROs are highly conservative because other attenuation mechanisms other than diffusion are not considered, such as dispersion and degradation.

2.2.2 Application of Tier 3 ROs in Rights-of-Way

As described in **Section 2.1.4**, benzene is the only COPC for the construction worker scenario (**Appendix 2-C**). Of the calculated LDN screening values, only benzene exceeded the construction worker screening value for depths greater than 5 feet below trench depth (i.e., 20 feet bgs) when compared to historical (prior to 1Q15) Site data. When compared to Site data from 1Q15 to 4Q16, benzene did not exceed the Tier 3 RO for a construction worker scenario. See **Chart 10** for a comparison of Site data to the Tier 3 ROs for benzene for a construction worker scenario for the VMPs located in non-residential rights-of-way.

A Tier 3 RO was calculated for benzene for VMP ports at 20 feet bgs[7] in the right-of-way. Benzene, as calculated with the LDN model, has a soil gas RO of 1,800 mg/m^3 at 5 feet below the bottom of the trench. The maximum depth of a trench is assumed to be 15 feet bgs. Therefore, the Tier 3 RO is evaluated at 20 feet bgs. This depth is supported by the existing monitoring network; 21 of the 39 VMPs in the proposed program have a port depth of 20 feet. The calculated construction worker RO for benzene at 20 foot VMP port depths is included in **Table 2-1**.

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[7] Depth based on monitoring program described in **Section 3**.

3 Proposed System Operation, Monitoring and Shutdown

Based on the results described in **Section 2**, the Tier 3 ROs have not been exceeded. This supports the position that the SVE system has successfully remediated the shallow and intermediate subsurface zones and continued operation is not needed. To assess this finding, SOPUS proposes to shut down the SVE system and move into a rebound monitoring period (demonstration period) as described in this section.

Section 3 presents the proposed approach to operation of the SVE system and soil gas monitoring to assess subsurface conditions during a period of system shut down relative to Tier 3 ROs. During this demonstration period, the system will be fully shut down and VMPs in the program will be monitored and compared against “shallow” and “intermediate” screening criteria which could lead to system restart if soil gas concentrations rebound to defined concentrations.

3.1 Proposed Screening Levels

Shallow and intermediate depths will be monitored during the demonstration period to assess if rebound will occur in the absence of applied vacuum. Shallow depth VMP ports screened between 7 and 10 feet bgs (below the assumed basement floor) will be monitored and will demonstrate if soil gas rebound is occurring in the shallow vadose zone. Intermediate and deep VMP ports screened between 10 and 20 feet bgs and >20 feet bgs, respectively, will also be monitored and used for informational purposes to qualitatively assess changes to intermediate and deep soil gas concentrations and update the site conceptual model as appropriate. The designated shallow, intermediate and deep VMPs to be included in the program are presented in **Table 3-1**. Soil gas samples from the VMPs within the program will be monitored on a monthly basis and field screened for petroleum hydrocarbon (PHC) using Tedlar® bag media after system shutdown. See **Figure 2-1** for VMP well locations.

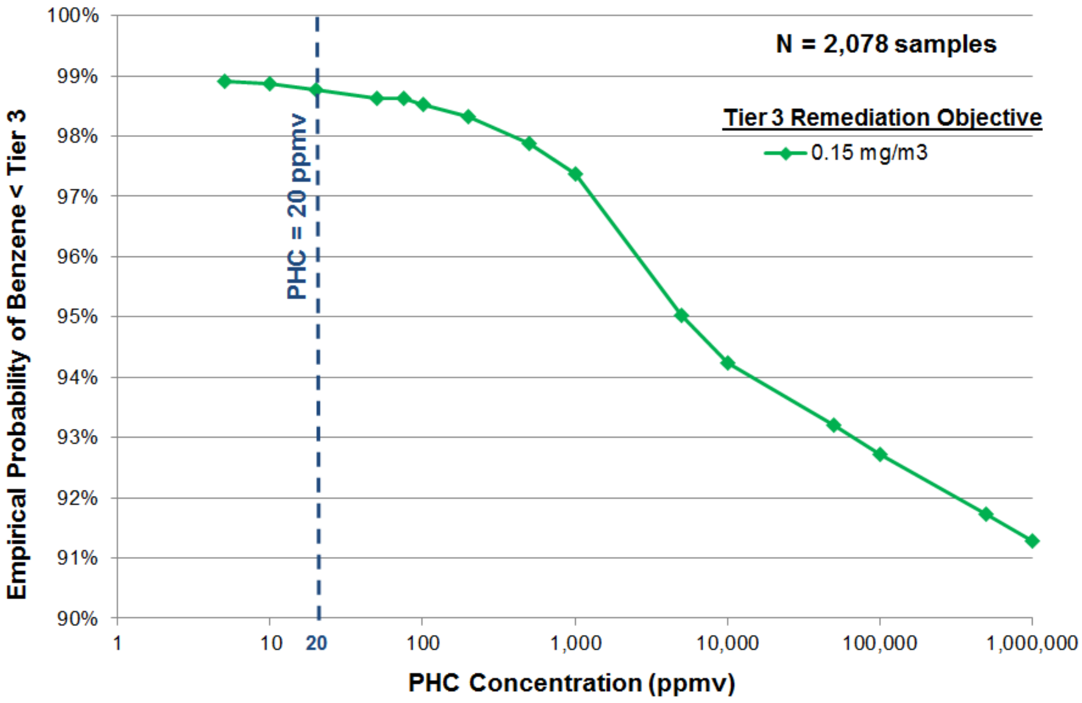
Certain VMPs within the current Quarterly Soil Vapor Monitoring sampling network will not be screened during the monthly rebound monitoring period. VMPs within the WRR do not provide data relevant to a vapor intrusion risk to receptors in the Village of Roxana and will not be screened. Additionally, VMP-15, VMP-25, and VMP-55 are located within the right-of-way of Illinois Route 111 and Rand Avenue (**Figure 2-1**) and potential exposures were evaluated under a construction worker scenario as described in **Section 2.2.2**. Site soil gas results have not exceeded the Tier 3 ROs during the evaluation period (1Q15 – 4Q16). For example, the maximum benzene concentration at all ports at VMP-15, VMP-25, and VMP-55 during this timeframe was 11 mg/m^3 (at VMP-25-21) compared to the Tier 3 RO of 1,800 mg/m^3. Based on the location of these VMPs and the analytical results relative to the calculated Tier 3 ROs for the construction worker scenario, monthly monitoring is not necessary; however, these VMPs will be included in the comprehensive canister sampling event described in **Section 3.2**.

3.1.1 Development of Field Screening Criteria

Currently, during the Quarterly Soil Vapor monitoring events, a field screened soil gas sample and an analytical soil gas sample are collected concurrently at a port for each VMP in the program. To date, over 2,000 co-collected samples have been analyzed via laboratory analysis and field screening. A graphical representation of the percentage of samples with benzene concentration below the Tier 3 criterion when at various PHC concentrations is depicted in **Exhibit 3-1**. A graphical representation of benzene concentration versus proposed screening criteria is depicted in **Appendix 3-A**.

Evaluation of these data show that a field screening PHC concentration of 20 ppmv may be used to identify locations where benzene concentrations are less than the Tier 3 RO of 0.15 mg/m^3. As shown in **Appendix 3-A**, there were 1,864 samples with field screening PHC concentrations less than 20 ppmv and only 23 samples (1.2%) had laboratory measured benzene concentrations in the paired sample greater than the Tier 3 RO. Based on this correlation, a PHC concentration of 20 ppmv was chosen as the preliminary screening concentration for the 7 to 10 foot bgs shallow VMPs.

Exhibit 3-1: Graphical Representation of Empirical Probability of Exceedance of Benzene Tier 3 Remediation Objective versus Measured PHC Concentrations



As described below, the Tier 3 ROs will be used to evaluate if SVE system restart is necessary if monthly field screened soil gas samples are confirmed to be over the preliminary screening concentration. The residential and construction worker Tier 3 ROs for each VMP to be monitored during the demonstration period are presented in **Table 2-1**.

3.2 Proposed SVE System Shutdown and Rebound Monitoring Program

Based on the screening values developed and presented in **Section 2** of this document, along with site knowledge accumulated over several years of investigation and monitoring, the following rebound monitoring program is proposed.

Review of rebound monitoring programs at other sites suggest a typical program can last from six (DENR, 2003) to twelve months (URS, 2008). The rebound monitoring program proposed will be implemented over a period of one year to evaluate soil gas conditions in a post-SVE environment. This proposed rebound monitoring period would also allow for observations to be made based on seasonal fluctuations. The SVE system will remain off as long as soil gas concentrations do not trigger restart based on the criteria described in this section. During this period, the system will be maintained to ensure that it is capable of a timely restart should soil gas concentrations rebound above the established criteria.

The shallow and intermediate VMP ports presented in **Table 3-1** will be monitored on a monthly basis using Tedlar® bag media after system shutdown.

Detailed flow charts describing the rebound monitoring the program can be found in **Figure 3-1** and **Figure 3-2**, and a general overview is provided below.

Monthly Monitoring

- On a monthly basis, soil gas samples will be collected using Tedlar® bag media from each VMP listed in **Table 3-1** using the procedure currently performed during the Roxana Monthly Effectiveness Monitoring event[8] for VMP locations.
- Each soil gas sample will be field screened for total hydrocarbon (THC) and methane concentrations. PHC concentration will then be calculated by subtracting the methane concentration from the THC.
- Results from the soil gas screening measurements will then be compared to the appropriate screening criteria. The next steps vary depending on from which depth the sample was taken and are described below.

  - Ports at >7-10 feet bgs (Shallow Zone [below basement floor]) (**Figure 3-1**):
    - If the PHC concentration is greater than 20 ppmv (shallow), a sequence of confirmatory soil gas samples are collected. If the average of these sample results exceeds 20 ppmv, an analytical sample will be collected using stainless steel canisters (e.g., SUMMA® canisters), hereafter "canisters", and analyzed for project list analytes (**Table 3-2**).
    - If the results of the analytical samples exceed one or more Tier 3 ROs, a sequence of confirmatory samples will be collected. If the average from two rounds of sampling exceeds the Tier 3 ROs a third confirmation sample is collected. If the results confirm the first two analytical samples, the SVE system will be restarted and a post-restart monitoring program will be initiated.
    - If the average of the first two or the third canister sample is below Tier 3 ROs, a multiple lines of evidence (MLE) evaluation will be performed. The MLE evaluation will evaluate VMP(s) with exceedance for trends consistent with rebound. Evaluation will include statistical techniques such as control charts.

  - Ports at >10-20 feet bgs (Intermediate Zone) and >20 feet bgs (Deep Zone):
    - Soil gas samples collected from >10-20 ft (Intermediate Zone) and deep ports (i.e., >20 feet bgs) will be collected as part of monthly monitoring to monitor changes in soil gas concentrations in deeper-zone VMPs and update the site conceptual model as appropriate; however, a reading of 200 ppmv or higher at a port within the >10-20 ft zone would trigger an assessment based on data from the overlying shallow zone. See **Figure 3-2**.

Post-System Restart Monitoring

- If the SVE system is restarted, soil gas samples will be collected with Tedlar® bags on a weekly basis for four weeks from the VMP(s) exhibiting exceedance(s). If the average PHC concentration of the four soil gas samples is below the applicable criterion (20 ppmv), a canister sample will be collected. If the concentrations of the constituents from the canister sample are below the Tier 3 ROs, SVE system shut down will be initiated, and the VMP will return to the regular monthly monitoring program. If the concentrations are still above the Tier 3 ROs, the SVE system may be operated longer, as deemed necessary based on site conditions, in which case a monthly sampling frequency from selected VMPs will be implemented.

The following additional sampling will be performed as conservative quality control measures:

- Each month one canister sample will be collected from a 10 ft VMP and analyzed for the constituents identified in **Table 3-2**. The location will be randomly selected prior to the monthly event. Canisters will be individually certified by the laboratory.

At the end of the demonstration period, a comprehensive canister sampling event will be conducted. The procedures followed for this sampling event will follow methods currently used in the Roxana Quarterly Soil Vapor Monitoring Program[9]. Samples will be analyzed for constituents identified in **Table 3-2**. This event will provide a complete data set that will allow for a full assessment of soil gas conditions relative to Tier 3 ROs (residential and construction worker scenarios) and will serve as confirmation of field screening data collected.

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[8] An overview of the Monthly Effectiveness sampling event is presented in **Section 4.1.4** of **Part 1** of the Tier 3 Demonstration.

[9] An overview of the Roxana Quarterly Soil Vapor Monitoring Program is presented in **Section 3.3** of **Part 1** of the Tier 3 Demonstration.

3.3 Proposed Procedure for Site Closeout

After the one year demonstration period has ended, the data collected will be evaluated and a report will be developed summarizing the data obtained during the rebound monitoring period. This report will contain recommended next steps. If the data show rebound is not occurring, a permanent shut down and dismantlement of the SVE system would be proposed. If the data indicate otherwise, steps would be proposed that could range from additional monitoring to focused system operations.

3.4 Institutional Controls

As stated in **Section 2**, institutional controls are required if certain assumptions are incorporated into the modeling. The key assumption for the J&E model is *"…the presence of a building with a full concrete slab-on-grade or a full concrete basement floor and walls"* (Section 742.1000(a)(9)). Since the LDN model calculates remediation objectives that are based on the absence of concrete slabs/ basements, institutional controls are not necessary.

- If vapors at depth (>20 feet bgs) were migrating toward residential basements at ample rates, exceedance of Tier 3 ROs would also have been observed at shallower ports.
- For the potential construction worker scenario, site data are below the conservative Tier 3 ROs. Future use in the transportation rights-of-way is expected to be similar to current use. As published by Illinois Department of Transportation (IDOT), there are no expected construction activities on Illinois Route 111 in the Roxana/Wood River area for Fiscal Year (FY) 2017-2022 (the next five years) (IDOT, 2016).

4 Conclusions

From 2006 to present (date of this report), SOPUS has been investigating and remediating subsurface petroleum impact in the Village of Roxana. Over the past 6 years of active SVE remediation, conditions have improved to the extent that the available information supports transitioning from active SVE operation to a demonstration period, assessing whether or not rebound will occur. Site characterization data is presented in Part 1 for soil, soil gas, and indoor air. Based on the conclusions derived from this data, Part 2 presents proposed Tier 3 ROs and a proposed rebound monitoring program. Key information from Parts 1 and 2 of this report is summarized below.

- Soil gas data collected over the past five years of SVE system operation demonstrate a significant reduction in hydrocarbon concentration in the subsurface, particularly in the shallow and intermediate zones.
- Site soil conditions have been assessed at over 190 soil boring locations. The information derived from the borings has demonstrated the presence of relatively thin, discontinuous layers of finer-grained, lower permeability soils (silts and clays) located sporadically throughout the Site, typically at depths between approximately 20 to 30 feet bgs. Petroleum impacts were more apparent in the finer-grained materials.
- Over 330 soil samples have been collected for laboratory testing for compounds characteristic of petroleum hydrocarbons. These compounds were more pronounced in the discontinuous lower permeability soil zones prior to remediation and at depth (influenced by groundwater conditions).
- Over 3,300 soil gas samples have been collected and analyzed, and over 17,000 soil gas samples have been collected and field-screened. Collectively, the nature and extent of petroleum impacts in soil gas and the temporal changes that have occurred since startup of the SVE system are well defined.
- Indoor air and sub-slab conditions were evaluated at over 50 structures, with no instances of vapor intrusion. Most of the indoor air and sub-slab sampling occurred prior to construction of the SVE system. Petroleum vapors were elevated in soil gas beneath five homes, and even though indoor air was not affected, a conservative approach was adopted and interim measures were taken to mitigate sub-slab vapors until the SVE system was operational.
- The SVE system, installed in 2011 and subsequently extended in 2013 and 2014, consists of 45 SVE wells, over 50% of which have been closed over the past 3 years as soil gas data demonstrates the shallow and intermediate zones have been remediated. Soil gas concentrations at depth have also decreased over time but remain in certain areas partly due to fluctuating groundwater conditions.
- The IEPA's TACO rules pertaining to soil gas (indoor air inhalation pathway) provide the regulatory framework to answer the question, "When will we know when cleanup is complete?" To help answer this question, modeling was performed (as allowed under Tier 3) to develop residential remediation objectives that are protective of indoor air for any style foundation (concrete foundation or crawl space, dirt floor or walls, etc.). Non-residential remediation objectives were similarly developed for transportation rights-of-way.
- Soil gas data were compared to the Tier 3 ROs, and the data for petroleum hydrocarbons in the residential area meet these objectives in the shallow zone (0-10 feet bgs). In certain areas, site data exceeded the objectives at depth (below 20 feet bgs). These results do not pose a concern as attenuation mechanisms decrease concentrations to below the objectives at shallower depths. The site data meet the Tier 3 ROs for non-residential areas.
- As the site data meet the calculated target values, SOPUS proposes to shut down active SVE operations and begin a one year rebound monitoring demonstration period. During this period, extensive monitoring will be performed to assess whether conditions will remain acceptable over the longer term or whether rebound occurs. The monitoring program includes triggers for increased monitoring and restart of the SVE system.

5 Statement of Limitations

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AECOM has performed services described herein in a manner consistent with that level of care and skill ordinarily exercised by members of the same profession currently practicing in the same locality under similar conditions. No expressed or implied representation or warranty is included or intended in this report, except that our services were performed, within the limits prescribed by our client, with the customary thoroughness and competence of our profession.

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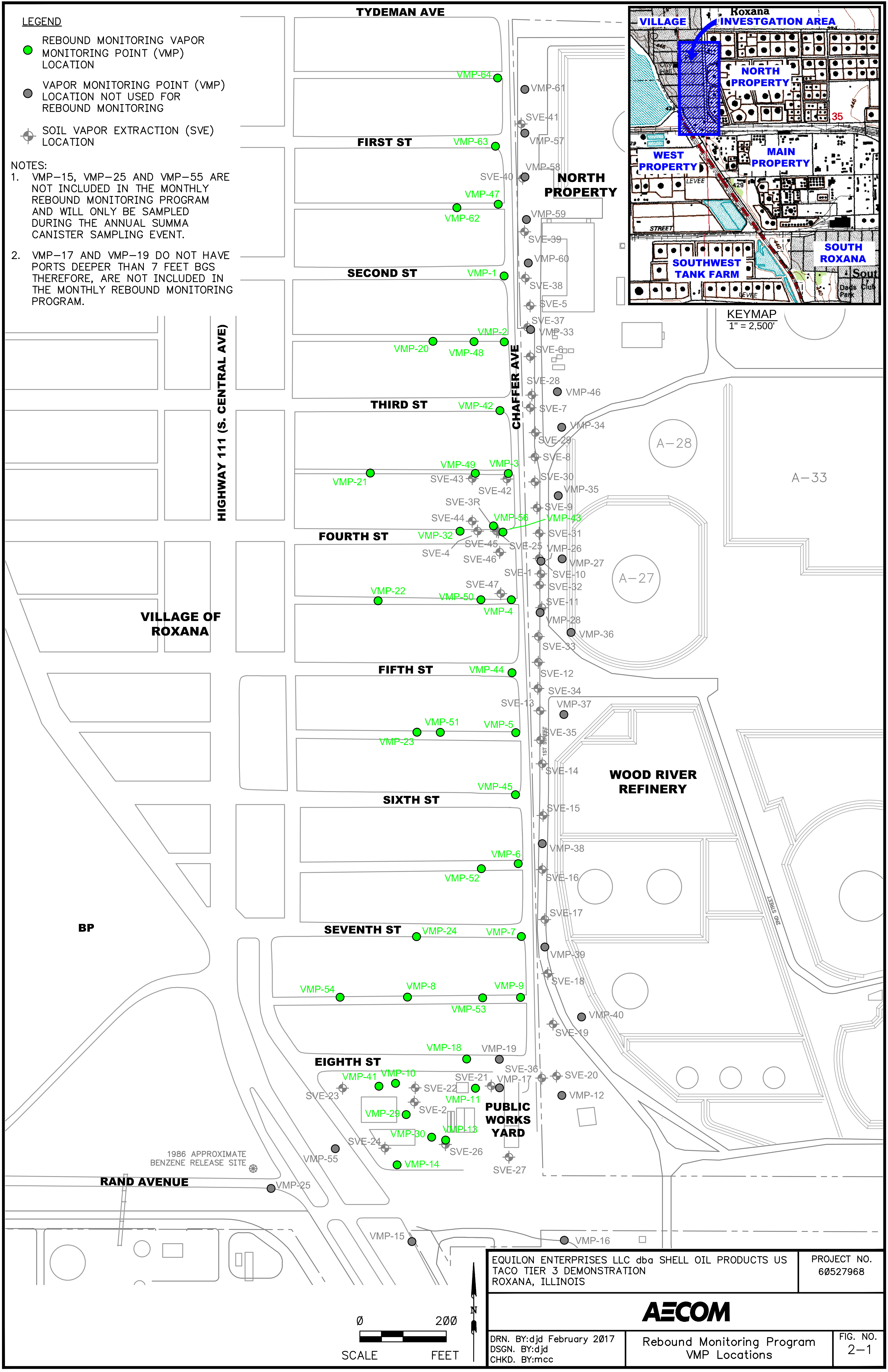
Figures.

File: P:\PROJECTS\ENVIRONMENTAL\SHELL\60477387_ROXANA2016\6.0_DELIVERABLES\SV_SVE REPORTING\TACO\DRAFT\FIGURES\FIGURE 2–1 REBOUND MONITORING PROGRAM VMP LOCATIONS.DWG Last edited: MAR. 20, 17 @ 5:22 p.m. by: david.deguire



LEGEND

● REBOUND MONITORING VAPOR MONITORING POINT (VMP) LOCATION

● VAPOR MONITORING POINT (VMP) LOCATION NOT USED FOR REBOUND MONITORING

⌖ SOIL VAPOR EXTRACTION (SVE) LOCATION

NOTES:

1. VMP–15, VMP–25 AND VMP–55 ARE NOT INCLUDED IN THE MONTHLY REBOUND MONITORING PROGRAM AND WILL ONLY BE SAMPLED DURING THE ANNUAL SUMMA CANISTER SAMPLING EVENT.
2. VMP–17 AND VMP–19 DO NOT HAVE PORTS DEEPER THAN 7 FEET BGS THEREFORE, ARE NOT INCLUDED IN THE MONTHLY REBOUND MONITORING PROGRAM.

EQUILON ENTERPRISES LLC dba SHELL OIL PRODUCTS US
TACO TIER 3 DEMONSTRATION
ROXANA, ILLINOIS

PROJECT NO.
60527968

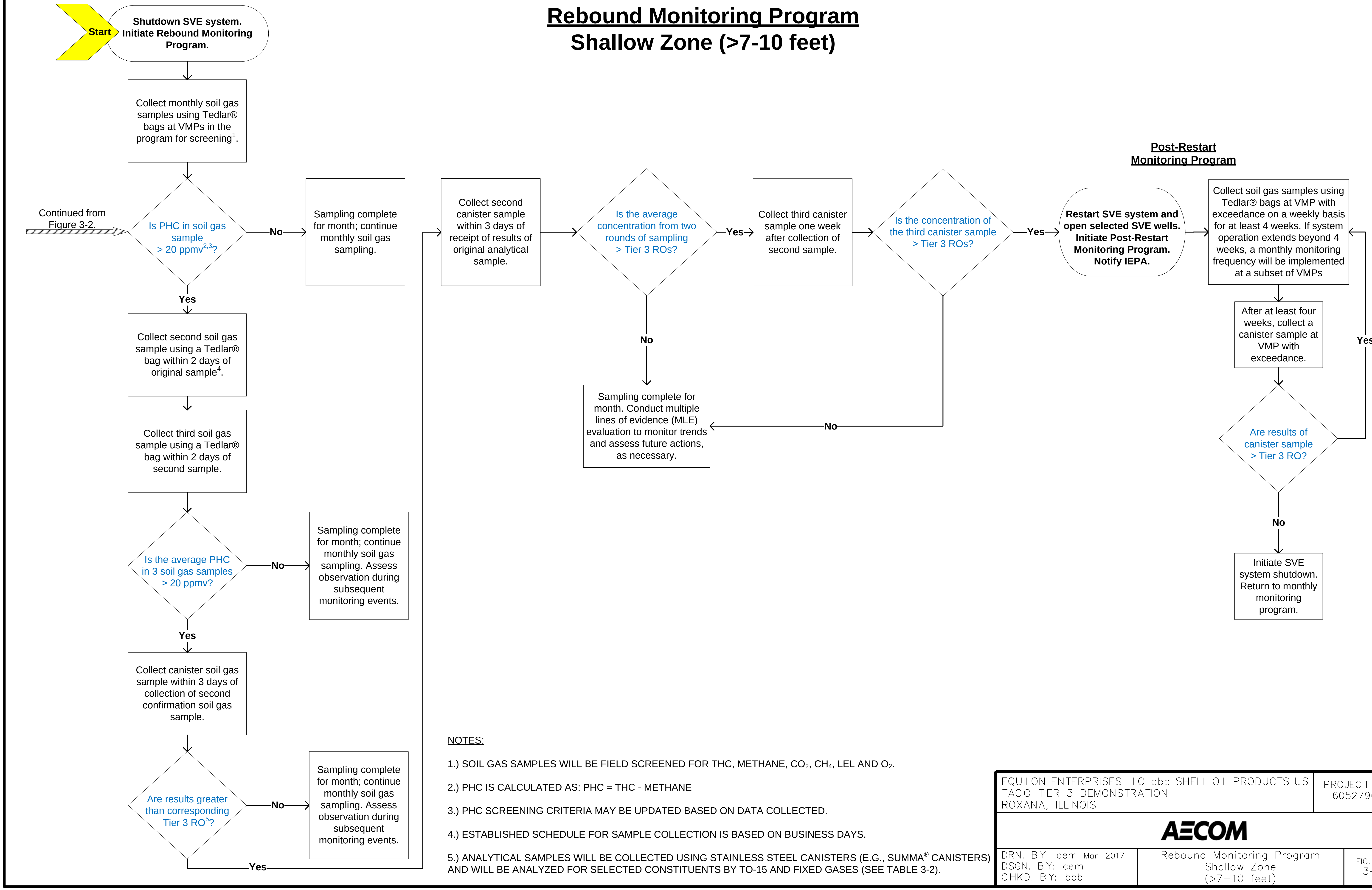
AECOM

DRN. BY:djd February 2017
DSGN. BY:djd
CHKD. BY:mcc

Rebound Monitoring Program
VMP Locations

FIG. NO.
2–1

Rebound Monitoring Program
Shallow Zone (>7-10 feet)



NOTES:

1.) SOIL GAS SAMPLES WILL BE FIELD SCREENED FOR THC, METHANE, CO_2, CH_4, LEL AND O_2.

2.) PHC IS CALCULATED AS: PHC = THC - METHANE

3.) PHC SCREENING CRITERIA MAY BE UPDATED BASED ON DATA COLLECTED.

4.) ESTABLISHED SCHEDULE FOR SAMPLE COLLECTION IS BASED ON BUSINESS DAYS.

5.) ANALYTICAL SAMPLES WILL BE COLLECTED USING STAINLESS STEEL CANISTERS (E.G., SUMMA® CANISTERS) AND WILL BE ANALYZED FOR SELECTED CONSTITUENTS BY TO-15 AND FIXED GASES (SEE TABLE 3-2).

EQUILON ENTERPRISES LLC dba SHELL OIL PRODUCTS US
TACO TIER 3 DEMONSTRATION
ROXANA, ILLINOIS

PROJECT NO.
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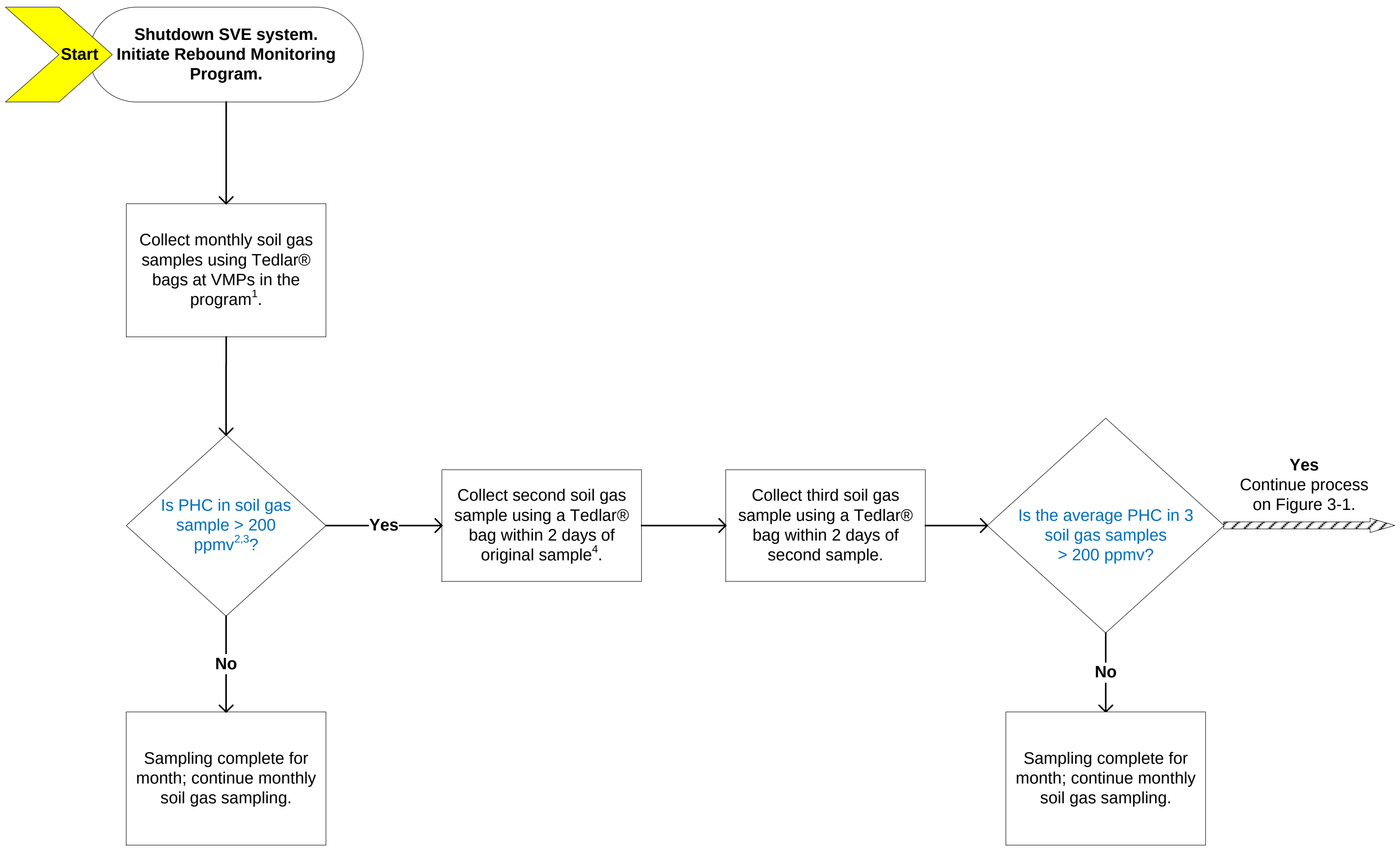
DSGN. BY: cem
CHKD. BY: bbb

Rebound Monitoring Program
Shallow Zone
(>7–10 feet)

FIG. NO.
3–1

Rebound Monitoring Program
Intermediate Zone (>10-20 feet)



NOTES:

1.) SOIL GAS SAMPLES WILL BE FIELD SCREENED FOR THC, METHANE, CO_2, CH_4, LEL AND O_2.

2.) PHC IS CALCULATED AS: PHC = THC - METHANE

3.) PHC SCREENING CRITERIA MAY BE UPDATED BASED ON DATA COLLECTED.

4.) ESTABLISHED SCHEDULE FOR SAMPLE COLLECTION IS BASED ON BUSINESS DAYS.

EQUILON ENTERPRISES LLC dba SHELL OIL PRODUCTS US
TACO TIER 3 DEMONSTRATION
ROXANA, ILLINOIS

PROJECT NO.
60527968

AECOM

DRN. BY: cem Mar. 2017
DSGN. BY: cem
CHKD. BY: bbb

Rebound Monitoring Program
Intermediate Zone
(>10-20 feet)

FIG. NO.
3-2

Tables.

TABLE 2-1
TIER 3 REMEDIATION OBJECTIVES (RESIDENTIAL AND CONSTRUCTION WORKER)

CAS	Chemical	Residential Tier 3 Remediation Objectives (10 ft bgs) (mg/m^3)	Construction Worker Tier 3 Remediation Objectives (20 ft bgs) (mg/m^3)
71-43-2	Benzene	0.15	1,800
110-82-7	Cyclohexane	3300	▨
100-41-4	Ethylbenzene	0.55	▨
110-54-3	Hexane	420	▨
91-20-3	Naphthalene	0.05	620[b]
108-88-3	Toluene	2800	▨
95-63-6	Trimethylbenzene, 1,2,4-	5.1	▨
108-67-8	Trimethylbenzene, 1,3,5-	7.3	▨
95-47-6	Xylenes, o-	64	▨
108-38-3/106-42-3	Xylenes[a], m,p-	57	▨

Notes:

a m,p-Xylenes screening value based on p-Xylene LDN calculations.

b Calculated Tier 3 concentration exceeded the C_v^{sat} value and was therefore adjusted to equal C_v^{sat} value.

▨ = No Tier 3 Remediation Objective

Acronyms:

bgs = below ground surface
CAS = Chemical Abstracts Service
C_v^{sat} = Soil Vapor Saturation Limit
LDN = Little, Daisey, Nazaroff
mg/m^3 = milligrams per meter cubed

TABLE 2-2
TIER 3 REMEDIAITON OBJECTIVES COMPARED TO TACO TIER 1 REMEDIATION OBJECTIVES

CAS	Chemical	TACO Tier 1 Residential Remediation Objectives (mg/m^3)	Residential Tier 3 Remediation Objectives (10 ft bgs) (mg/m^3)	Construction Worker Tier 3 Remediation Objectives (20 ft bgs) (mg/m^3)	C_v^{sat} (mg/m^3)[a]
71-43-2	Benzene	0.37	0.15	1,800	4.2E+05
110-82-7	Cyclohexane	No TACO Tier 1	3300	▨	4.4E+05
100-41-4	Ethylbenzene	1.3	0.55	▨	5.9E+04
110-54-3	Hexane	No TACO Tier 1	420	▨	7.0E+05
91-20-3	Naphthalene	0.11	0.05	620[d]	6.2E+02
108-88-3	Toluene	6200	2800	▨	1.4E+05
95-63-6	Trimethylbenzene, 1,2,4-	No TACO Tier 1	5.1	▨	1.4E+04
108-67-8	Trimethylbenzene, 1,3,5-	No TACO Tier 1	7.3	▨	1.6E+04
95-47-6	Xylenes, o-	120	64	▨	4.1E+04
108-38-3/106-42-3	Xylenes[b,c], m,p-	130	57	▨	5.2E+04

Notes:

a C_v^{sat} values not provided in TACO were calculated using J&E Equation 5 and USEPA RSL toxicity data last updated May 2016.

b m,p-Xylenes screening value based on p-Xylene LDN calculations.

c m,p-Xylenes C_v^{sat} value based on m-Xylene.

d Calculated Tier 3 concentration exceeded the C_v^{sat} value and was therefore adjusted to equal C_v^{sat} value.

▨ = No Tier 3 Remediation Objective

Acronyms:

bgs = below ground surface
CAS = Chemical Abstracts Service
C_v^{sat} = Soil Vapor Saturation Limit
LDN = Little, Daisey, Nazaroff
mg/m^3 = milligrams per meter cubed
RSL = Regional Screening Level
TACO = Tiered Approach to Corrective Action Objectives (35 IAC 742)
USEPA = United States Environmental Protection Agency

TABLE 3-1
REBOUND MONITORING PROGRAM VMP PORT DEPTHS

Location	Shallow Ports [a] (>7-10 ft bgs)	Intermediate Ports [b] (>10-20 ft bgs)	Deep Ports [c] (>20 ft bgs)
VMP-1	8.5	N/A	23.5 / 38.5
VMP-2	8.5	N/A	22 / 42
VMP-3	10	N/A	31.5 / 39
VMP-4	N/A	12	23.5 / 39
VMP-5	N/A	12.5	31 / 40
VMP-6	10	N/A	31.5 / 39
VMP-7	N/A	13.5	29.5 / 38
VMP-8	9.5	N/A	23.5 / 35.5
VMP-9	N/A	11.5	25.5 / 38.5
VMP-10	10	20	30
VMP-11	8	N/A	29 / 38
VMP-13	N/A	10.5	21.5 / 29.5
VMP-14	N/A	11.5 / 20	29
VMP-18	8.5	N/A	N/A
VMP-20	10	N/A	25 / 39.5
VMP-21	10	N/A	25 / 33
VMP-22	10	18	N/A
VMP-23	10	N/A	25 / 40
VMP-24	10	N/A	22 / 34
VMP-29	10	20	30 / 40
VMP-30	10	20	30 / 40
VMP-32	10	20	30
VMP-41	10	20	30
VMP-42	10	20	30
VMP-43	10	20	30
VMP-44	10	20	30
VMP-45	10	20	30
VMP-47	10	20	30
VMP-48	10	20	30
VMP-49	10	20	30
VMP-50	10	20	30
VMP-51	10	20	30
VMP-52	10	20	30
VMP-53	10	20	30
VMP-54	10	20	30
VMP-56	10	25	38.5
VMP-62	10	20	30
VMP-63	10	20	30
VMP-64	10	20	28

Notes:

a VMP will be sampled during monthly rebound monitoring events and compared against Shallow criteria. Sampling program defined in **Figure 3-1**.

b VMP will be sampled during monthly rebound monitoring events for informational purposes only. Sampling program defined in **Figure 3-2**.

c VMP will be sampled during monthly rebound monitoring events for informational purposes only.

TABLE 3-2
REBOUND MONITORING PROGRAM TO-15 MONITORING LIST

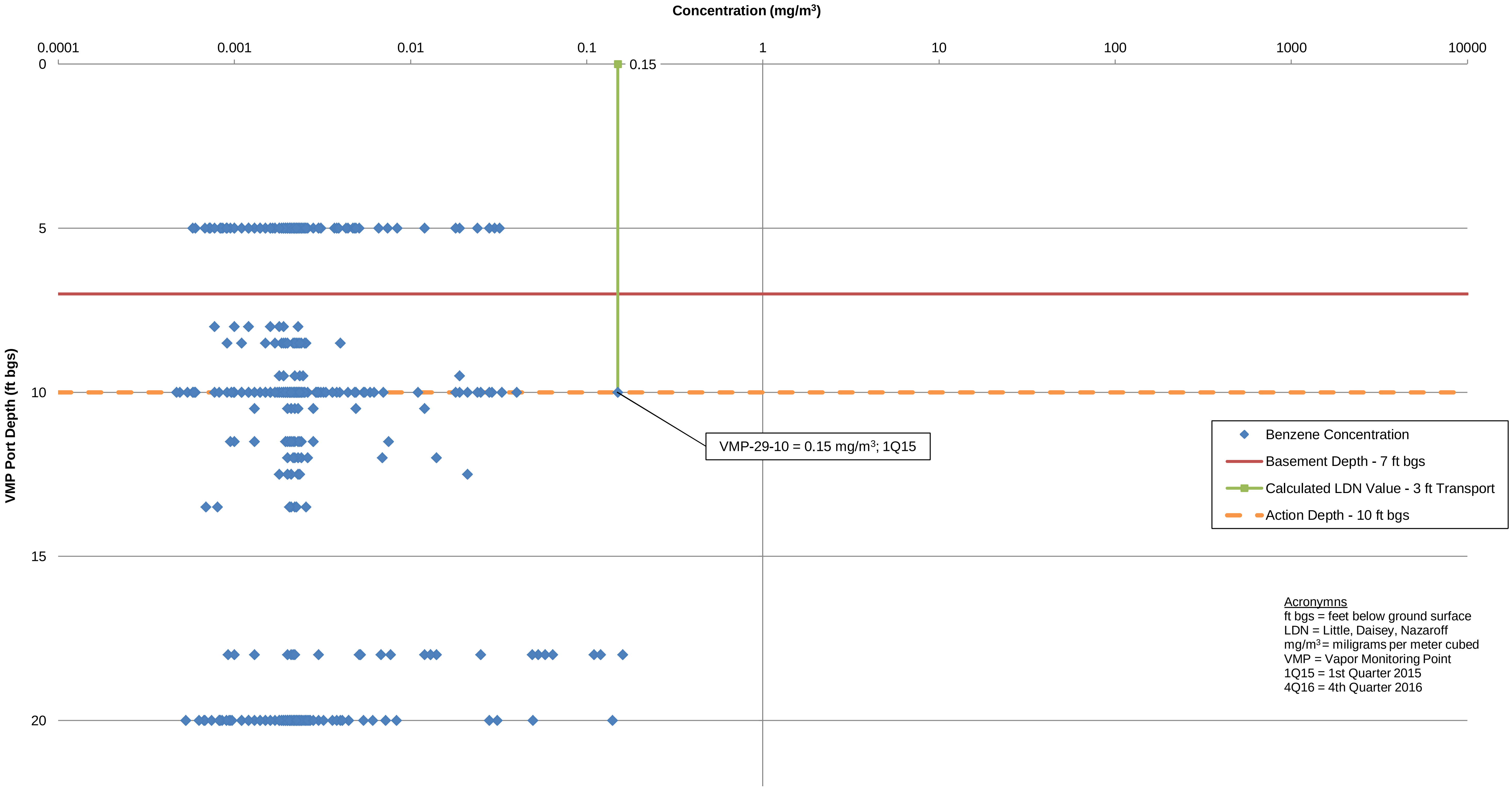
Chemical
Benzene
Cyclohexane
Ethylbenzene
Hexane
Naphthalene
Toluene
Trimethylbenzene, 1,2,4-
Trimethylbenzene, 1,3,5-
Xylenes, m,p-
Xylenes, o-

Notes:

1.) Samples will be analyzed by EPA Method TO-15.
2.) Samples will be analyzed for natural (fixed) gases by Modified ASTM D-1946 + Helium.

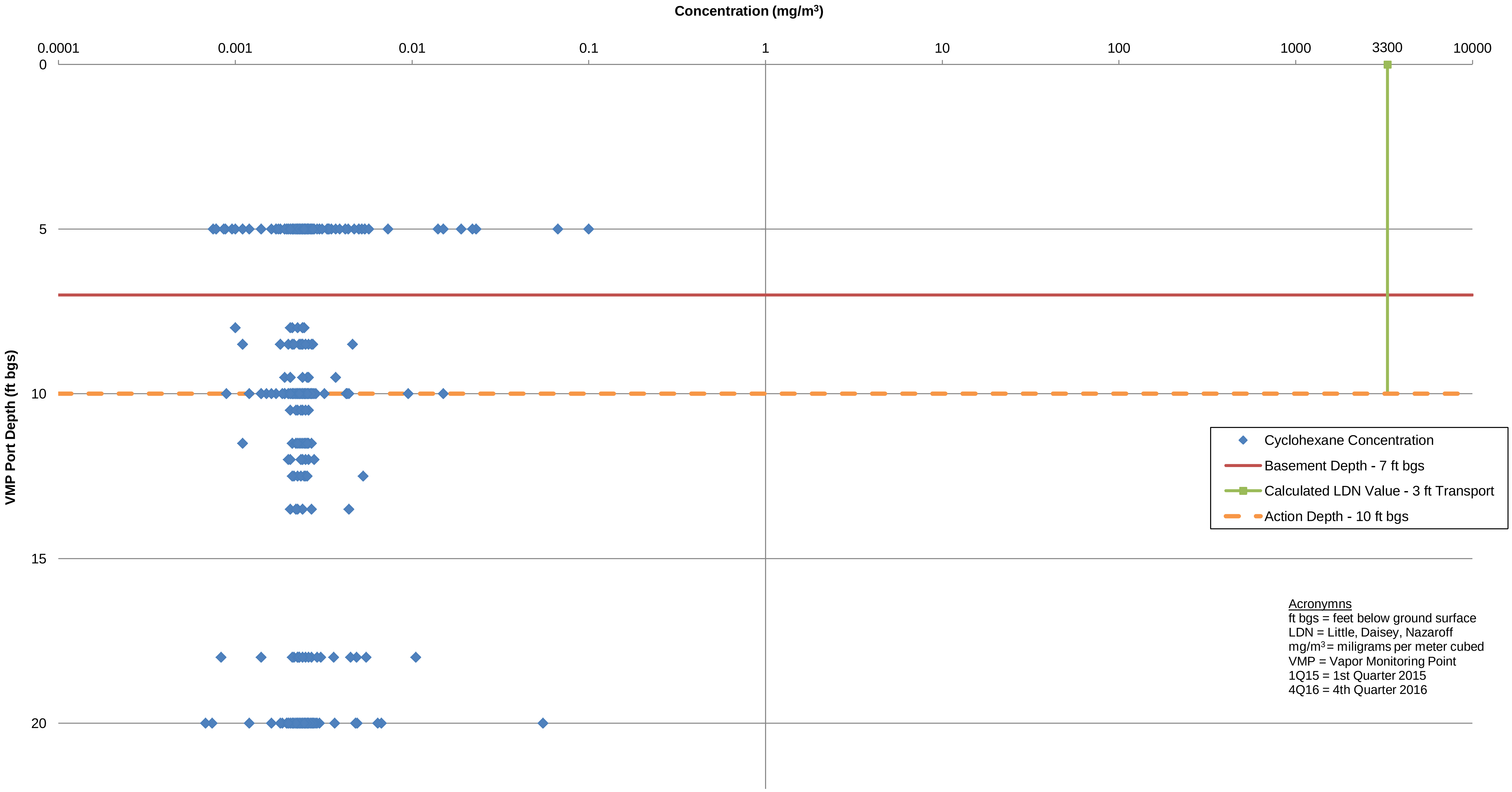
Charts.

CHART 1
Benzene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

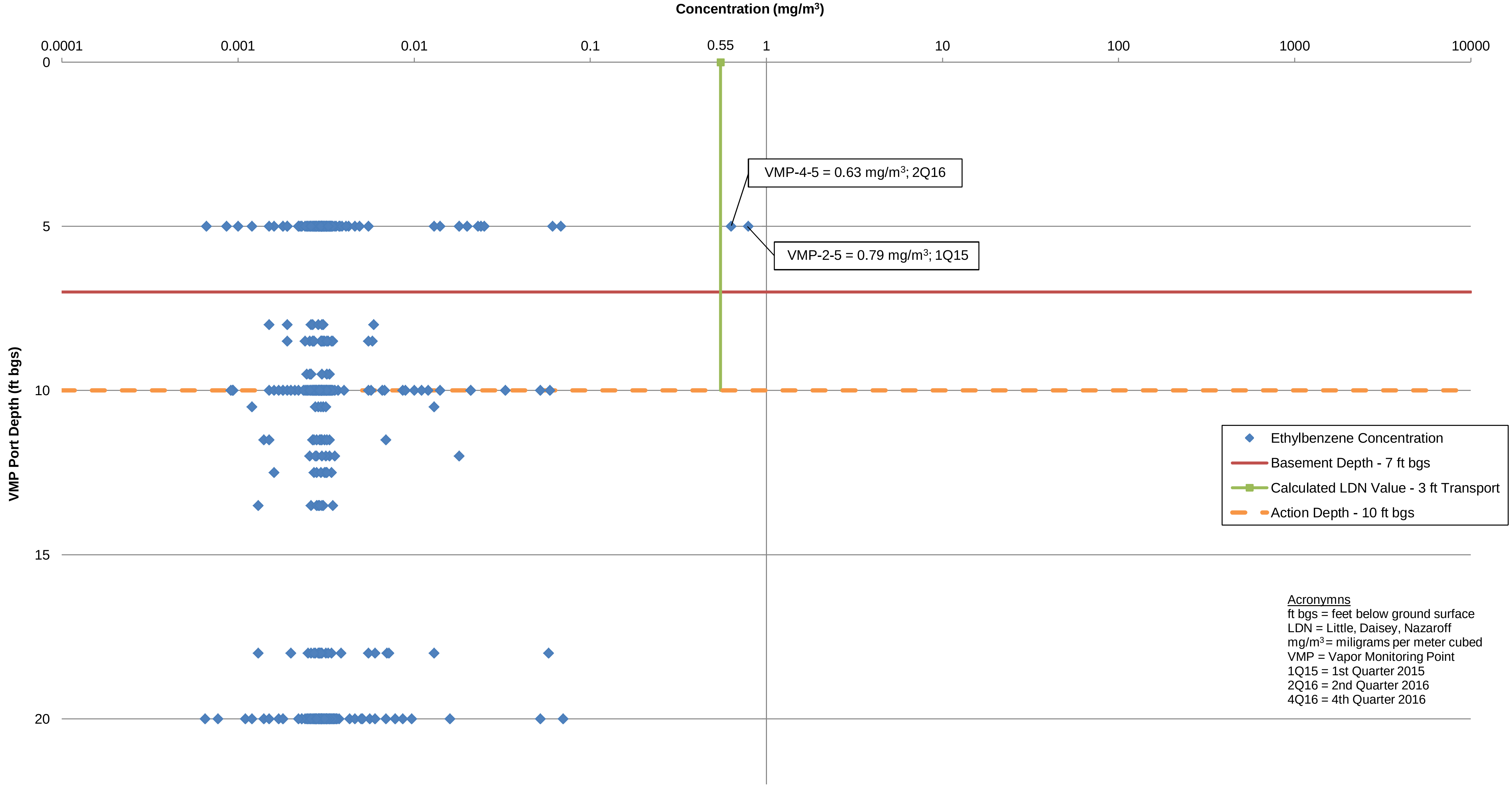
CHART 2
Cyclohexane Concentration at VMPs in Village of Roxana and Public Works
Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 3

Ethylbenzene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives (1Q15-4Q16)

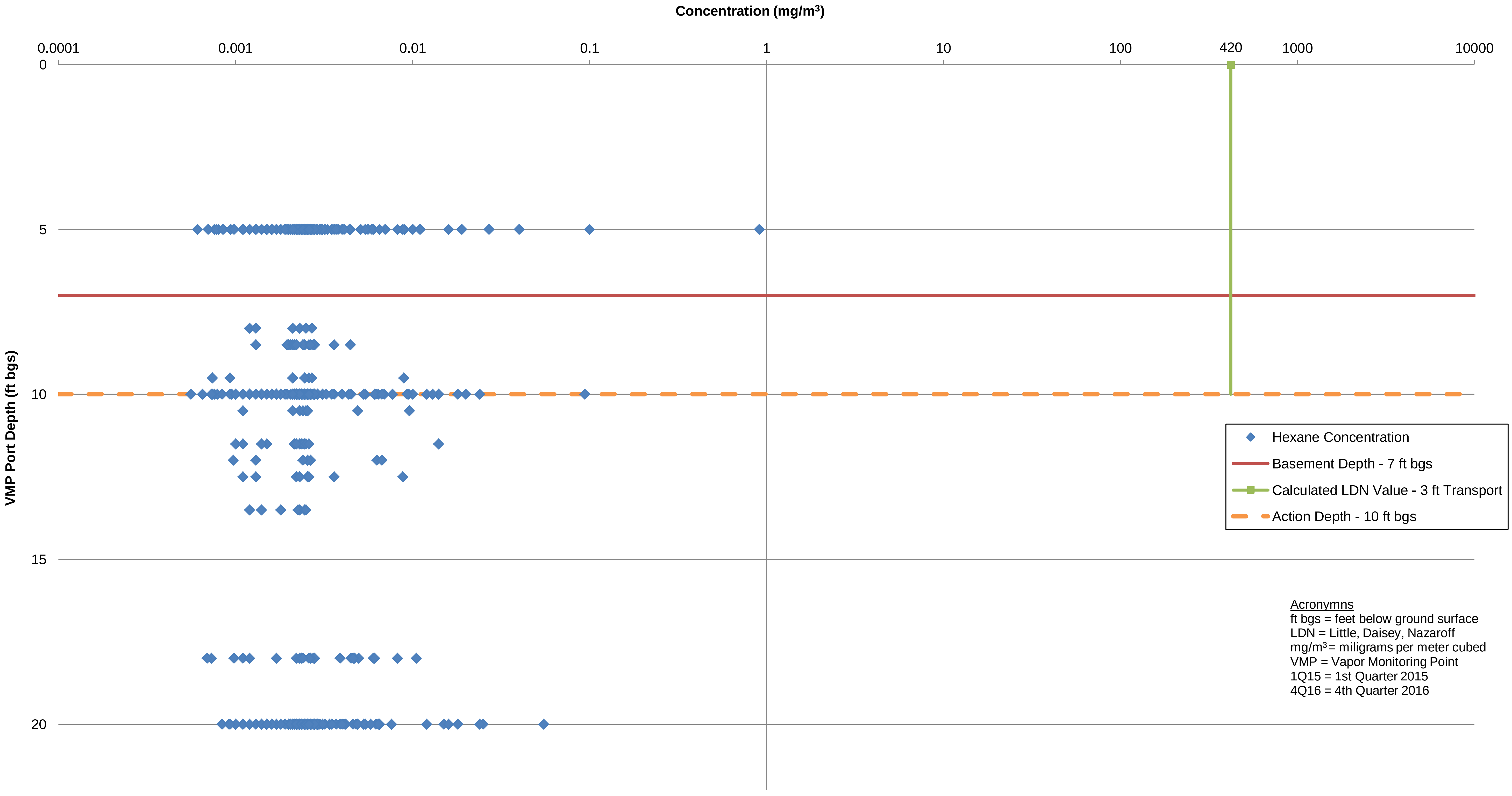


Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
2Q16 = 2nd Quarter 2016
4Q16 = 4th Quarter 2016

CHART 4

Hexane Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives

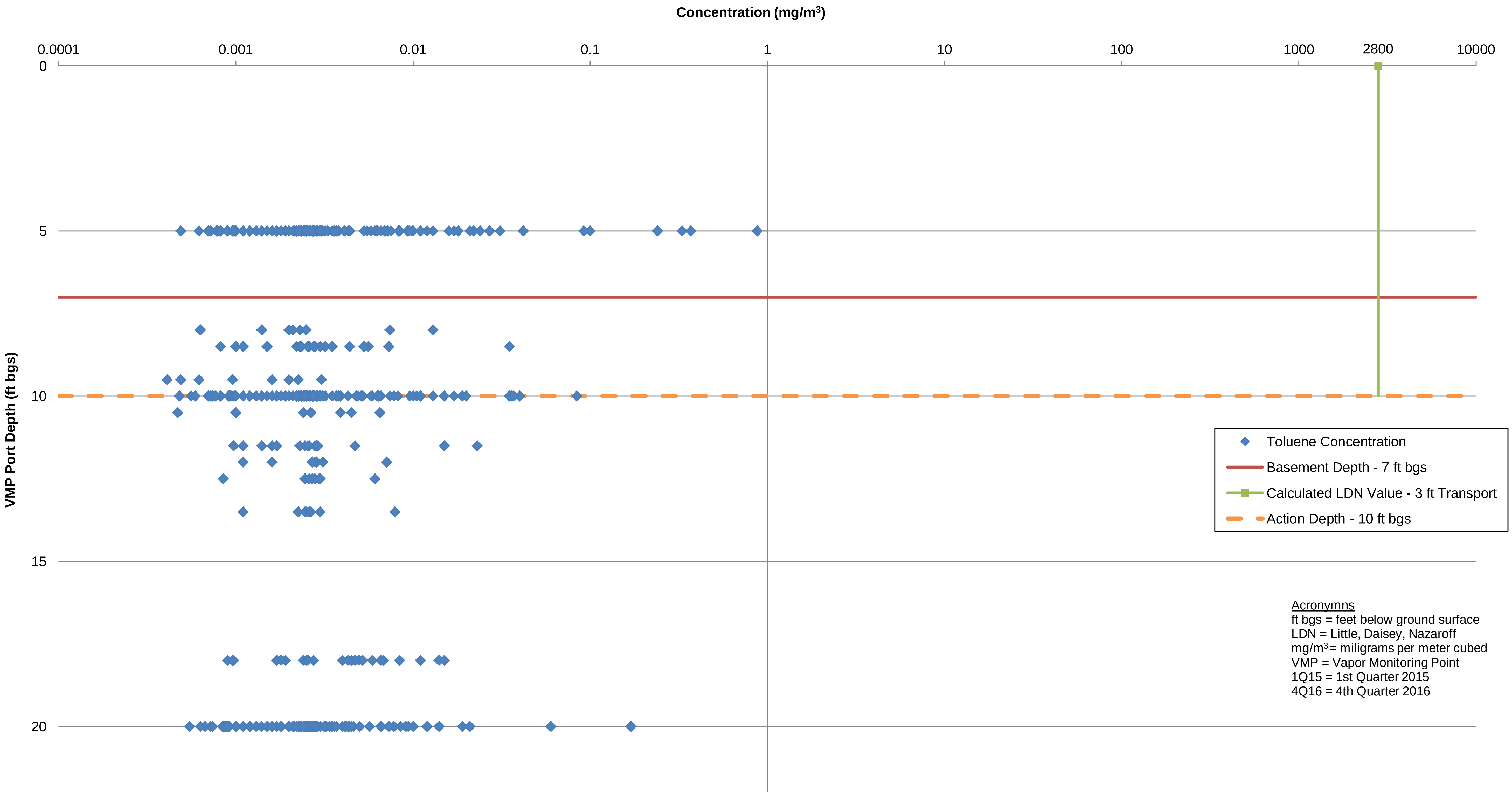
(1Q15-4Q16)



Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

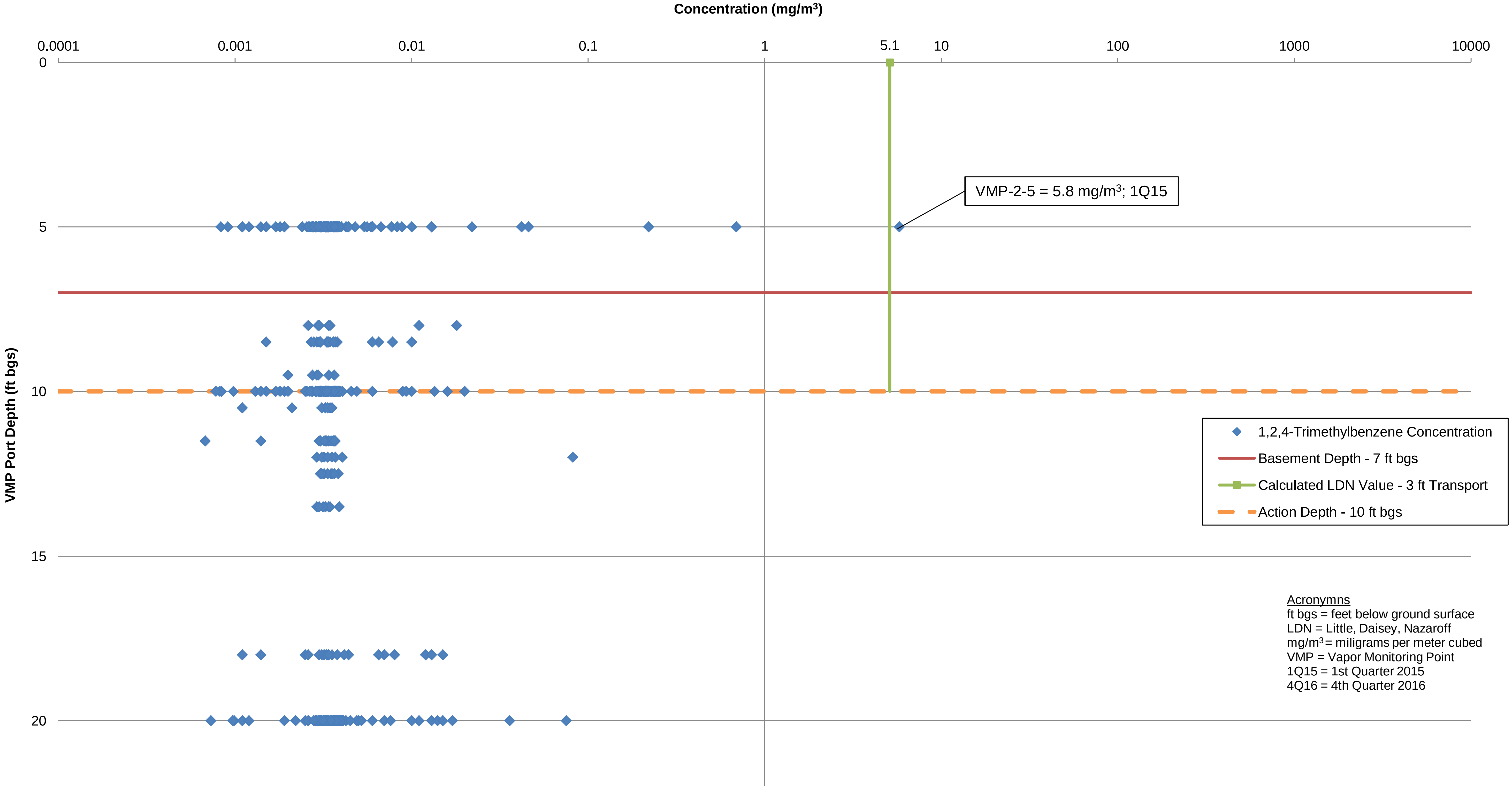
CHART 5

Toluene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives (1Q15-4Q16)



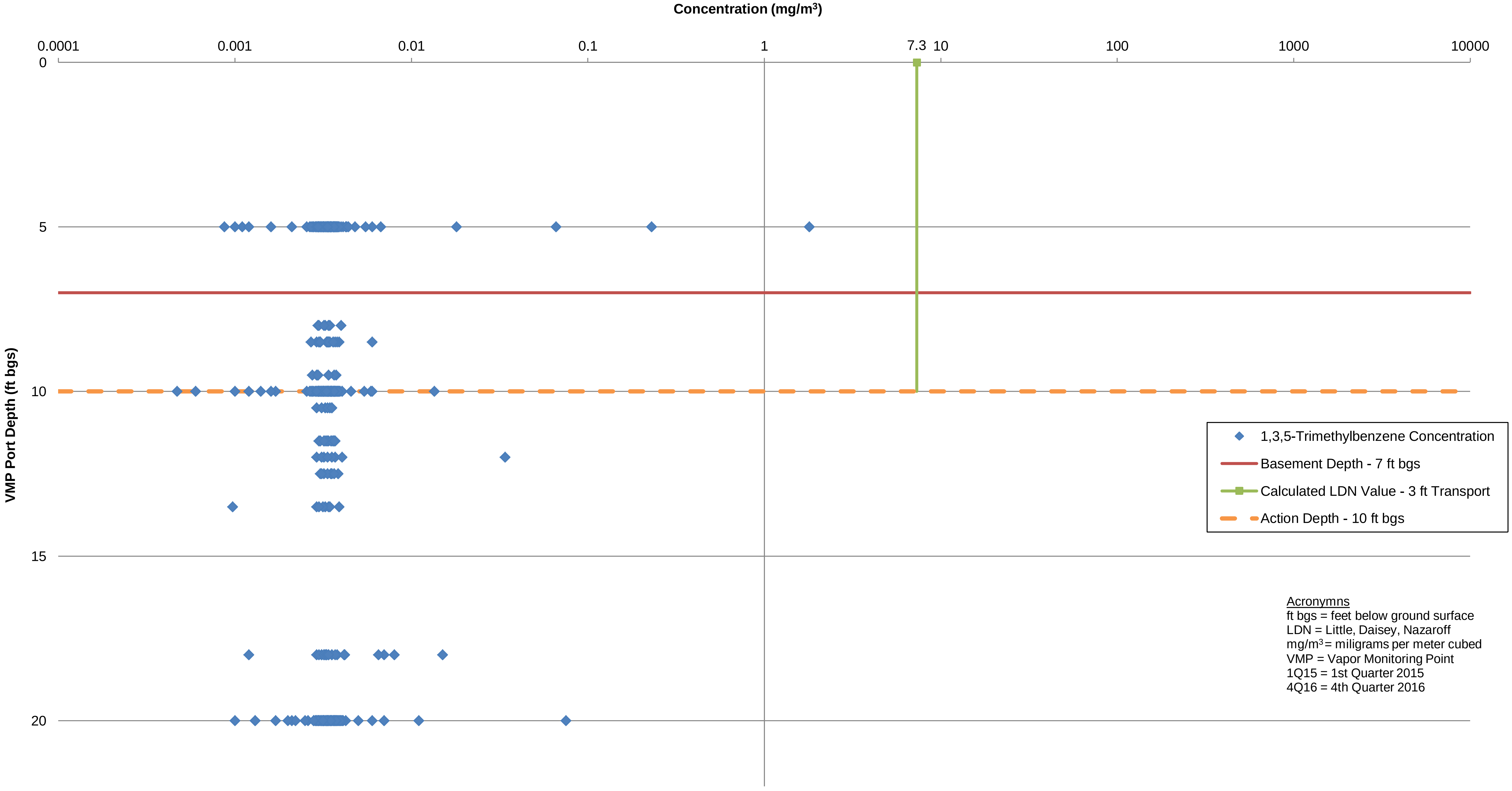
Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 6
1,2,4-Trimethylbenzene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



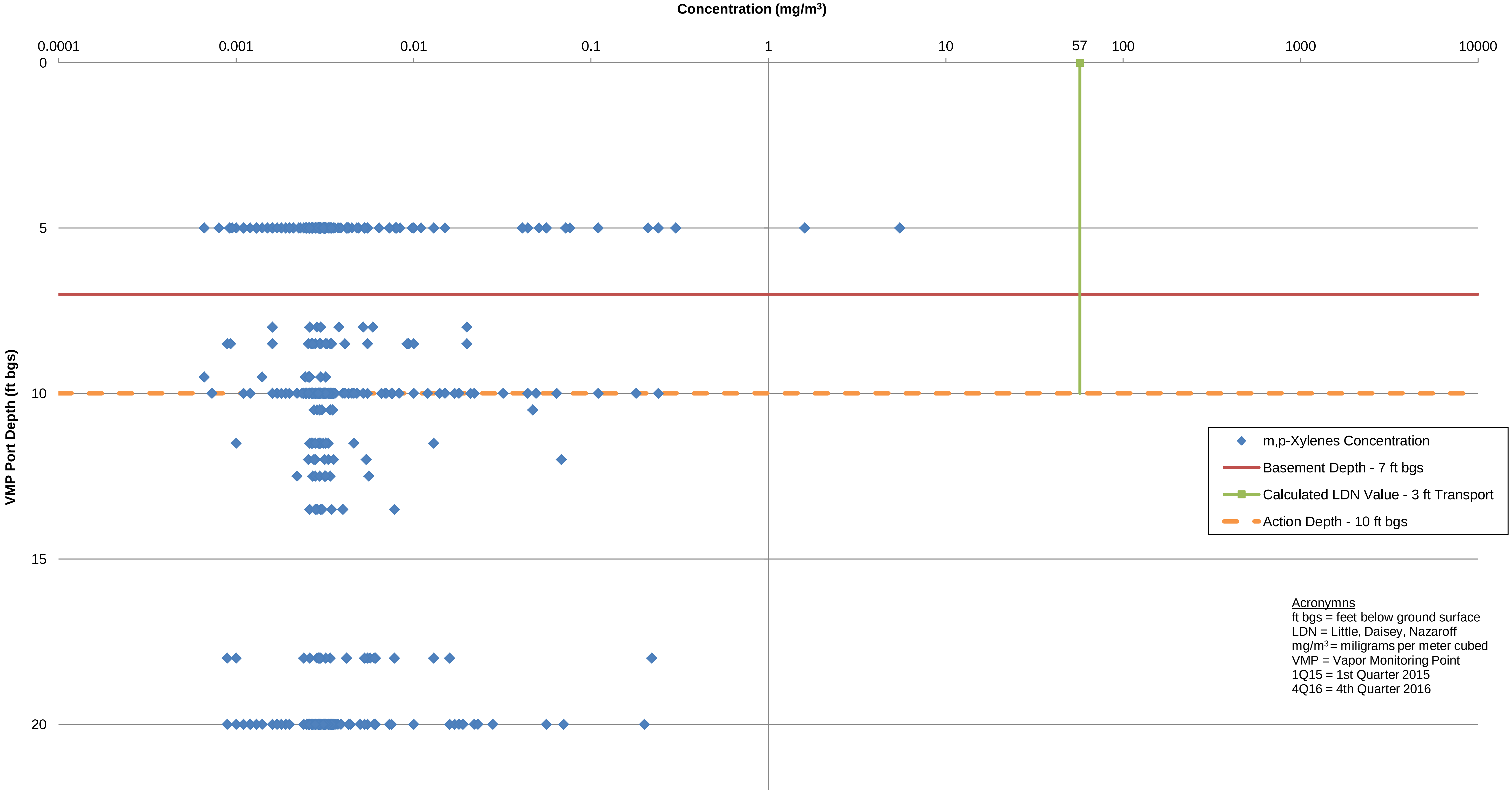
Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 7
1,3,5-Trimethylbenzene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



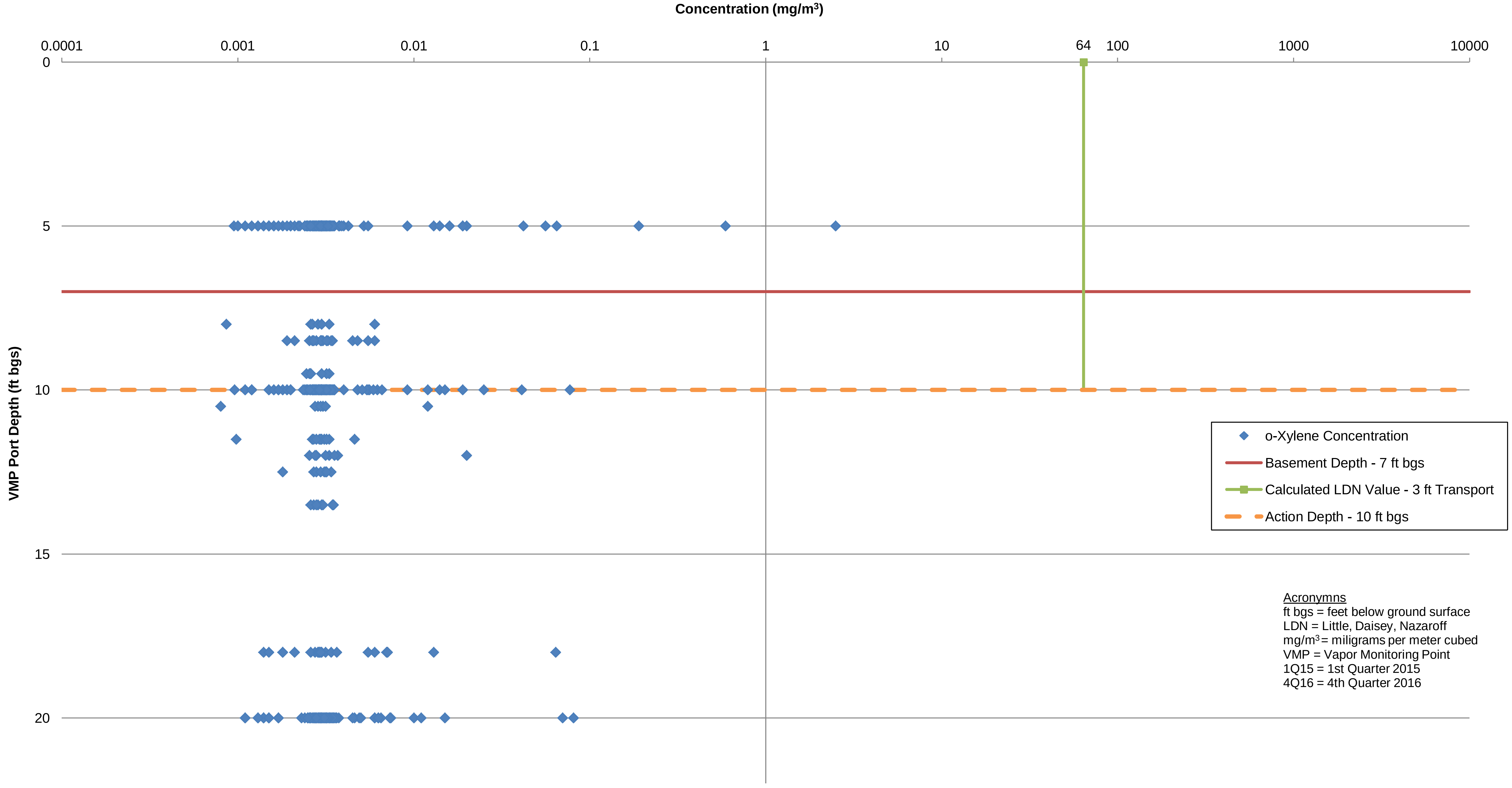
Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 8
m,p-Xylenes Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives (1Q15-4Q16)



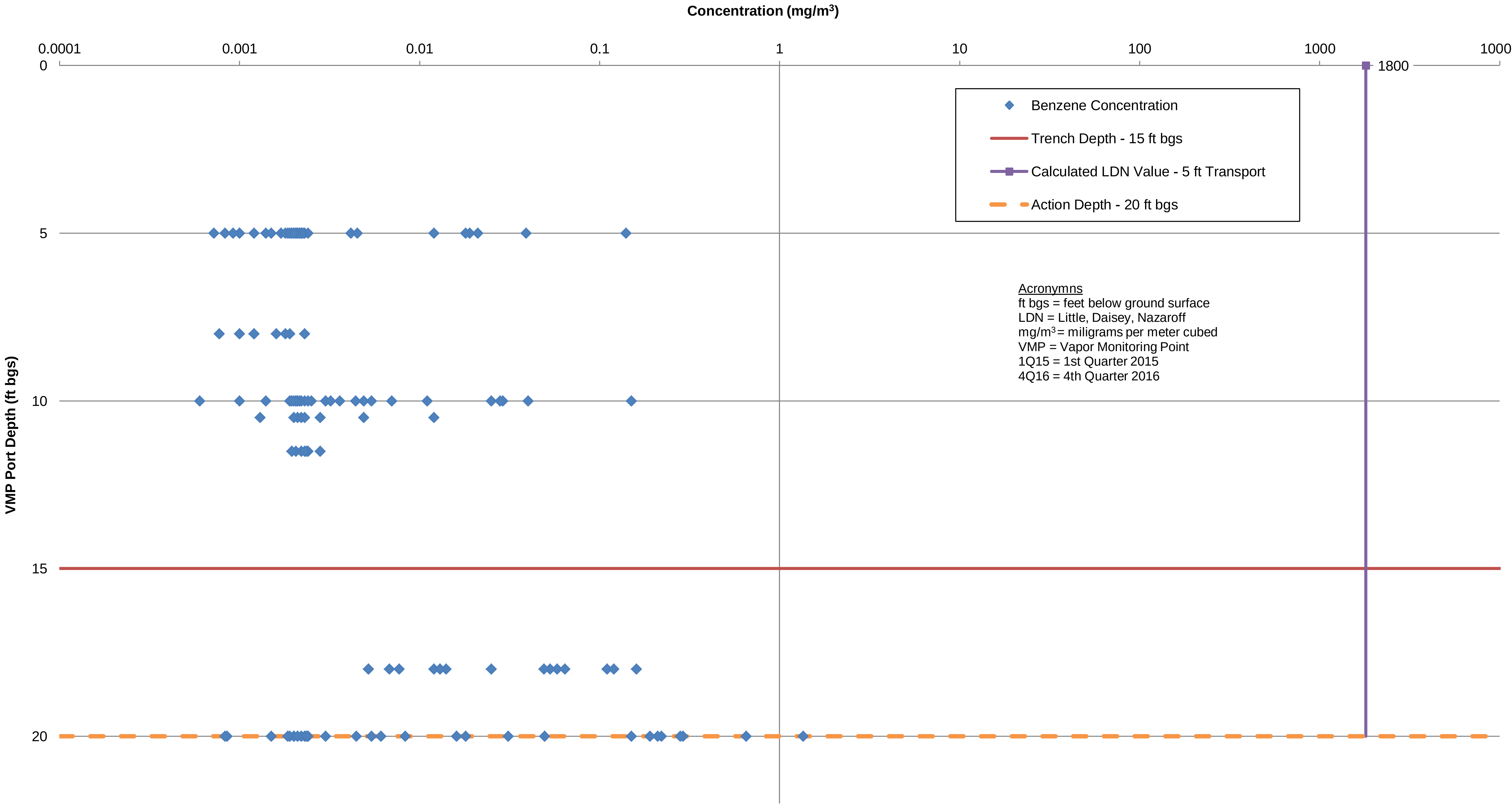
Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 9
o-Xylene Concentration at VMPs in Village of Roxana and Public Works Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

CHART 10
Benzene Concentration at VMPs in the Rights-of-Way Compared to Proposed Tier 3 Remediation Objectives
(1Q15-4Q16)



Acronymns
ft bgs = feet below ground surface
LDN = Little, Daisey, Nazaroff
mg/m³ = miligrams per meter cubed
VMP = Vapor Monitoring Point
1Q15 = 1st Quarter 2015
4Q16 = 4th Quarter 2016

Appendix 2-A. LDN Paper- *Transport of Subsurface Contaminants into Buildings, An Exposure Pathway for Volatile Organics*

ES&T

TRANSPORT of Subsurface CONTAMINANTS into Buildings

AN EXPOSURE PATHWAY FOR VOLATILE ORGANICS

JOHN C. LITTLE
JOAN M. DAISEY
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

WILLIAM W. NAZAROFF
University of California
Berkeley, CA 94720

Populations living near hazardous waste sites and landfills may be exposed to volatile organic compounds (VOCs) via several pathways, including inhalation of contaminated outdoor air (*1*), ingestion of contaminated water (*2*), inhalation of contaminants that volatilize during residential water use (*3–5*), and dermal sorption of contaminants while showering (*6*). The subsurface transport of volatile contaminants into buildings near contaminated sites has been considered an additional route of exposure (*7–14*), but the overall impact of the pathway has not yet been placed in perspective.

The flow of soil gas into buildings is driven by a pressure gradient that results from temperature differences between indoors and outdoors, wind loading on the building superstructure, and, in some instances, the operation of devices such as furnaces and exhaust fans. The small (several pascals) but persistent pressure difference that is established between the exterior and interior of the building may cause infiltration of soil gas through the substructure. This advective flow of soil gas has been shown to be a dominant mechanism for radon entry into houses (*15*). Soil gas contaminants may also diffuse through cracks or openings in the building substructure, or through building materials.

Despite mounting evidence (reviewed in the following section) of the importance of subsurface transport of VOCs into buildings, the significance of such exposures has not been evaluated quantitatively, and our understanding of the pathway is rudimentary. The purpose of this paper is to provide order-of-magnitude estimates of the possible increase in VOC concentrations in buildings near contaminated sites using current understanding of radon transport, an evaluation of various sources of subsurface contamination, and simple transport models.

Experimental evidence

Wood and Porter (*7*) conducted an investigation at the BKK Landfill in southern California. Methane was detected in enclosed spaces in nearby homes at concentrations approaching 1% (7000 mg m^{-3}), and chlorinated hydrocarbons had migrated into a house 180 m from the landfill. The migration of VOCs appeared to have resulted when a lowered water table opened a subsurface pathway through a permeable sandstone layer.

In a study carried out in The Netherlands, Kliest et al. (*8*) found that seven out of 77 homes located on contaminated soil had elevated concentrations of the contaminants indoors and in the crawl space compared to the average concentrations found in 20 reference homes. The average contaminant concentrations in the "polluted" houses were 250 to 8000 times higher in the crawl space and about two to 12 times higher in the living room relative to the reference homes. These relationships were found to be most influenced by groundwater depth, crawl space ventilation rate, and the type of flooring.

Garbesi and Sextro (*9*) and Hodgson et al. (*14*) developed more specific evidence in a study conducted in a single, unoccupied house near a landfill. In that study, chlorinated hydrocarbons, freons, and aromatic and aliphatic hydrocarbons were found in the soil gases around the house at levels ranging up to about 1 mg m^{-3}. The same VOCs were found in cavities in the cement blocks of the basement walls at similar levels, and in the house at concentrations one to two orders of magnitude lower. When the basement of the house was artificially depressurized, the indoor concentrations of those VOCs present in the soil gas increased. The indoor concentration of a tracer gas that had been injected into the soil on two sides of the house also increased with increasing basement depressurization. The contributions of contaminated soil gas accounted for more than three-quarters of the daily exposure to tetrachloroethylene (PCE), exceeding the combined exposures estimated for ingestion of water, inhalation in a shower, and inhalation of outdoor air. It should be noted that subsurface ventilation pumps had been installed between the landfill and the house before the study began.

The California Air Resources Board (CARB) (*10*) reported sampling conducted by the South Coast Air Quality Management District (SCAQMD) in the vicinity of the BKK Landfill. A total of 500 air samples were taken at two outdoor sites and four indoor sites downwind of the landfill. All of the 120 samples that equaled or exceeded the state vinyl chloride standard of 10 ppb (0.025 mg m^{-3}) were taken inside homes, with a maximum indoor vi-

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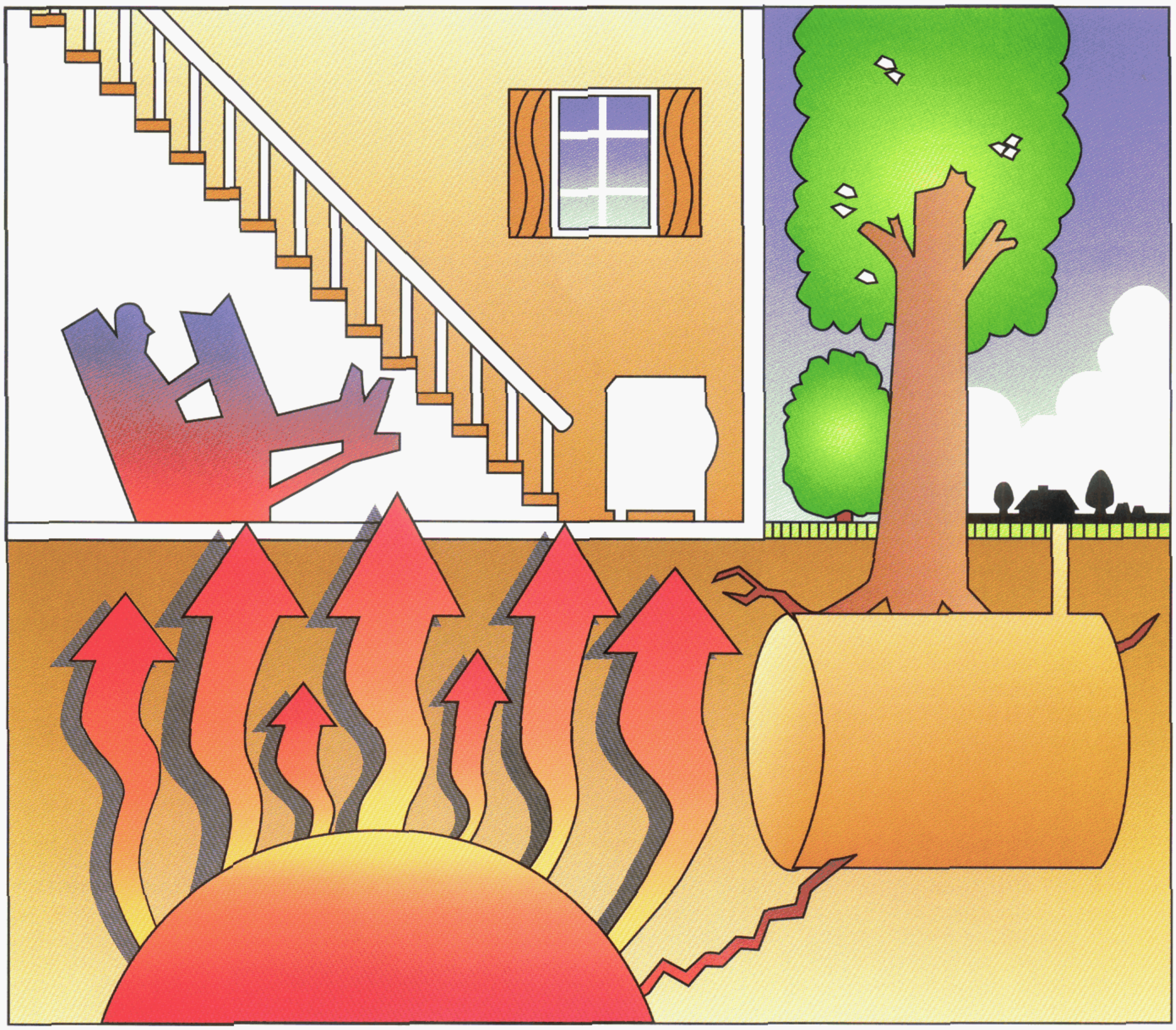


nyl chloride concentration of 0.13 mg m^{-3}. While sampling at a second landfill (OII), the SCAQMD measured concentrations of vinyl chloride in nearby homes from 0.02–0.3 mg m^{-3}. Because the maximum outdoor air concentration measured at this landfill was only 0.03 mg m^{-3}, atmospheric transport alone could not have accounted for the elevated indoor levels. In fact, grab samples of air taken from within water meter boxes at houses adjacent to the OII Landfill revealed vinyl chloride concentrations ranging from 0.03–90 mg m^{-3}. The CARB concluded that inhalation of indoor air may represent the most significant source of exposure to vinyl chloride for people residing near landfills.

Kullman and Hill (*11*) reported that gasoline contamination of indoor air at an office building was traced to three abandoned gasoline tanks buried beneath an adjacent building. Levels of benzene, toluene, and xylene at 1.7, 3.8, and 7.5 mg m^{-3} respectively, were found in the indoor air, with total gasoline hydrocarbons at 9.5 mg m^{-3}. Periodic gasoline odors had been reported over several years, and office workers complained of eye irritation, headache, and nausea. Even after the tanks had been removed, the contaminated soil beneath the building continued to be a source of occasional odors and complaints.

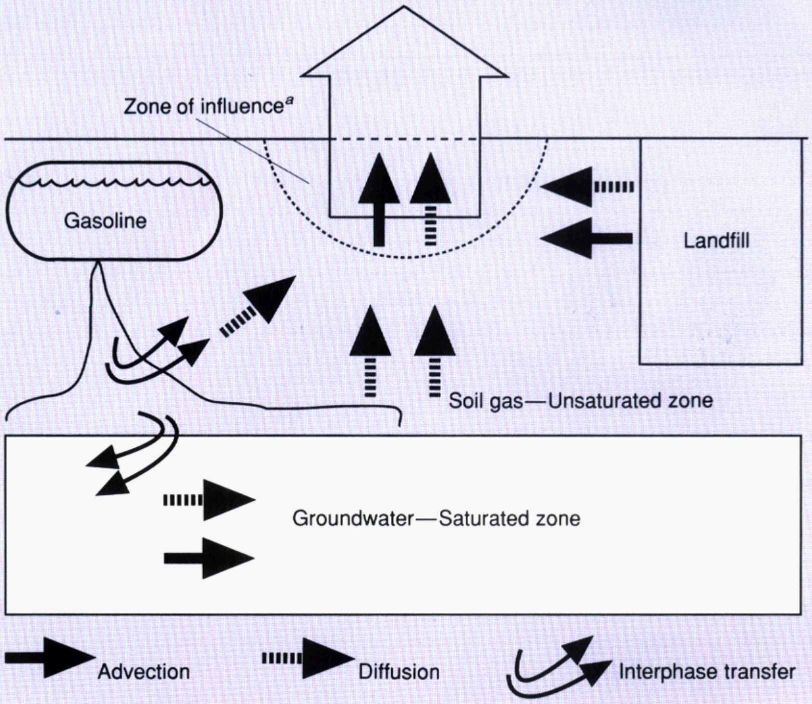
Finally, Moseley and Meyer (*13*) described the results of an air, soil gas, and groundwater monitoring survey that was undertaken following the discovery of explosive levels of gasoline vapors in a house approximately 50 m from a gasoline storage tank. (The lower explosive limit, LEL, for gasoline is 1.3% by volume.) Several centimeters of "free product" found floating in nearby groundwater monitoring wells confirmed subsurface leakage from the tank. A contaminated groundwater plume was detected moving down the gradient in the water table accompanied by a plume of contaminated soil gas. Four months after the initial discovery, the plumes reached a school about 250 m from the tank, and some staff and students became ill from noxious indoor odors. The local fire department measured levels of airborne vapors in the school of up to 40% of the LEL. During further air sampling at the school, total hydrocarbons were measured at 8.4 mg m^{-3} in classrooms and 390 mg m^{-3} in the crawl space beneath the floor. Both the residence and the school were evacuated.

Contaminant sources, pathways

Figure 1 is a conceptual scenario for the contamination of indoor air with VOCs from various subsurface sources. Potential sources of contamination include volatile liquids such as gasoline or chlorinated solvents, contaminated landfill gas, and contaminated groundwater. The VOCs introduced into the soil gas by these sources can be transported toward building substructures by advection under a pressure gradient or by diffusion if a concentration gradient exists. On arrival at the zone of influence surrounding the building, the VOCs may enter through openings in the substructure via advection, diffusion, or a combination of these two mechanisms. A schematic representation of the potential sources, partitioning mechanisms, and transport pathways is given in Figure 2.

FIGURE 1

Contamination of indoor air with VOCs from subsurface sources



[a] The region in which the building influences the movement of soil gas.

Evaluating source strengths

Soil gas surveys (*16–19*) increasingly are used to determine the source and extent of subsurface contamination. Surveys undertaken near dry cleaners (*16*) and gasoline stations (*19*) found average soil gas concentrations of 460 and 920 mg m^{-3} and maximum values of 11,000 and 14,000 mg m^{-3} for PCE and benzene, respectively. These soil gas concentrations may be compared with median levels reported for indoor air by Shah and Singh (*20*) of 0.0007, 0.005, and 0.01 mg m^{-3} for trichloroethylene (TCE), PCE, and benzene, respectively. The median indoor air concentrations will be assumed to represent baseline levels and will serve as a point of reference for ascertaining whether indoor contamination arising from subsurface sources is significant. Both the average and the maximum soil gas concentrations quoted above are many orders of magnitude higher than the baseline indoor air concentrations, suggesting the potential for high indoor exposures should efficient transport pathways exist near contaminated sites.

The VOCs found in the field surveys originated from spills or leaks of volatile organic liquids. However, as indicated in Figure 2, VOCs may also enter soil gas from other sources including landfills and contaminated groundwater. These potential sources are examined briefly in turn.

Chlorinated solvents. Liquid solvents such as PCE and TCE that leak into permeable unsaturated soil will sink under the influence of gravity, and interfacial forces will smear out the flow of liquid contaminant (*21*). Should a sufficient quantity of liquid reach a relatively impermeable and horizontal soil layer, it will form a pool. If the liquid is denser than water, it will penetrate any unconfined groundwater aquifer it encounters. Wherever solvent contacts soil gas, it will vaporize, forming a boundary vapor concentration that drives diffusive transfer of the VOC into the soil gas. Therefore, the vapor pressure of a pure solvent determines the source concentration of contaminant in the soil gas. At 20 °C, TCE and PCE vapor concentrations are 420,000 and 130,000 mg m^{-3}, respectively (*22*).

Gasoline. Gasoline that passes into the unsaturated soil zone will behave similarly to the chlorinated solvents with the important distinction that gasoline is less dense than water and will spread out on the top of a water table (*21*). Gasoline is a complex mixture of VOCs, and the vapor concentration at the liquid surface will depend on the liquid composition of the gasoline, which can vary widely (*23*). Also, the liquid composition may change with time as volatile components vaporize more rapidly. Therefore, predicting the vapor composition in equilibrium with a liquid gasoline spill is a more complex task than for pure solvents such as PCE. However, the estimated vapor concentration in equilibrium with typical fresh gasoline is 7000 and 11,000 mg m^{-3} for benzene and toluene, respectively (*22*).

Contaminated landfill gas. The major components of landfill gas are methane and carbon dioxide; both are generated during anaerobic microbiological activity. The presence of VOCs in landfill gas may be caused by vaporization of organic liquids dumped in the landfill, volatilization from contaminated water, microbial action, or chemical reaction. A survey of 20 landfills (*24*) found average concentrations of 10 and 66 mg m^{-3} and maximum concentrations of 170 and 1300 mg m^{-3} for benzene and PCE, respectively. Although dependent on landfill construction and on the rate of gas generation, the pressure in a typical older municipal landfill is of the order of 1500 Pa (J. Pacey, EMCON, San Mateo, CA, personal communication, 1992).

Contaminated groundwater. The VOCs that are present in groundwater will volatilize into the soil gas. The gas-phase concentration at the groundwater surface that is in equilibrium with the water acts as a source of VOCs. In a survey of 1006 wells belonging to large water suppliers in California (*25*), 302 wells were found to contain detectable levels of PCE and TCE with maximum concentrations of 170 and 540 mg m^{-3}, respectively. Assuming equilibrium predicted by Henry's law, the concentrations that would be present in air next to the contaminated groundwater are 92 and 170 mg m^{-3} for PCE and TCE, respectively (*22*).

Attenuation coefficients

A first-order estimate of the elevation in indoor VOC concentration resulting from subsurface contamination may be obtained by assuming that VOCs are transported into buildings in an analogous fashion to radon. However, the ratio of indoor concentration to source concentration—which can be thought of as an attenuation coefficient (*12*)—should be smaller for VOCs than for radon because radon emanates from the soil next to the building whereas the VOCs are transported over some distance to the building.

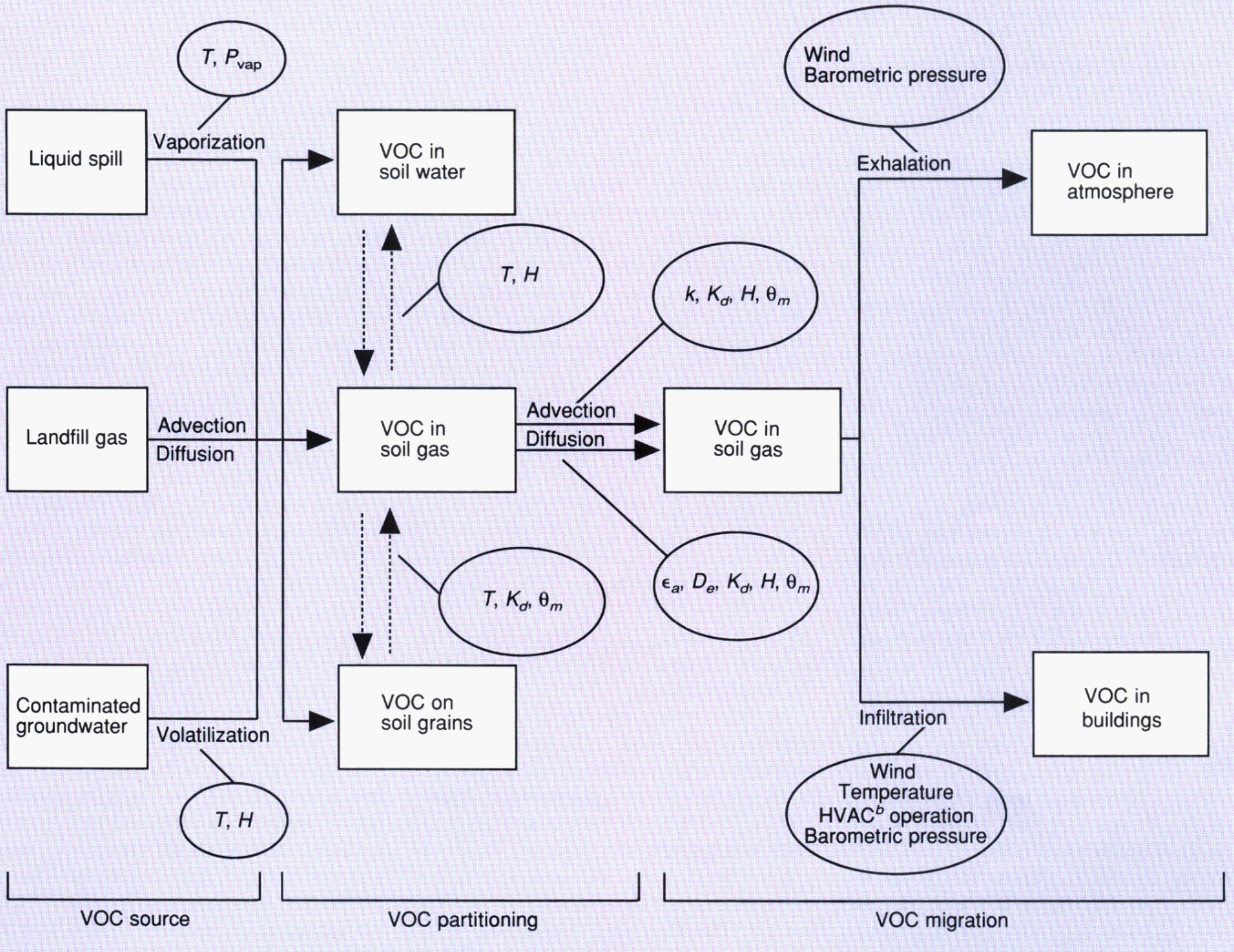
In this section the radon analogy is first applied. Next, because VOCs are subject to sorption processes as they pass through soil, a linear sorption isotherm is described and then incorporated into three subsurface transport models in the form of a retardation factor. The first transport model considers diffusion from a planar source located some distance from a building. In a second diffusion-based model, a building in an extensive region of uniformly contaminated soil and soil gas is examined. Finally, a simple advective model is used to estimate the transport of VOCs from a landfill to a building. To simplify the three transport models, it is assumed that the VOCs are swept into the building as fast as they arrive at the zone of influence (an assumption that is largely consistent with current understanding of radon entry) and that the concentration at the building perimeter is much lower than the source concentration. Furthermore, the source concentration of the contaminant is assumed to be constant over time, and the soil medium is assumed to be isotropic and homogeneous.

Radon analogy. Using the mean indoor radon concentration found in the living space of single-family homes (*26*) and an estimate of the mean radon concentration in soil pores, a representative attenuation coefficient for radon is found to be $\alpha = C_{\text{indoor}}/C_{\text{source}} = 0.0016$ (see box). This ratio varies widely across the housing stock. If it is assumed that VOCs behave similarly to radon, then α can be used to obtain a first-order estimate of the likely indoor concentrations resulting from contaminated soil gas. Applying α to the maximum measured PCE and benzene concentrations found in the soil gas surveys gives indoor concentrations of about 20 mg m^{-3}, a value more than 2000 times higher than the baseline indoor concentrations.

Sorption. The simplest model used to describe sorption between soil gas and soil assumes that the sorption equilibrium may be ex-

FIGURE 2

Schematic representation of VOC sources and pathways in the unsaturated soil zone[a]



[a] Rectangular boxes represent the possible states that the VOCs may assume; arrows indicate transport pathways. Parameters that influence source strength, partitioning, and transport are shown in ovals and are defined in the glossary.

[b] Heating, ventilation, and air-conditioning systems.

pressed as a linear isotherm, or

$$q = K_d C \tag{1}$$

where q is the mass of VOC sorbed per unit dry mass of soil, C is the gas-phase VOC concentration, and K_d is a partition coefficient. Ong and Lion (*27*) have shown that the sorption coefficient, K_d, for VOCs on soils that are close to field capacity in moisture content is related to K_d^{sat}, the water saturated sorption coefficient, and H, the dimensionless Henry's law constant, by

$$K_d = \left(\frac{K_d^{sat}}{H}\right) + \left(\frac{\theta_m}{H}\right) \tag{2}$$

where θ_m is the soil moisture content. The field capacity of a soil is its moisture content when well drained following saturation. Ong and Lion found that Equation 2 successfully predicted K_d for TCE at soil moisture contents greater than 4%. In experiments with seven different soils, Ong and Lion found that K_d^{sat} for TCE varied between 0.06×10^{-3} and 3.3×10^{-3} m^3 kg^{-1}. The average value of 0.9×10^{-3} m^3 kg^{-1} will be used in this study as a representative sorption coefficient for TCE.

Transport models. The equation describing diffusion through sorbing unsaturated porous media is

$$\frac{\partial C}{\partial t} = \left(\frac{D_e}{\epsilon_a R}\right)\frac{\partial^2 C}{\partial x^2} \tag{3}$$

where t is time and x is distance. The effective diffusion coefficient D_e governs the rate of diffusion of VOCs through soil gas and, according to Millington (*28*), is related to the diffusion coefficient of the VOC in air, D_{air}, and the soil porosity by

$$D_e = D_{air}\left(\frac{\epsilon_a^{3.33}}{\epsilon^2}\right) \tag{4}$$

where $\epsilon_a = \epsilon - \theta_m \rho_b$ is the gas-filled porosity of the soil, ϵ is the total porosity, and ρ_b is the bulk density of the soil. Equation 4 has been verified experimentally by Karimi et al. (*29*) for diffusion of benzene through unsaturated soil. In Equation 3, R is the retardation factor, or the ratio of the total amount of the VOC to the amount present in the soil gas, and is defined as $R = 1 + \rho_b K_d/\epsilon_a$. If no sorption occurs, $K_d = 0$, and R reduces to unity.

In the first diffusion model, a plane of contamination with gas-phase concentration C_{source} is introduced at a distance L from a building in an otherwise uncontaminated region of soil, as shown in Figure 3 (top). This model is intended to approximate, for example, a layer of liquid solvent resting on an impermeable soil layer below a building, fresh gasoline floating on the water table, or contaminated groundwater itself. The areal extent of the source is assumed to be substantially greater than that of the building. The flux of VOCs through the soil, when multiplied by the appropriate cross-sectional area of the zone of influence A, gives the mass flow of VOCs that enters the building. The resulting indoor concentration C_{indoor} may be estimated as the rate at which the mass of VOC enters the building divided by the volumetric flow rate of air through the building Q_b. A transient solution for the attenuation coefficient is (*22*)

$$\alpha = \frac{C_{indoor}}{C_{source}} = \left(\frac{D_e A}{L Q_b}\right)\left(1 + 2\sum_{n=1}^{\infty}\left(\cos(n\pi)\exp(-D_e n^2 \pi^2 t/R\epsilon_a L^2)\right)\right) \tag{5}$$

At infinite time, the summation term reduces to zero, yielding the steady-state solution.

Typical transport and building parameters are listed in Table 1. As indicated, certain parameters are taken from Johnson and Ettinger (*12*) to facilitate comparison with that work, and a detailed discussion of soil properties is presented in a recent review of radon transport from soil to air by Nazaroff (*30*). Equation 5 is used to calculate the steady-state value of α and the time taken to reach 90% of the steady-state value (τ_{ssc}) for source distances varying from 0.1 m to 100 m with the results reported in Table 2 (top). Although the attenuation coefficient falls in a linear fashion from 0.03 to 0.00003 as the distance from the source increases, the time to steady state increases rapidly. For a retardation factor of 1, the time taken to reach steady state is about 20 min at $L = 0.1$ m, but 36 years for a source 100 m from the building. Sorption will delay the time taken to reach steady state by a factor equal to the retardation factor, which amounts to about 20 using the representative sorption coefficient for TCE. This shows that sorption can have a large impact on transport of VOCs through the unsaturated zone.

Attenuation coefficient for radon entry from soil

The mean indoor radon concentration in the living space of single-family dwellings in the United States is approximately 55 Bq m^{-3} (*26, 39*). The dominant source of this radon is soil adjacent to the building substructure. The maximum or undepleted radon concentration in soil pores C_{source} is related to primary factors as follows:

$$C_{source} = f \rho_s A_{Ra}\left(\frac{1-\epsilon}{\epsilon}\right)$$

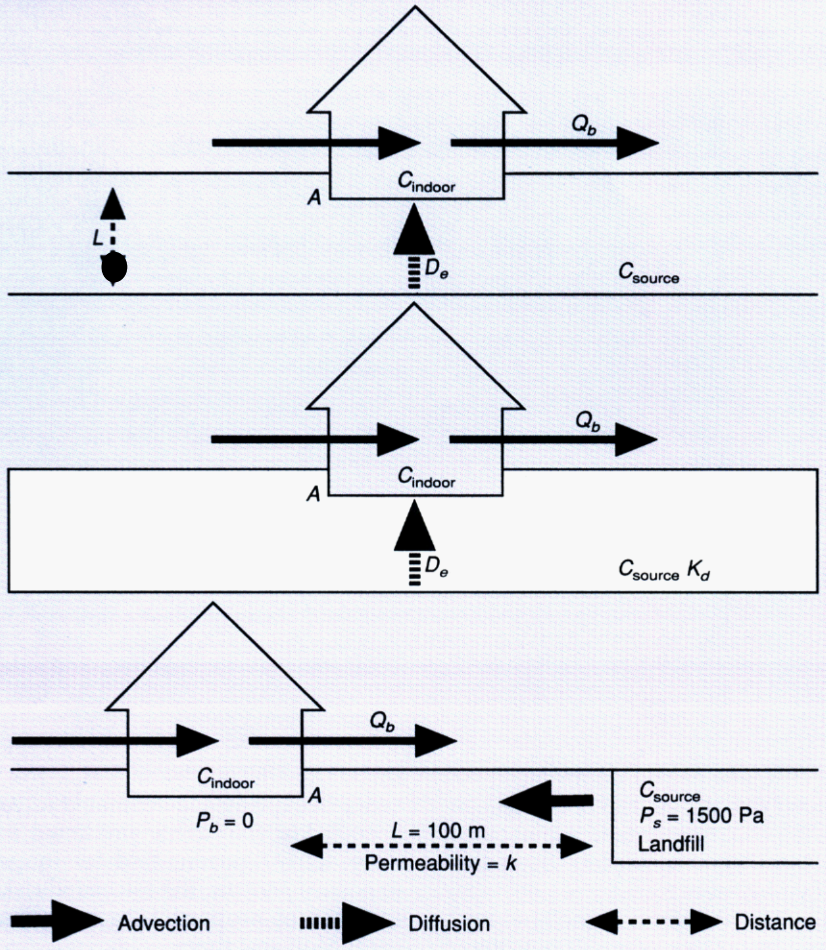
where the parameters can be estimated from data compiled by Nazaroff and co-workers (*15, 30*). Data on the radium content of surface soils A_{Ra} indicate a typical range of 10–100 Bq kg^{-1} with 40 Bq kg^{-1} constituting a reasonable estimate of the mean. The emanation coefficient f of ^{222}Rn has been observed to range from 0.05 to 0.7, and the geometric mean value of these limits, 0.2, can be taken as a baseline estimate. Typical values for the soil grain density ρ_s and total porosity ϵ are listed in Table 1. Combining these values yields C_{source} = 35,000 Bq m^{-3}, a number that is consistent with measured data. The resulting representative ratio C_{indoor}/C_{source} is therefore 55/35,000 = 0.0016.

The building substructure may be expected to influence the rate of soil gas entry. Cohen (*40*) reported annual average indoor radon measurements in the living space of houses in the United States as 59, 48, and 47 Bq m^{-3} for basement, slab-on-grade, and crawl space substructures, respectively. This suggests that the type of substructure has a relatively small influence on the rate of soil gas entry.

In the second diffusion model, a uniform source with gas-phase concentration C_{source} surrounds the building as shown in Figure 3 (center). In this case, the model is intended to approximate a new house built in an extensive, uniformly contaminated region. The VOC in the soil gas is assumed to be in equilibrium with that sorbed on the soil. For simplicity, it is assumed that there is no transport of VOCs from the ground surface to the surrounding ambient air. This model should therefore only be applied to approximately these conditions—paved environments, for example. Once the house has been built, the VOCs in the zone of influence are swept into the building, setting up a concentration gradient in the surrounding soil with a resulting flux of VOCs toward the building. The

FIGURE 3

Schematic representation of the subsurface transport of VOCs from a planar source (top), uniform source (center), and landfill (bottom) into a building[a]



[a] Terms are defined in the glossary.

physical situation resembles diffusion into a region bounded internally by the sphere with radius $r = r_b$, where r_b is the equivalent radius of the zone of influence. A solution is (*22*)

$$\alpha = \frac{C_{\text{indoor}}}{C_{\text{source}}} = \left(\frac{D_e}{r_b} + \sqrt{\frac{D_e \epsilon_a R}{\pi t}}\right)\left(\frac{A}{Q_b}\right) \tag{6}$$

The distance that the contaminant front has receded from the building may be estimated as $r - r_b$, where r is the radius at which the concentration is equal to 0.9 C_{source}, and obtained from

$$\frac{C}{C_{\text{source}}} = 1 - \left(\frac{r_b}{r}\right) erfc \left(\frac{r - r_b}{2\sqrt{(D_e t)/(R\epsilon_a)}}\right) \tag{7}$$

Using the parameters in Table 1, equations 6 and 7 give the results reported in Table 2 (center). The attenuation coefficient falls with time as the contaminant front slowly recedes from the building. For a situation without sorption, the attenuation coefficient varies from 0.004 after 1 day to 0.0007 after 10 years. During the 10-year period, the contaminant front recedes by about 20 m. In contrast to the previous case, sorption results in higher levels of indoor contamination and a reduction in the rate at which the front recedes because the sorbed fraction acts as a reservoir of contaminant. These calculations illustrate how indoor air contamination in such a case may persist for many years.

The equation describing advection through sorbing unsaturated porous media is

$$\frac{\partial C}{\partial t} = -\left(\frac{v}{R\,\epsilon_a}\right)\frac{\partial C}{\partial x} \tag{8}$$

where all variables are as previously defined except v, which is the Darcy velocity, given by

$$v = -\left(\frac{k}{\mu}\right)\left(\frac{dP}{dx}\right) \tag{9}$$

where k is soil permeability, μ is dynamic viscosity of the soil gas, and P is pressure.

For the advection model, a landfill with gas-phase concentration C_{source} is located a distance L from a building as shown in Figure 3 (bottom). The ground surface between the building and the landfill is assumed to have a much lower permeability than the unsaturated zone. Practically, this could take the form of a thin surface clay layer or a paved surface. The landfill is at pressure P_s; the pressure at the building perimeter is P_b. The size of the landfill is assumed to be substantially greater than the width of the building as well as the distance to the building. The contaminant flux passing between landfill and building is $v\,C_{\text{source}}$, which gives the following steady-state solution (*22*)

$$\alpha = \frac{C_{\text{indoor}}}{C_{\text{source}}} = \left(\frac{k}{\mu}\right)\left(\frac{P_s - P_b}{L}\right)\left(\frac{A}{Q_b}\right) \tag{10}$$

Equation 10 is based on a crude estimate of the actual contaminant flux and tends to underestimate α because the transport will not be entirely one dimensional (*22*). The characteristic time to establish the pressure gradient is (*31, 32*)

$$\tau_{ssp} \sim \left(\frac{\mu\,\epsilon_a\,L^2}{k\,P_{\text{atm}}}\right) \tag{11}$$

whereas the time to reach steady-state concentration is the time for the contaminant to travel from the landfill to the building, or

$$\tau_{ssc} \sim \left(\frac{L\,\epsilon_a\,R}{v}\right) \tag{12}$$

Under these idealized conditions, and providing that $\tau_{ssp} << \tau_{ssc}$, the attenuation coefficient should remain essentially zero until the steady-state conditions for concentration are met.

For the advection model, the attenuation coefficient is calculated using Equation 10 and the appropriate parameters taken from Table 1. The landfill is assumed to be 100 m from the building, and the values of α for different soil permeabilities along with the times taken to reach steady state are reported in Table 2 (bottom). The attenuation coefficient falls as soil permeability decreases, and sorption delays the arrival of the contaminant at the building. As k varies from 10^{-10} m^2 to 10^{-13} m^2, α ranges from 0.4 to 0.0004 with τ_{ssc} varying between 90 h and 10 years for $R = 1$. The steady-state pressure gradient is established within about 1.5% of τ_{ssc} at $R = 1$.

Johnson and Ettinger's model. The three transport models described above all assume that the entire flux of VOC arriving at the zone of influence is swept into the building. To assess the impact of this assumption, consider the results of Johnson and Ettinger (*12*), who coupled steady-state diffusion from a planar source to the rate of infiltration into a building via both advection and diffusion. For a source located 10 m from the building, and for crack spaces in the building substructure amounting to 0.1% of the total subsurface area, the coupled model predicts upper and lower bounds for α of 0.0003 and 0.00002, respectively. Surprisingly, the range spans only an order of magnitude. The high value corresponds to the condition for high advective soil gas flow; the lower value arises where the soil is so impermeable that there is no soil gas flow and the VOCs enter the building via diffusion alone. The high value of 0.0003 is consistent with that for diffusion from a planar source at $L = 10$ m (Table 2 top).

TABLE 1

Typical transport and building parameters

Parameter	Symbol	Value or range	Reference
Diffusivity in air (TCE at 20 °C)	D_{air}	8.4×10^{-6} m^2 s^{-1}	41
Henry's constant[a] (TCE at 20 °C)	H	0.32	41
Saturated partition coefficient[b] (TCE at 20 °C)	K_d^{sat}	8.9×10^{-4} m^3 kg^{-1}	27
Total soil porosity	ϵ	0.38	12
Soil moisture content	θ_m	7×10^{-5} m^3 kg^{-1}	12
Bulk density of soil	ρ_b	1700 kg m^{-3}	12
Soil grain density	ρ_s	2650 kg m^{-3}	31
Permeability of soil to soil gas	k	10^{-10} to 10^{-13} m^2	30
Dynamic viscosity of soil gas (air at 20 °C)	μ	1.8×10^{-5} kg m^{-1} s^{-1}	30
Ambient air pressure	P_{atm}	101 kPa	–
Dynamic landfill gas pressure	P_s	1.5 kPa	–
Dynamic pressure at building perimeter	P_b	0	–
Ventilation rate of building	Q_b	105 m^3 h^{-1}	12
Effective contaminant flux area	A	138 m^2	12
Effective radius of zone of influence	r_b	4.7 m	–

[a] Defined as equilibrium ratio, $H = C/C_w$.

[b] Defined as equilibrium ratio, $K_d^{sat} = q/C_w$.

Estimating contamination and risk

When soil gas contaminant concentrations for the various sources have been evaluated and a range of attenuation coefficients for different situations have been calculated, the source concentrations can be multiplied by the attenuation coefficients to obtain order-of-magnitude estimates of the likely ranges of indoor air contaminant concentration as shown in Table 3. The range of reasonable α values for diffusive transport is taken as 0.00003 to 0.003; for advective transport, the likely range in α is taken as 0.0004 to 0.04.

Table 3 shows that the elevation in indoor air VOC concentrations attributable to subsurface contamination can be substantially higher than typical baseline levels. Even if the models used to arrive at these estimates predict values that are too high by an order of magnitude, the results still are cause for concern. For the representative conditions considered in this study, a liquid spill creates the greatest potential hazard for contaminant exposure through indoor air. In addition, notice that for the gasoline, landfill, and groundwater sources, only a single component has been considered, and the presence of other components will increase the overall indoor contamination. Also, the landfill source has been considered at a distance of 100 m; for buildings located directly on top of or adjacent to a landfill, the contamination could be significantly higher than that shown in Table 3.

The health effects associated with living in houses near contaminated sites or landfills could be substantial. The upper limits of the estimated ranges of indoor concentrations for benzene and TCE are near or above the 8-h threshold limit values for occupational exposures (*33*). Because the average person spends about 115 h per week in the home (*34*), the exposure in houses close to strong sources could be almost three times greater than in occupational settings. Furthermore, more susceptible populations such as children, the chronically ill, and the elderly, are exposed in homes.

The cancer risks associated with indoor exposures to the benzene and TCE concentration ranges reported in Table 3 are well above the generally accepted lifetime risks of 10^{-6}, even under quite conservative exposure assumptions (*34–36*). For example, taking the lowest estimated indoor concentration of benzene (0.2 mg m^{-3}), the lifetime cancer risk for a person who spends 115 h per week in a house for 5 years amounts to 1×10^{-4}. Similarly, for the lowest estimated indoor concentration of TCE arising from a liquid spill (13 mg m^{-3}), the lifetime cancer risk for 5 years of exposure is estimated as 2.6×10^{-3}. For the higher predicted indoor concentrations and for longer exposure periods, the estimated risks increase in proportion to both concentration and time.

Research directions

Contamination of indoor air by VOCs from the subsurface is of concern only in the relatively small fraction of houses located near contaminated sites or landfills. However, the high levels of contamination that have been measured in a few buildings and that are predicted by the simple transport models suggest that a clearer understanding of this transport pathway is urgently needed. Simple screening models for identifying buildings in which soil gas infiltration may be a major pathway of contamination will be valuable. Such models could also allow estimates to be made of the size of the population subject to increased risks via this exposure pathway. The models presented here should provide a useful starting point in this regard.

Field studies at contaminated sites should be carried out to provide further evidence for the existence of this exposure pathway as well as to improve the general understanding of the transport mechanisms involved. For example, the

TABLE 2

Attenuation coefficients (α) for subsurface transport of VOCs into a building

Diffusive transport from a planar source: Attenuation coefficient and time to steady-state for various source distances

	Distance from source (m)			
	0.1	1	10	100
α	0.03	0.003	0.0003	0.00003
τ_{ssc}^{a} ($R = 1$)	20 min	32 h	140 days	36 years
τ_{ssc} ($R = 20$)	7 h	27 days	7 years	720 years

Diffusive transport from a uniform source: Attenuation coefficient and distance to contaminant front as a function of time

	Time			
	1 day	30 days	1 year	10 years
α ($R = 1$)	0.004	0.001	0.0009	0.0007
Distance to front (m)	1	5	12	22
α ($R = 20$)	0.02	0.004	0.002	0.001
Distance to front (m)	0.2	1	4	10

Advective transport from a landfill at 100 m: Attenuation coefficient and time to steady-state as a function of soil permeability

	Permeability (m^2)			
	10^{-10}	10^{-11}	10^{-12}	10^{-13}
α	0.4	0.04	0.004	0.0004
τ_{ssp}^{b}	1 h	10 h	5 days	50 days
τ_{ssc} ($R = 1$)	90 h	40 days	1 year	10 years
τ_{ssc} ($R = 20$)	70 days	2 years	20 years	200 years

[a] Steady-state concentration.
[b] Steady-state pressure.

TABLE 3

Potential ratio of indoor air VOC concentration at contaminated site relative to baseline levels (α = 0.00003–0.003)

Source	C_{source} (mg m^{-3})	C_{indoor}^{a} (mg m^{-3})	$C_{baseline}$ (mg m^{-3})	$\frac{C_{indoor}}{C_{baseline}}$
Pure solvent (TCE)	420,000	13–1300	0.0007	20,000–2,000,000
Landfill^{b} (PCE)	1300	0.5–50	0.005	100–10,000
Gasoline (benzene)	7000	0.2–20	0.01	20–2000
Groundwater (TCE)	170	0.005–0.5	0.0007	7–700

[a] Calculated as αC_{source}.
[b] α = 0.0004–0.04 for a landfill at 100 m.

role of weather may be most rapidly elucidated via this research approach. Field studies can also provide a basis for testing the usefulness of screening models (*37*), which in turn can suggest suitable methods to control the subsurface infiltration of VOCs into buildings. Existing techniques for the mitigation and control of radon entry (*38*) are a useful starting point for research into the prevention of VOC entry.

Laboratory studies will be of most benefit in investigating specific aspects of the soil gas transport pathway. For example, the transport of VOCs through unsaturated soil media needs to be more clearly understood. In particular, further research is required on multicomponent sorption and transport and on the influence of soil moisture on soil sorption coefficients in the unsaturated zone at low moisture levels. An additional research requirement is to investigate the microbiological decay or generation of VOCs as they pass through the unsaturated zone. Depending on the rate of transport, these biotic mechanisms could have a large impact on the concentration of VOCs arriving at a building's zone of influence.

Conclusions

This work has shown that subsurface transport of volatile contaminants into buildings near contaminated sites and landfills may result in levels of indoor air contamination that are many orders of magnitude higher than typical baseline levels. The associated risks are, in turn, orders of magnitude above acceptable levels. The transport models used are necessarily based on highly idealized representations of reality and are intended to give only first-order estimates of indoor contamination levels. Indeed, these models should only be used with a clear understanding of the simplifying assumptions on which they are based. Nevertheless, the predicted risks are sufficiently high to justify further urgent attention to this exposure pathway.

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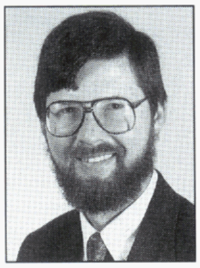
***John C. Little** is a postdoctoral fellow in the Energy and Environment Division at Lawrence Berkeley Laboratory. His M.Sc. from the University of Cape Town, South Africa, is in physical chemistry, and his Ph.D. in environmental engineering is from the University of California–Berkeley.*



***Joan M. Daisey** is a senior scientist and the program leader for the Indoor Environment Program in the Energy and Environment Division at Lawrence Berkeley Laboratory. She is also the director of the Center for Atmospheric and Biospheric Effects of Technology at LBL.*

***William W. Nazaroff** is associate professor of environmental engineering at the University of California–Berkeley and faculty associate in the Indoor Environment Program, Lawrence Berkeley Laboratory.*

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Glossary

A	effective contaminant flux area (m^2)
A_{Ra}	radium activity concentration of soil (B_q kg^{-1})
C	gas-phase concentration of contaminant (mg m^{-3})
$C_{baseline}$	baseline concentration of contaminant in indoor air (mg m^{-3})
C_{indoor}	concentration of contaminant in indoor air (mg m^{-3})
C_{source}	gas-phase contaminant source concentration (mg m^{-3})
C_w	aqueous-phase concentration of contaminant (mg m^{-3})
D_{air}	diffusion coefficient for contaminant in air (m^2 s^{-1})
D_e	effective diffusion coefficient for contaminant in soil gas (m^2 s^{-1})
f	emanation coefficient of radon from soil (dimensionless)
H	Henry's law constant (dimensionless, concentration basis)
k	permeability of soil to soil gas (m^2)
K_d	air-to-unsaturated-soil partition coefficient (m^3 kg^{-1})
K_d^{sat}	water-to-soil partition coefficient (m^3 kg^{-1})
L	distance from contaminant source to building (m)
P	dynamic gas pressure (kPa)
P_{atm}	ambient air pressure (kPa)
P_b	dynamic soil gas pressure at building (kPa)
P_s	dynamic gas pressure in landfill (kPa)
P_{vap}	vapor pressure (kPa)
q	mass fraction of contaminant sorbed to soil (kg kg^{-1})
Q_b	volumetric air flow rate through building (m^3 s^{-1})
r	radial distance (m)
r_b	effective radius of zone of influence (m)
R	retardation factor
t	time (s)
T	temperature (K)
v	Darcy velocity (m s^{-1})
x	linear distance (m)
α	attenuation coefficient (dimensionless)
ϵ	total soil porosity (dimensionless)
ϵ_a	gas-filled soil porosity (dimensionless)
μ	dynamic viscosity of soil gas (kg m^{-1} s^{-1})
θ_m	soil moisture content (m^3 kg^{-1})
ρ_b	bulk density of soil (kg m^{-3})
ρ_s	density of soil grains (kg m^{-3})
τ_{ssc}	characteristic time to establish steady-state concentration profile(s)
τ_{ssp}	characteristic time to establish steady-state pressure profile(s)

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Appendix 2-B. LDN Calculations

Table 1: Little, Daisey, Nazaroff Model Input Parameters and Calculations (Residential)

Table 2: Indoor Air Calculations (Residential)

Table 3: Little, Daisey, Nazaroff Model Input Parameters and Calculations (Construction Worker)

Table 4: Industrial Air Calculations (Construction Worker)

APPENDIX 2-B, TABLE 1
LITTLE, DAISEY, NAZAROFF MODEL INPUT PARAMETERS AND CALCULATIONS (RESIDENTIAL)

Little, Daisey, Nazaroff Model			CAS:	71-43-2	75-15-0	110-82-7	100-41-4	110-54-3	591-78-6	98-82-8	91-20-3	108-10-1	103-65-1	115-07-1	100-42-5
			Chemical:	Benzene	Carbon Disulfide	Cyclohexane	Ethylbenzene	Hexane	2-Hexanone	Isopropylbenzene (Cumene)	Naphthalene	4-Methyl-2-pentanone	n-Propylbenzene	Propylene	Styrene
	Symbol	Definition	Units												
TACO Values	RO_IA	Indoor Air RO	mg/m3	3.12E-04	7.30E-01	6.26E+00	9.73E-04	7.30E-01	3.13E-02	4.17E-01	7.16E-05	3.13E+00	1.04E+00	3.13E+00	1.04E+00
Chemical Properties	MW	Molecular Weight	g/mol	7.81E+01	7.61E+01	8.42E+01	1.06E+02	8.62E+01	1.00E+02	1.20E+02	1.28E+02	1.00E+02	1.20E+02	4.21E+01	1.04E+02
	Da	Diffusivity in Air	cm2/sec	8.80E-02	1.04E-01	8.00E-02	7.50E-02	7.31E-02	7.04E-02	6.03E-02	5.90E-02	6.98E-02	6.02E-02	1.10E-01	7.10E-02
	Dw	Diffusivity in Water	cm2/sec	1.02E-05	1.00E-05	9.11E-06	7.80E-06	8.17E-06	8.44E-06	7.86E-06	7.50E-06	8.35E-06	7.83E-06	1.07E-05	8.00E-06
	H'	Henry's Law Constant	unitless	0.134	0.806	6.132	0.164	73.590	0.004	0.470	0.008	0.006	0.429	8.013	0.005
	H	"	atm-m3/mol	5.55E-03	1.44E-02	1.50E-01	7.88E-03	1.80E+00	9.32E-05	1.15E-02	1.97E-02	1.38E-04	1.05E-02	1.96E-01	2.75E-03
	S	Water Solubility	mg/L	1,800	1,200	55	170	10	17,200	61	31	19,000	52	200	310
	Koc	Organic carbon partition	cm3/g	50	63	145.8	320	131.5	14.98	697.8	500	12.6	813.1	21.73	316
	P	Vapor Pressure	mm Hg	95	360	96.86	9.6	151.3	11.6	4.5	8.50E-02	19.86	3.42	8,690	6.1
Soil Properties	T	Temperature	°C	13	13	13	13	13	13	13	13	13	13	13	13
	"	"	°K	286	286	286	286	286	286	286	286	286	286	286	286
	Et	Total porosity	unitless	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	Ew	Water-filled porosity	unitless	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	Ea	Air-filled porosity	unitless	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Building Dimensions	L	Length	m	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	W	Width	m	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	H	Ceiling height	m	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
	A	Slab Footprint	m2	100	100	100	100	100	100	100	100	100	100	100	100
	Vbldg	Internal volume	m3	244	244	244	244	244	244	244	244	244	244	244	244
Building Ventilation	AER	Air changes per hour	hr^{-1}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Qbldg	Air flow rate	m3/hr	129	129	129	129	129	129	129	129	129	129	129	129
Millington-Quirk Relationship	D_e	effective diffusivity	cm^2/sec	0.0069	0.0081	0.0062	0.0059	0.0057	0.0055	0.0047	0.0046	0.0055	0.0047	0.0086	0.0056
	D_e	effective diffusivity	m^2/hr	0.0025	0.0029	0.0022	0.0021	0.0021	0.0020	0.0017	0.0017	0.0020	0.0017	0.0031	0.0020
	Da	diffusivity in air	cm^2/sec	0.088	0.104	0.080	0.075	0.073	0.070	0.060	0.059	0.070	0.060	0.110	0.071
	q_a	air-filled porosity of soil	vol/vol	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	q_t	total porosity of soil	vol/vol	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43

Calculated Tier 3 Soil Gas Attenuation Factors	Transport Distance			Benzene	Carbon Disulfide	Cyclohexane	Ethylbenzene	Hexane	2-Hexanone	Isopropylbenzene (Cumene)	Naphthalene	4-Methyl-2-pentanone	n-Propylbenzene	Propylene	Styrene
	(ft)	(m)		--	--	--	--	--	--	--	--	--	--	--	--
	3	0.91		2.09E-03	2.47E-03	1.90E-03	1.78E-03	1.74E-03	1.68E-03	1.43E-03	1.40E-03	1.66E-03	1.43E-03	2.60E-03	1.69E-03

Calculated Tier 3 LDN Screening Values	Transport Distance			Benzene	Carbon Disulfide	Cyclohexane	Ethylbenzene	Hexane	2-Hexanone	Isopropylbenzene (Cumene)	Naphthalene	4-Methyl-2-pentanone	n-Propylbenzene	Propylene	Styrene
	(ft)	(m)		mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3
	3	0.91		0.15	300	3300	0.55	420	19	290	0.05	1900	730	1200	620
C_v^{sat} Values				420,000	1,500,000	440,000	59,000	700,000	63,000	30,000	620	110,000	22,000	20,000,000	34,000

APPENDIX 2-B, TABLE 1
LITTLE, DAISEY, NAZAROFF MODEL INPUT PARAMETERS AND CALCULATIONS (RESIDENTIAL)

Little, Daisey, Nazaroff Model	Symbol	Definition	Units								Comments
			CAS:	109-99-9	108-88-3	95-63-6	108-67-8	108-38-3	106-42-3	95-47-6	
			Chemical:	Tetrahydrofuran	Toluene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	m-Xylenes	p-Xylenes	o-Xylenes	
TACO Values	RO_IA	Indoor Air RO	mg/m3	2.09E+00	5.21E+00	7.30E-03	1.04E-02	1.04E-01	1.04E-01	1.04E-01	
Chemical Properties	MW	Molecular Weight	g/mol	7.21E+01	9.21E+01	1.20E+02	1.20E+02	1.06E+02	1.06E+02	1.06E+02	USEPA RSL Chemical Specific Parameters in Blue,
	Da	Diffusivity in Air	cm2/sec	9.94E-02	7.78E-02	6.07E-02	6.02E-02	7.00E-02	7.69E-02	6.89E-02	all others provided in TACO, Appendix C, Table E
	Dw	Diffusivity in Water	cm2/sec	1.08E-05	9.20E-06	7.92E-06	7.84E-06	7.80E-06	8.44E-06	8.53E-06	
	H'	Henry's Law Constant	unitless	0.003	0.271	0.252	0.359	0.152	0.159	0.107	at 13 deg C / at 25 deg C
	H	"	atm-m3/mol	7.05E-05	6.64E-03	6.16E-03	8.77E-03	7.18E-03	6.90E-03	5.18E-03	at 25 deg C
	S	Water Solubility	mg/L	1,000,000	526	57	48	160	160	180	
	Koc	Organic carbon partition	cm3/g	10.75	233.9	614.3	602.1	398	316	316	
	P	Vapor Pressure	mm Hg	162.2	28.4	2.1	2.48	8.5	8.9	8.9	
Soil Properties	T	Temperature	°C	13	13	13	13	13	13	13	
	"	"	°K	286	286	286	286	286	286	286	TACO default value
	Et	Total porosity	unitless	0.43	0.43	0.43	0.43	0.43	0.43	0.43	TACO default value
	Ew	Water-filled porosity	unitless	0.15	0.15	0.15	0.15	0.15	0.15	0.15	TACO default value
	Ea	Air-filled porosity	unitless	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
Building Dimensions	L	Length	m	10.0	10.0	10.0	10.0	10.0	10.0	10.0	= 100 cm
	W	Width	m	10.0	10.0	10.0	10.0	10.0	10.0	10.0	= 100 cm
	H	Ceiling height	m	2.44	2.44	2.44	2.44	2.44	2.44	2.44	= 244 cm
	A	Slab Footprint	m2	100	100	100	100	100	100	100	= L x W
	Vbldg	Internal volume	m3	244	244	244	244	244	244	244	= L x W x H
Building Ventilation	AER	Air changes per hour	hr^{-1}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	TACO default value
	Qbldg	Air flow rate	m3/hr	129	129	129	129	129	129	129	=4564 ft3/hr
Millington-Quirk Relationship	D_e	effective diffusivity	cm^2/sec	0.0078	0.0061	0.0047	0.0047	0.0055	0.0060	0.0054	Eq. 2 $D_e = D_i [(q_a)^{3.33} / (q_t)^2]$
	D_e	effective diffusivity	m^2/hr	0.0028	0.0022	0.0017	0.0017	0.0020	0.0022	0.0019	
	Da	diffusivity in air	cm^2/sec	0.099	0.078	0.061	0.060	0.070	0.077	0.069	
	q_a	air-filled porosity of soil	vol/vol	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
	q_t	total porosity of soil	vol/vol	0.43	0.43	0.43	0.43	0.43	0.43	0.43	

Calculated Tier 3 Soil Gas Attenuation Factors	Transport Distance		Tetrahydro-furan	Toluene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	m-Xylenes	p-Xylenes	o-Xylenes
	(ft)	(m)	--	--	--	--	--	--	--
	3	0.91	2.37E-03	1.85E-03	1.44E-03	1.43E-03	1.66E-03	1.83E-03	1.64E-03

Calculated Tier 3 LDN Screening Values	Transport Distance		Tetrahydro-furan	Toluene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	m-Xylenes	p-Xylenes	o-Xylenes	
	(ft)	(m)	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	
	3	0.91	880	2800	5.1	7.3	63	57	64	Tier 3 Screening Criteria
C_v^{sat} Values			630,000	140,000	14,000	16,000	52,000	55,000	41,000	TACO Default Value or Calculated using J&E Equation 5

APPENDIX 2-B, TABLE 2
INDOOR AIR CALCULATIONS (RESIDENTIAL)

Indoor Air Calculations
TACO J&E Equations

Village of Roxana Study Site
Roxana, IL

Equations: J&E1

$$RO_{indoor\ air} = \frac{TR \times AT_c \times 365 \frac{days}{yr}}{ED \times EF \times URF \times 1000 \frac{\mu g}{mg}}$$

J&E2

$$RO_{indoor\ air} = \frac{THQ \times AT_{nc} \times 365 \frac{days}{yr} \times RfC}{ED \times EF}$$

Where:
AT = Averaging time for non-carcinogenic effects (year)
AT_c = Averaging time for carcinogenic effects (year)
CF1 = Conversion factor (365 days/year)
CF2 = Conversion factor (1000 ug/mg)
ED = Exposure duration (years)
EF = Exposure frequency (days/year)
RfC = Reference concentraiton (ug/m^3)
URF = Unit risk factor (ug/m^3)$^{-1}$
THQ = Target Hazard Quotient (unitless)
TR = Target Risk (unitless)

												TACO Tier 1 Resident Indoor Air Remediation Objective	
Chemical	Carcinogenic or Non-Carcinogenic	TR unitless	THQ unitless	AT_c year	AT year	CF1 days/year	CF2 ug/mg	ED year	EF days/year	URF (ug/m^3)$^{-1}$	RfC ug/m^3	Carcinogenic mg/m^3	Non-Carcinogenic mg/m^3
Benzene	Carcinogenic	1.00E-06	1	70	30	365	1000	30	350	7.80E-06	3.00E-02	3.12E-04	3.13E-02
Carbon Disulfide	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		7.00E-01		7.30E-01
Cyclohexane	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		6.00E+00		6.26E+00
Ethylbenzene	Carcinogenic	1.00E-06	1	70	30	365	1000	30	350	2.50E-06	1.00E+00	9.73E-04	1.04E+00
Hexane	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		7.00E-01		7.30E-01
Hexanone, 2- (Methyl n-butyl ketone)	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		3.00E-02		3.13E-02
Isopropylbenzene (Cumene)	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		4.00E-01		4.17E-01
Naphthalene	Carcinogenic	1.00E-06	1	70	30	365	1000	30	350	3.40E-05	3.00E-03	7.16E-05	3.13E-03
Pentanone, 4-Methyl-2- (Methyl Isobutyl Ke	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		3.00E+00		3.13E+00
Propylbenzene, n-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E+00		1.04E+00
Propylene	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		3.00E+00		3.13E+00
Styrene	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E+00		1.04E+00
Tetrahydrofuran	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		2.00E+00		2.09E+00
Toluene	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		5.00E+00		5.21E+00
Trimethylbenzene, 1,2,4-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		7.00E-03		7.30E-03
Trimethylbenzene, 1,3,5-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E-02		1.04E-02
Xylenes, m-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E-01		1.04E-01
Xylenes, o-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E-01		1.04E-01
Xylenes, p-	Non-carcinogenic	1.00E-06	1	70	30	365	1000	30	350		1.00E-01		1.04E-01

Toxicity data used from USEPA RSL website, last updated May 2016.

APPENDIX 2-B, TABLE 3
LITTLE, DAISEY, NAZAROFF MODEL INPUT PARAMETERS AND CALCULATIONS (CONSTRUCTION WORKER)

Little, Daisey, Nazaroff Model			CAS:	71-43-2	75-15-0	110-82-7	100-41-4	110-54-3	591-78-6	98-82-8	91-20-3	108-10-1	103-65-1	115-07-1	100-42-5
			Chemical	Benzene	Carbon Disulfide	Cyclohexane	Ethylbenzene	Hexane	2-Hexanone	Isopropylbenzene (Cumene)	Naphthalene	4-Methyl-2-pentanone	n-Propylbenzene	Propylene	Styrene
	Symbol	Definition	Units												
USEPA Values	RO_CW	Industrial Air RO	mg/m3	3.28E-01	2.56E+01	6.57E+02	1.02E+00	7.30E+01	1.10E+00	3.29E+00	7.51E+01	2.92E+01	3.65E+01	1.10E+02	1.10E+02
Chemical Properties	MW	Molecular Weight	g/mol	7.81E+01	7.61E+01	8.42E+01	1.06E+02	8.62E+01	1.00E+02	1.20E+02	1.28E+02	1.00E+02	1.20E+02	4.21E+01	1.04E+02
	Da	Diffusivity in Air	cm2/sec	8.80E-02	1.04E-01	8.00E-02	7.50E-02	7.31E-02	7.04E-02	6.03E-02	5.90E-02	6.98E-02	6.02E-02	1.10E-01	7.10E-02
	Dw	Diffusivity in Water	cm2/sec	1.02E-05	1.00E-05	9.11E-06	7.80E-06	8.17E-06	8.44E-06	7.86E-06	7.50E-06	8.35E-06	7.83E-06	1.07E-05	8.00E-06
	H'	Henry's Law Constant	unitless	0.134	0.806	6.132	0.164	73.590	0.004	0.470	0.008	0.006	0.429	8.013	0.005
	H	"	atm-m3/mol	5.55E-03	1.44E-02	1.50E-01	7.88E-03	1.80E+00	9.32E-05	1.15E-02	1.97E-02	1.38E-04	1.05E-02	1.96E-01	2.75E-03
	S	Water Solubility	mg/L	1,800	1,200	55	170	10	17,200	61	31	19,000	52	200	310
	Koc	Organic carbon partition	cm3/g	50	63	145.8	320	131.5	14.98	697.8	500	12.6	813.1	21.73	316
	P	Vapor Pressure	mm Hg	95	360	96.86	9.6	151.3	11.6	4.5	8.50E-02	19.86	3.42	8,690	6.1
Soil Properties	T	Temperature	°C	13	13	13	13	13	13	13	13	13	13	13	13
	"	"	°K	286	286	286	286	286	286	286	286	286	286	286	286
	Et	Total porosity	unitless	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	Ew	Water-filled porosity	unitless	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	Ea	Air-filled porosity	unitless	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Trench Dimensions	L	Length	m	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	W	Width	m	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	H	Ceiling height	m	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
	A	Slab Footprint	m2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	Vbldg	Internal volume	m3	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Building Ventilation	AER	Air changes per hour	hr^{-1}	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Qbldg	Air flow rate	m3/hr	20	20	20	20	20	20	20	20	20	20	20	20
Millington-Quirk Relationship	D_e	effective diffusivity	cm^2/sec	0.0069	0.0081	0.0062	0.0059	0.0057	0.0055	0.0047	0.0046	0.0055	0.0047	0.0086	0.0056
	D_e	effective diffusivity	m^2/hr	0.0025	0.0029	0.0022	0.0021	0.0021	0.0020	0.0017	0.0017	0.0020	0.0017	0.0031	0.0020
	Da	diffusivity in air	cm^2/sec	0.088	0.104	0.080	0.075	0.073	0.070	0.060	0.059	0.070	0.060	0.110	0.071
	q_a	air-filled porosity of soil	vol/vol	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	q_t	total porosity of soil	vol/vol	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43

Calculated Tier 3 Soil Gas Attenuation Factors	(ft)	Transport Distance (m)	Benzene --	Carbon Disulfide --	Cyclohexane --	Ethylbenzene --	Hexane --	2-Hexanone --	Isopropylbenzene (Cumene) --	Naphthalene --	4-Methyl-2-pentanone --	n-Propylbenzene --	Propylene --	Styrene --
	5	1.52	1.77E-04	2.10E-04	1.61E-04	1.51E-04	1.47E-04	1.42E-04	1.22E-04	1.19E-04	1.41E-04	1.21E-04	2.21E-04	1.43E-04

Calculated Tier 3 LDN Screening Values	(ft)	Transport Distance (m)	Benzene mg/m3	Carbon Disulfide mg/m3	Cyclohexane mg/m3	Ethylbenzene mg/m3	Hexane mg/m3	2-Hexanone mg/m3	Isopropylbenzene (Cumene) mg/m3	Naphthalene mg/m3	4-Methyl-2-pentanone mg/m3	n-Propylbenzene mg/m3	Propylene mg/m3	Styrene mg/m3
	5	1.52	1,800	120,000	4,100,000	6,700	500,000	7,700	27,000	630,000	210,000	300,000	500,000	770,000
C_v^{sat} Values			420,000	1,500,000	440,000	59,000	700,000	63,000	30,000	620	110,000	22,000	20,000,000	34,000

APPENDIX 2-B, TABLE 3
LITTLE, DAISEY, NAZAROFF MODEL INPUT PARAMETERS AND CALCULATIONS (CONSTRUCTION WORKER)

Little, Daisey, Nazaroff Model			CAS:	109-99-9	108-88-3	95-63-6	108-67-8	108-38-3	106-42-3	95-47-6	
			Chemical	Tetrahydro-furan	Toluene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	m-Xylenes	p-Xylenes	o-Xylenes	
	Symbol	Definition	Units								Comments
USEPA Values	RO_CW	Industrial Air RO	mg/m3	7.30E+01	1.83E+02	2.56E+00	3.65E-01	3.65E+00	3.65E+00	3.65E+00	
Chemical Properties	MW	Molecular Weight	g/mol	7.21E+01	9.21E+01	1.20E+02	1.20E+02	1.06E+02	1.06E+02	1.06E+02	USEPA RSL Chemical Specific Parameters in Blue,
	Da	Diffusivity in Air	cm2/sec	9.94E-02	7.78E-02	6.07E-02	6.02E-02	7.00E-02	7.69E-02	6.89E-02	all others provided in TACO, Appendix C, Table E
	Dw	Diffusivity in Water	cm2/sec	1.08E-05	9.20E-06	7.92E-06	7.84E-06	7.80E-06	8.44E-06	8.53E-06	
	H'	Henry's Law Constant	unitless	0.003	0.271	0.252	0.359	0.152	0.159	0.107	at 13 deg C / at 25 deg C
	H	"	atm-m3/mol	7.05E-05	6.64E-03	6.16E-03	8.77E-03	7.18E-03	6.90E-03	5.18E-03	at 25 deg C
	S	Water Solubility	mg/L	1,000,000	526	57	48	160	160	180	
	Koc	Organic carbon partition	cm3/g	10.75	233.9	614.3	602.1	398	316	316	
	P	Vapor Pressure	mm Hg	162.2	28.4	2.1	2.48	8.5	8.9	8.9	
Soil Properties	T	Temperature	°C	13	13	13	13	13	13	13	
	"	"	°K	286	286	286	286	286	286	286	TACO default value
	Et	Total porosity	unitless	0.43	0.43	0.43	0.43	0.43	0.43	0.43	TACO default value
	Ew	Water-filled porosity	unitless	0.15	0.15	0.15	0.15	0.15	0.15	0.15	TACO default value
	Ea	Air-filled porosity	unitless	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
Trench Dimensions	L	Length	m	2.4	2.4	2.4	2.4	2.4	2.4	2.4	= 8 ft
	W	Width	m	0.9	0.9	0.9	0.9	0.9	0.9	0.9	= 3 ft
	H	Ceiling height	m	4.6	4.6	4.6	4.6	4.6	4.6	4.6	= 15 ft
	A	Slab Footprint	m2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	= L x W
	Vbldg	Internal volume	m3	10.2	10.2	10.2	10.2	10.2	10.2	10.2	= L x W x H
Building Ventilation	AER	Air changes per hour	hr^{-1}	2.00	2.00	2.00	2.00	2.00	2.00	2.00	TACO default value
	Qbldg	Air flow rate	m3/hr	20	20	20	20	20	20	20	=4564 ft3/hr
Millington-Quirk Relationship	D_e	effective diffusivity	cm^2/sec	0.0078	0.0061	0.0047	0.0047	0.0055	0.0060	0.0054	Eq. 2 $D_e = D_i [(q_a)^{3\ 33} / (q_t)^2$
	D_e	effective diffusivity	m^2/hr	0.0028	0.0022	0.0017	0.0017	0.0020	0.0022	0.0019	
	Da	diffusivity in air	cm^2/sec	0.099	0.078	0.061	0.060	0.070	0.077	0.069	
	q_a	air-filled porosity of soil	vol/vol	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
	q_t	total porosity of soil	vol/vol	0.43	0.43	0.43	0.43	0.43	0.43	0.43	

Calculated Tier 3 Soil Gas Attenuation Factors	Transport Distance (ft)	(m)	Tetrahydro-furan	Toluene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	m-Xylenes	p-Xylenes	o-Xylenes	
			--	--	--	--	--	--	--	
	5	1.52	2.01E-04	1.57E-04	1.22E-04	1.21E-04	1.41E-04	1.55E-04	1.39E-04	

Calculated Tier 3 LDN Screening Values	Transport Distance (ft)	(m)	Tetrahydro-furan	Toluene	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	m-Xylenes	p-Xylenes	o-Xylenes	
			mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	mg/m3	
	5	1.52	360,000	1,200,000	21,000	3,000	26,000	24,000	26,000	Tier 3 Screening Criteria
C_v^{sat} Values			630,000	140,000	14,000	16,000	52,000	55,000	41,000	TACO Default Value or Calculated using J&E Equation 5

APPENDIX 2-B, TABLE 4
INDUSTRIAL AIR CALCULATIONS (CONSTRUCTION WORKER)

Site-specific
Outdoor Worker Equation Inputs for Air

Variable	Value
TR (target cancer risk) unitless	0.000001
THQ (target hazard quotient) unitless	1
ATow (averaging time - outdoor worker)	365
EFow (exposure frequency - outdoor worker) day/yr	30
EDow (exposure duration - outdoor worker) yr	1
ETow (exposure time - outdoor worker) hr	8
LT (lifetime) yr	70

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Site-specific
Outdoor Worker Screening Levels (RSL) for Air

ca=Cancer, nc=Noncancer, ca* (Where nc SL < 100 x ca SL),
ca** (Where nc SL < 10 x ca SL), max=SL exceeds ceiling limit (see User's Guide), sat=SL exceeds csat,
Smax=Soil SL exceeds ceiling limit and has been substituted with the max value (see User's Guide),
Ssat=Soil inhalation SL exceeds csat and has been substituted with the csat

Chemical	**CAS Number**	**Mutagen?**	**VOC?**	**Inhalation** Unit Risk **$(ug/m^3)^{-1}$**	**IUR Ref**	**Subchronic** RfC **(mg/m^3)**	**Subchronic RfC Ref**	Carcinogenic SL TR=1.0E-6 (ug/m^3)	Noncarcinogenic SL THI=1 (ug/m^3)	Screening Level (ug/m^3)
Benzene	71-43-2	No	Yes	7.80E-06	I	8.00E-02	P	3.28E+02	2.92E+03	3.28E+02 ca**
Carbon Disulfide	75-15-0	No	Yes	-		7.00E-01	H	-	2.56E+04	2.56E+04 nc
Cumene	98-82-8	No	Yes	-		9.00E-02	H	-	3.29E+03	3.29E+03 nc
Cyclohexane	110-82-7	No	Yes	-		1.80E+01	P	-	6.57E+05	6.57E+05 nc
Ethylbenzene	100-41-4	No	Yes	2.50E-06	C	9.00E+00	P	1.02E+03	3.29E+05	1.02E+03 ca
Tetrahydrofuran	109-99-9	No	Yes	-		2.00E+00	I	-	7.30E+04	7.30E+04 nc
Hexane, N-	110-54-3	No	Yes	-		2.00E+00	P	-	7.30E+04	7.30E+04 nc
Hexanone, 2-	591-78-6	No	Yes	-		3.00E-02	I	-	1.10E+03	1.10E+03 nc
Methyl Isobutyl Ketone (4-methyl-2-pentanone)	108-10-1	No	Yes	-		8.00E-01	H	-	2.92E+04	2.92E+04 nc
Naphthalene	91-20-3	No	Yes	3.40E-05	C	3.00E-03	CI	7.51E+01	1.10E+02	7.51E+01 ca**
Propyl benzene	103-65-1	No	Yes	-		1.00E+00	S	-	3.65E+04	3.65E+04 nc
Propylene	115-07-1	No	Yes	-		3.00E+00	C	-	1.10E+05	1.10E+05 nc
Styrene	100-42-5	No	Yes	-		3.00E+00	H	-	1.10E+05	1.10E+05 nc
Toluene	108-88-3	No	Yes	-		5.00E+00	P	-	1.83E+05	1.83E+05 nc
Trimethylbenzene, 1,2,4-	95-63-6	No	Yes	-		7.00E-02	P	-	2.56E+03	2.56E+03 nc
Trimethylbenzene, 1,3,5-	108-67-8	No	Yes	-		1.00E-02	P	-	3.65E+02	3.65E+02 nc
Xylene, P-	106-42-3	No	Yes	-		1.00E-01	S	-	3.65E+03	3.65E+03 nc
Xylene, m-	108-38-3	No	Yes	-		1.00E-01	S	-	3.65E+03	3.65E+03 nc
Xylene, o-	95-47-6	No	Yes	-		1.00E-01	S	-	3.65E+03	3.65E+03 nc

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Appendix 2-C. Soil Gas Analytical Detection Statistics

SEE LAST PAGE OF TABLE NOTES

APPENDIX 2-C, TABLE 1
SOIL GAS ANALYTICAL DETECTION STATISTICS AND CONSTITUENTS OF POTENTIAL CONCERN DETERMINATION (RESIDENTIAL)

CAS	Chemical	Total Samples Collected[a]	Number of Detections	Detection Frequency[b] (%)	Minimum Detected Concentration (mg/m^3)	Maximum Detected Concentration (MDC) (mg/m^3)	Average Concentration (ND = 1/2PQL[c]) (mg/m^3)	Location of MDC	Range PQL[c] (mg/m^3)	LDN Screening Value (3 ft transport) (mg/m^3)	COPC Determination[d]
71-43-2	Benzene	3436	2277	66%	0 00026 J	90000	284 3129	VMP-13	0 0022 - 300	0.15	COPC - MDC > LDN Screening Value
110-82-7	Cyclohexane	3436	1376	40%	0 00022 J	3400 J	46.6695	VMP-4	0 0023 - 320	3300	COPC - MDC > LDN Screening Value
100-41-4	Ethylbenzene	3436	927	27%	0 00022 J	1200	6.4557	VMP-4	0.003 - 410	0.55	COPC - MDC > LDN Screening Value
110-54-3	Hexane	3436	2073	60%	0.0003 J	27000	180 9807	VMP-3	0 0024 - 330	420	COPC - MDC > LDN Screening Value
108-88-3	Toluene	3436	1922	56%	0 00016 J	5500	18.5445	VMP-56	0 0026 - 350	2800	COPC - MDC > LDN Screening Value
95-63-6	Trimethylbenzene 1 2 4-	3436	747	22%	0 00021 J	1200	3 5269	VMP-50	0 0033 - 620	5.1	COPC - MDC > LDN Screening Value
108-67-8	Trimethylbenzene 1 3 5-	3436	382	11%	0 00036 J	330	2 2457	VMP-50	0 0033 - 460	7.3	COPC - MDC > LDN Screening Value
108-38-3/106-42-3	Xylenes m p-[e]	3436	1457	42%	0 00015 J	3300	11 606	VMP-4	0.003 - 410	57	COPC - MDC > LDN Screening Value
95-47-6	Xylenes, o-	3436	764	22%	0 00033 J	1100	4.4502	VMP-4	0.003 - 410	64	COPC - MDC > LDN Screening Value
75-15-0	Carbon disulfide	3436	888	26%	0 00032 J	130 J	1 3838	VMP-2	0 003 - 1000	300	Not a COPC - MDC < LDN Screening Value
591-78-6	Hexanone, 2- (Methyl N-Butyl Ketone)	3436	356	10%	0 00028 J	0 32	6 0271	VMP-47	0 011 - 1700	19	Not a COPC - MDC < LDN Screening Value
98-82-8	Isopropylbenzene (Cumene)	3436	742	22%	0 00016 J	75	1 9871	VMP-16	0 0033 - 460	290	Not a COPC - MDC < LDN Screening Value
108-10-1	Pentanone, 4-Methyl-2- (Methyl Isobutyl Ketone)	3436	689	20%	0 00026 J	35 J	2 2056	VMP-2	0.0028 - 1700	1900	Not a COPC - MDC < LDN Screening Value
103-65-1	Propylbenzene, n-	3436	560	16%	0 00024 J	190	2.4589	VMP-50	0 0033 - 460	730	Not a COPC - MDC < LDN Screening Value
115-07-1	Propylene	56	13	23%	0 002 J	0.0083	0.4157	VMP-42	0.0063 - 39	1200	Not a COPC - MDC < LDN Screening Value
100-42-5	Styrene	3436	222	6%	0 00031 J	22 J	2 2113	VMP-2	0.0029 - 1800	620	Not a COPC - MDC < LDN Screening Value
109-99-9	Tetrahydrofuran	3436	426	12%	0 00048 J	330	1 3653	VMP-30	0.002 - 280	880	Not a COPC - MDC < LDN Screening Value
67-64-1	Acetone	3436	2787	81%	0.0022 J	2000 J	6 0452	VMP-1	0.0065 - 1900	NC	Not a COPC - Non-petroleum hydrocarbon
75-27-4	Bromodichloromethane	3436	218	6%	0 00042 J	1.6	2 2608	VMP-14	0 0046 - 630	NC	Not a COPC - Non-petroleum hydrocarbon
78-93-3	Butanone, 2-	3436	1792	52%	0 00087 J	390	3.7991	VMP-30	0 003 - 1100	NC	Not a COPC - Non-petroleum hydrocarbon
67-66-3	Chloroform	3436	1095	32%	0 00024 J	33 J	1 6403	VMP-16	0 0033 - 460	NC	Not a COPC - Non-petroleum hydrocarbon
74-87-3	Chloromethane	3436	201	6%	0 00023 J	62	3.4112	VMP-25	0.0056 - 1700	NC	Not a COPC - Non-petroleum hydrocarbon
75-71-8	Dichlorodifluoromethane	3436	2445	71%	0.0011 J	0 5 J	1 6741	VMP-1	0 0034 - 460	NC	Not a COPC - Non-petroleum hydrocarbon
75-09-2	Dichloromethane (Methylene chloride)	3436	701	20%	0 00031 J	160	1 9519	VMP-14	0.0024 - 2800	NC	Not a COPC - Non-petroleum hydrocarbon
67-63-0	Propanol, 2-	3436	2278	66%	0 00094 J	90 J	3 2666	VMP-2	0 0067 - 920	NC	Not a COPC - Non-petroleum hydrocarbon
127-18-4	Tetrachloroethene	3429	569	17%	0 00035 J	1100	2 52	VMP-3	0 0046 - 640	NC	Not a COPC - Non-petroleum hydrocarbon
79-01-6	Trichloroethene	3436	220	6%	0 00056 J	54	1.7976	VMP-25	0 0036 - 500	NC	Not a COPC - Non-petroleum hydrocarbon
75-69-4	Trichlorofluoromethane	3436	1197	35%	0 00055 J	0.46 J	1 8988	VMP-1	0 0038 - 530	NC	Not a COPC - Non-petroleum hydrocarbon
107-05-1	Allyl chloride (3-Chloropropene)	3436	0	0%	ND	ND	4 2276	NA	0.0085 - 1200	NC	Not a COPC - detection frequency <5%
75-25-2	Bromoform	3436	13	0%	0 00049 J	3 9 J	3 8478	VMP-1	0 007 - 1300	NC	Not a COPC - detection frequency <5%
74-83-9	Bromomethane	3436	59	2%	0 0012 J J	4 2 J	3 0132	VMP-3	0.0026 - 3100	NC	Not a COPC - detection frequency <5%
106-99-0	Butadiene 1 3-	3436	13	0%	0 00084 J	420	0 8568	VMP-1	0 0015 - 210	NC	Not a COPC - detection frequency <5%
56-23-5	Carbon tetrachloride	3436	62	2%	0 00021 J	3.7 J	2.1256	VMP-3	0 0043 - 590	NC	Not a COPC - detection frequency <5%
108-90-7	Chlorobenzene	3436	73	2%	0 00072 J	44 J	1 5703	VMP-25	0 0031 - 430	NC	Not a COPC - detection frequency <5%
124-48-1	Chlorodibromomethane	3436	40	1%	0 00051 J	0.0079 J	2 8732	VMP-43	0 0058 - 800	NC	Not a COPC - detection frequency <5%
75-00-3	Chloroethane	3436	17	0%	0 00096 J	11 J	2 9568	VMP-25	0.002 - 990	NC	Not a COPC - detection frequency <5%
100-44-7	Chlorotoluene, alpha-	3436	37	1%	0.0004 J	22 J	1 9743	VMP-2	0 0035 - 650	NC	Not a COPC - detection frequency <5%
106-93-4	Dibromoethane, 1,2-	3436	31	1%	0.0008 J	0.49 J	2 5933	VMP-20	0 0052 - 720	NC	Not a COPC - detection frequency <5%
95-50-1	Dichlorobenzene, 1,2-	3436	42	1%	0 00036 J	24 J	2 0096	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
541-73-1	Dichlorobenzene, 1,3-	3436	65	2%	0 00029 J	27 J	2 0222	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
106-46-7	Dichlorobenzene, 1,4-	3436	65	2%	0 00075 J	32 J	2 0216	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
75-34-3	Dichloroethane, 1,1-	3436	15	0%	0 00041 J	7.7 J	1 3641	VMP-25	0 0028 - 380	NC	Not a COPC - detection frequency <5%
107-06-2	Dichloroethane, 1,2-	3436	73	2%	0 00016 J	13 J	1 3721	VMP-4	0 0028 - 380	NC	Not a COPC - detection frequency <5%
75-35-4	Dichloroethene, 1,1-	3436	11	0%	0.0008 J	22 J	1 3385	VMP-25	0 0027 - 370	NC	Not a COPC - detection frequency <5%
156-59-2	Dichloroethene, cis-1,2-	3436	34	1%	0 00059 J	11 J	1 3373	VMP-25	0 0027 - 370	NC	Not a COPC - detection frequency <5%
156-60-5	Dichloroethene, trans-1,2-	3436	9	0%	0 00092 J	0.0064	1 3387	VMP-48	0 0027 - 370	NC	Not a COPC - detection frequency <5%
78-87-5	Dichloropropane, 1,2-	3436	42	1%	0.0005 J	48 J	1 5904	VMP-16	0 0031 - 430	NC	Not a COPC - detection frequency <5%
10061-01-5	Dichloropropene, cis-1,3-	3436	6	0%	0.0013 J	0.0045 J	1 5309	VMP-13	0 0031 - 430	NC	Not a COPC - detection frequency <5%
10061-02-6	Dichloropropene, trans-1,3-	3436	29	1%	0 00022 J	0.4 J	1 5308	VMP-20	0 0031 - 430	NC	Not a COPC - detection frequency <5%
123-91-1	Dioxane, 1,4-	3436	96	3%	0 00052 J	0.093	4 8787	VMP-8	0.0098 - 1400	NC	Not a COPC - detection frequency <5%
141-78-6	Ethyl Acetate	56	0	0%	ND	ND	0 8657	NA	0.013 - 81	NC	Not a COPC - detection frequency <5%
76-13-1	Freon 113	3436	54	2%	0 00042 J	3 J J	2 5856	VMP-16	0 0052 - 720	NC	Not a COPC - detection frequency <5%
76-14-2	Freon 114	3436	6	0%	0 00098 J	0.62 J	2.355	VMP-1	0 0048 - 660	NC	Not a COPC - detection frequency <5%
87-68-3	Hexachlorobutadiene	3436	18	1%	0.0015 J	53 J	14.3624	VMP-2	0 029 - 4000	NC	Not a COPC - detection frequency <5%
1634-04-4	Methyl tert-Butyl Ether (MTBE)	3436	133	4%	0 00014 J	7.4 J	1 2108	VMP-25	0 0024 - 340	NC	Not a COPC - detection frequency <5%
79-34-5	Tetrachloroethane 1 1 2 2-	3436	23	1%	0 00041 J	16 J	2.309	VMP-2	0 0047 - 640	NC	Not a COPC - detection frequency <5%
120-82-1	Trichlorobenzene 1 2 4-	3436	50	1%	0 00072 J	92 J	9 9782	VMP-2	0.02 - 2800	NC	Not a COPC - detection frequency <5%
71-55-6	Trichloroethane 1 1 1- (Methyl chloroform)	3436	67	2%	0 00034 J	80	1 8564	VMP-25	0 0037 - 510	NC	Not a COPC - detection frequency <5%
79-00-5	Trichloroethane, 1,1,2-	3436	14	0%	0 00075 J	0.18 J	1 8413	VMP-1	0 0037 - 510	NC	Not a COPC - detection frequency <5%
108-05-4	Vinyl acetate	56	0	0%	ND	ND	0 8564	NA	0.013 - 80	NC	Not a COPC - detection frequency <5%
593-60-2	Vinyl Bromide	56	0	0%	ND	ND	1 0603	NA	0.016 - 99	NC	Not a COPC - detection frequency <5%
75-01-4	Vinyl chloride	3436	6	0%	0 00042 J	0.0028 J	0 8655	VMP-41	0 0017 - 240	NC	Not a COPC - detection frequency <5%
106-97-8	Butane	3185	1401	44%	0.0011 J	98000	616.1266	VMP-3	0.0065 - 1000	N/A	Not a COPC - no toxicity data available
64-17-5	Ethanol	3436	1667	49%	0.0013 J	300	2.7865	VMP-16	0 0051 - 710	N/A	Not a COPC - no toxicity data available
622-96-8	Ethyltoluene, 4-	3436	724	21%	0 00034 J	1000	3 6762	VMP-50	0 0033 - 460	N/A	Not a COPC - no toxicity data available
142-82-5	Heptane	3436	1396	41%	0 00033 J	4700 J	39.2837	VMP-4	0 0028 - 380	N/A	Not a COPC - no toxicity data available

APPENDIX 2-C, TABLE 1
SOIL GAS ANALYTICAL DETECTION STATISTICS AND CONSTITUENTS OF POTENTIAL CONCERN DETERMINATION (RESIDENTIAL)

CAS	Chemical	Total Samples Collected[a]	Number of Detections	Detection Frequency[b] (%)	Minimum Detected Concentration (mg/m^3)	Maximum Detected Concentration (MDC) (mg/m^3)	Average Concentration (ND = 1/2PQL[c]) (mg/m^3)	Location of MDC	Range PQL[c] (mg/m^3)	LDN Screening Value (3 ft transport) (mg/m^3)	COPC Determination[d]
78-78-4	Isopentane	3186	2118	66%	0 00081 J	120000	802.1239	VMP-3	0 008 - 1100	N/A	Not a COPC - no toxicity data available
540-84-1	Trimethylpentane, 2,2,4-	3436	2555	74%	0 00032 J	13000	311 9441	VMP-16	0 0032 - 440	N/A	Not a COPC - no toxicity data available

Notes:

a Samples included in the statistical analysis were collected from 4th Quarter 2009 through 4th Quarter 2016.

b Detection frequency is the number of detected samples out of total number of samples collected.

c Reporting Limits

d Per RAGS Part A (USEPA 1989), any chemical detected at a frequency less than 5% can be eliminated as a COPC.

e m,p-Xylenes screening value based on p-Xylene LDN calculations.

Acronyms:

CAS = Chemical Abstracts Service
COPC = Chemical of potentail concern
IAC = Illinois Administrative Code
J = Estimated value
LDN = Little, Daisey, Nazaroff
MDC = Maximum Detected Concentration
mg/m^3 = milligrams per meter cubed
NA = not applicable; screening values and/or toxicity values are unavailable (i.e., IUR or RfC toxicity data)
NC = not calculated; detection frequency <5%, therefore, LDN screening calculation not performed
ND = non-detect
PQL = Practical Quantification Limit (Reporting Limit)
RAGS, 1989 = USEPA Risk Assessment Guidance for Superfunds, Volume I Part A, December 1989
RO = Remediation Objective
RSL = Regional Screening Level
TACO = Tiered Approach to Corrective Action Objectives (35 IAC 742)
USEPA = United States Environmental Protection Agency

APPENDIX 2-C, TABLE 2
SOIL GAS ANALYTICAL DETECTION STATISTICS AND CONSTITUENTS OF POTENTIAL CONCERN DETERMINATION (CONSTRUCTION WORKER)

CAS	Chemical	Total Samples Collected[a]	Number of Detections	Detection Frequency[b] (%)	Minimum Detected Concentration (mg/m^3)	Maximum Detected Concentration (MDC) (mg/m^3)	Average Concentration (ND = 1/2PQL[c]) (mg/m^3)	Location of MDC	Range PQL[c] (mg/m^3)	LDN Screening Value (5 ft transport) (mg/m^3)	COPC Determination[d]
71-43-2	Benzene	3436	2277	66%	0 00026 J	90000	284 3129	VMP-13	0 0022 - 300	1,800	COPC - MDC > LDN Screening Value
75-15-0	Carbon disulfide	3436	888	26%	0 00032 J	130 J	1 3838	VMP-2	0 003 - 1000	120 000	Not a COPC - MDC < LDN Screening Value
110-82-7	Cyclohexane	3436	1376	40%	0 00022 J	3400 J	46.6695	VMP-4	0 0023 - 320	440 000[f]	Not a COPC - MDC < LDN Screening Value
100-41-4	Ethylbenzene	3436	927	27%	0 00022 J	1200	6.4557	VMP-4	0.003 - 410	6 700	Not a COPC - MDC < LDN Screening Value
110-54-3	Hexane	3436	2073	60%	0.0003 J	27000	180 9807	VMP-3	0 0024 - 330	500 000	Not a COPC - MDC < LDN Screening Value
591-78-6	Hexanone 2- (Methyl N-Butyl Ketone)	3436	356	10%	0 00028 J	0 32	6 0271	VMP-47	0 011 - 1700	7 700	Not a COPC - MDC < LDN Screening Value
98-82-8	Isopropylbenzene (Cumene)	3436	742	22%	0 00016 J	75	1 9871	VMP-16	0 0033 - 460	27 000	Not a COPC - MDC < LDN Screening Value
108-10-1	Pentanone 4-Methyl-2- (Methyl Isobutyl Ketone)	3436	689	20%	0 00026 J	35 J	2 2056	VMP-2	0.0028 - 1700	110 000[f]	Not a COPC - MDC < LDN Screening Value
103-65-1	Propylbenzene, n-	3436	560	16%	0 00024 J	190	2.4589	VMP-50	0 0033 - 460	22,000[f]	Not a COPC - MDC < LDN Screening Value
115-07-1	Propylene	56	13	23%	0 002 J	0.0083	0.4157	VMP-42	0.0063 - 39	500,000	Not a COPC - MDC < LDN Screening Value
100-42-5	Styrene	3436	222	6%	0 00031 J	22 J	2 2113	VMP-2	0.0029 - 1800	34,000[f]	Not a COPC - MDC < LDN Screening Value
109-99-9	Tetrahydrofuran	3436	426	12%	0 00048 J	330	1 3653	VMP-30	0.002 - 280	360,000	Not a COPC - MDC < LDN Screening Value
108-88-3	Toluene	3436	1922	56%	0 00016 J	5500	18.5445	VMP-56	0 0026 - 350	140,000[f]	Not a COPC - MDC < LDN Screening Value
95-63-6	Trimethylbenzene, 1,2,4-	3436	747	22%	0 00021 J	1200	3 5269	VMP-50	0 0033 - 620	14,000[f]	Not a COPC - MDC < LDN Screening Value
108-67-8	Trimethylbenzene, 1,3,5-	3436	382	11%	0 00036 J	330	2 2457	VMP-50	0 0033 - 460	3,000	Not a COPC - MDC < LDN Screening Value
108-38-3/106-42-3	Xylenes m p-[e]	3436	1457	42%	0 00015 J	3300	11 606	VMP-4	0.003 - 410	24,000	Not a COPC - MDC < LDN Screening Value
95-47-6	Xylenes, o-	3436	764	22%	0 00033 J	1100	4.4502	VMP-4	0.003 - 410	26,000	Not a COPC - MDC < LDN Screening Value
67-64-1	Acetone	3436	2787	81%	0.0022 J	2000 J	6 0452	VMP-1	0.0065 - 1900	NC	Not a COPC - Non-petroleum hydrocarbon
75-27-4	Bromodichloromethane	3436	218	6%	0 00042 J	1.6	2 2608	VMP-14	0 0046 - 630	NC	Not a COPC - Non-petroleum hydrocarbon
78-93-3	Butanone, 2-	3436	1792	52%	0 00087 J	390	3.7991	VMP-30	0 003 - 1100	NC	Not a COPC - Non-petroleum hydrocarbon
67-66-3	Chloroform	3436	1095	32%	0 00024 J	33 J	1 6403	VMP-16	0 0033 - 460	NC	Not a COPC - Non-petroleum hydrocarbon
74-87-3	Chloromethane	3436	201	6%	0 00023 J	62	3.4112	VMP-25	0.0056 - 1700	NC	Not a COPC - Non-petroleum hydrocarbon
75-71-8	Dichlorodifluoromethane	3436	2445	71%	0.0011 J	0 5 J	1 6741	VMP-1	0 0034 - 460	NC	Not a COPC - Non-petroleum hydrocarbon
75-09-2	Dichloromethane (Methylene chloride)	3436	701	20%	0 00031 J	160	1 9519	VMP-14	0.0024 - 2800	NC	Not a COPC - Non-petroleum hydrocarbon
67-63-0	Propanol, 2-	3436	2278	66%	0 00094 J	90 J	3 2666	VMP-2	0 0067 - 920	NC	Not a COPC - Non-petroleum hydrocarbon
127-18-4	Tetrachloroethene	3429	569	17%	0 00035 J	1100	2 52	VMP-3	0 0046 - 640	NC	Not a COPC - Non-petroleum hydrocarbon
79-01-6	Trichloroethene	3436	220	6%	0 00056 J	54	1.7976	VMP-25	0 0036 - 500	NC	Not a COPC - Non-petroleum hydrocarbon
75-69-4	Trichlorofluoromethane	3436	1197	35%	0 00055 J	0.46 J	1 8988	VMP-1	0 0038 - 530	NC	Not a COPC - Non-petroleum hydrocarbon
107-05-1	Allyl chloride (3-Chloropropene)	3436	0	0%	ND	ND	4 2276	NA	0.0085 - 1200	NC	Not a COPC - detection frequency <5%
75-25-2	Bromoform	3436	13	0%	0 00049 J	3 9 J	3 8478	VMP-1	0 007 - 1300	NC	Not a COPC - detection frequency <5%
74-83-9	Bromomethane	3436	59	2%	0 0012 J J	4 2 J	3 0132	VMP-3	0.0026 - 3100	NC	Not a COPC - detection frequency <5%
106-99-0	Butadiene 1 3-	3436	13	0%	0 00084 J	420	0 8568	VMP-1	0 0015 - 210	NC	Not a COPC - detection frequency <5%
56-23-5	Carbon tetrachloride	3436	62	2%	0 00021 J	3.7 J	2.1256	VMP-3	0 0043 - 590	NC	Not a COPC - detection frequency <5%
108-90-7	Chlorobenzene	3436	73	2%	0 00072 J	44 J	1 5703	VMP-25	0 0031 - 430	NC	Not a COPC - detection frequency <5%
124-48-1	Chlorodibromomethane	3436	40	1%	0 00051 J	0.0079 J	2 8732	VMP-43	0 0058 - 800	NC	Not a COPC - detection frequency <5%
75-00-3	Chloroethane	3436	17	0%	0 00096 J	11 J	2 9568	VMP-25	0.002 - 990	NC	Not a COPC - detection frequency <5%
100-44-7	Chlorotoluene, alpha-	3436	37	1%	0.0004 J	22 J	1 9743	VMP-2	0 0035 - 650	NC	Not a COPC - detection frequency <5%
106-93-4	Dibromoethane, 1,2-	3436	31	1%	0.0008 J	0.49 J	2 5933	VMP-20	0 0052 - 720	NC	Not a COPC - detection frequency <5%
95-50-1	Dichlorobenzene, 1,2-	3436	42	1%	0 00036 J	24 J	2 0096	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
541-73-1	Dichlorobenzene, 1,3-	3436	65	2%	0 00029 J	27 J	2 0222	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
106-46-7	Dichlorobenzene, 1,4-	3436	65	2%	0 00075 J	32 J	2 0216	VMP-2	0 0041 - 560	NC	Not a COPC - detection frequency <5%
75-34-3	Dichloroethane, 1,1-	3436	15	0%	0 00041 J	7.7 J	1 3641	VMP-25	0 0028 - 380	NC	Not a COPC - detection frequency <5%
107-06-2	Dichloroethane, 1,2-	3436	73	2%	0 00016 J	13 J	1 3721	VMP-4	0 0028 - 380	NC	Not a COPC - detection frequency <5%
75-35-4	Dichloroethene, 1,1-	3436	11	0%	0.0008 J	22 J	1 3385	VMP-25	0 0027 - 370	NC	Not a COPC - detection frequency <5%
156-59-2	Dichloroethene, cis-1,2-	3436	34	1%	0 00059 J	11 J	1 3373	VMP-25	0 0027 - 370	NC	Not a COPC - detection frequency <5%
156-60-5	Dichloroethene, trans-1,2-	3436	9	0%	0 00092 J	0.0064	1 3387	VMP-48	0 0027 - 370	NC	Not a COPC - detection frequency <5%
78-87-5	Dichloropropane, 1,2-	3436	42	1%	0.0005 J	48 J	1 5904	VMP-16	0 0031 - 430	NC	Not a COPC - detection frequency <5%
10061-01-5	Dichloropropene, cis-1,3-	3436	6	0%	0.0013 J	0.0045 J	1 5309	VMP-13	0 0031 - 430	NC	Not a COPC - detection frequency <5%
10061-02-6	Dichloropropene, trans-1,3-	3436	29	1%	0 00022 J	0.4 J	1 5308	VMP-20	0 0031 - 430	NC	Not a COPC - detection frequency <5%
123-91-1	Dioxane, 1,4-	3436	96	3%	0 00052 J	0.093	4 8787	VMP-8	0.0098 - 1400	NC	Not a COPC - detection frequency <5%
141-78-6	Ethyl Acetate	56	0	0%	ND	ND	0 8657	NA	0.013 - 81	NC	Not a COPC - detection frequency <5%
76-13-1	Freon 113	3436	54	2%	0 00042 J	3 J J	2 5856	VMP-16	0 0052 - 720	NC	Not a COPC - detection frequency <5%
76-14-2	Freon 114	3436	6	0%	0 00098 J	0.62 J	2.355	VMP-1	0 0048 - 660	NC	Not a COPC - detection frequency <5%
87-68-3	Hexachlorobutadiene	3436	18	1%	0.0015 J	53 J	14.3624	VMP-2	0 029 - 4000	NC	Not a COPC - detection frequency <5%
1634-04-4	Methyl tert-Butyl Ether (MTBE)	3436	133	4%	0 00014 J	7.4 J	1 2108	VMP-25	0 0024 - 340	NC	Not a COPC - detection frequency <5%
79-34-5	Tetrachloroethane 1 1 2 2-	3436	23	1%	0 00041 J	16 J	2.309	VMP-2	0 0047 - 640	NC	Not a COPC - detection frequency <5%
120-82-1	Trichlorobenzene 1 2 4-	3436	50	1%	0 00072 J	92 J	9 9782	VMP-2	0.02 - 2800	NC	Not a COPC - detection frequency <5%
71-55-6	Trichloroethane 1 1 1- (Methyl chloroform)	3436	67	2%	0 00034 J	80	1 8564	VMP-25	0 0037 - 510	NC	Not a COPC - detection frequency <5%
79-00-5	Trichloroethane, 1,1,2-	3436	14	0%	0 00075 J	0.18 J	1 8413	VMP-1	0 0037 - 510	NC	Not a COPC - detection frequency <5%
108-05-4	Vinyl acetate	56	0	0%	ND	ND	0 8564	NA	0.013 - 80	NC	Not a COPC - detection frequency <5%
593-60-2	Vinyl Bromide	56	0	0%	ND	ND	1 0603	NA	0.016 - 99	NC	Not a COPC - detection frequency <5%
75-01-4	Vinyl chloride	3436	6	0%	0 00042 J	0.0028 J	0 8655	VMP-41	0 0017 - 240	NC	Not a COPC - detection frequency <5%
106-97-8	Butane	3185	1401	44%	0.0011 J	98000	616.1266	VMP-3	0.0065 - 1000	N/A	Not a COPC - no toxicity data available
64-17-5	Ethanol	3436	1667	49%	0.0013 J	300	2.7865	VMP-16	0 0051 - 710	N/A	Not a COPC - no toxicity data available
622-96-8	Ethyltoluene, 4-	3436	724	21%	0 00034 J	1000	3 6762	VMP-50	0 0033 - 460	N/A	Not a COPC - no toxicity data available
142-82-5	Heptane	3436	1396	41%	0 00033 J	4700 J	39.2837	VMP-4	0 0028 - 380	N/A	Not a COPC - no toxicity data available

APPENDIX 2-C, TABLE 2

SOIL GAS ANALYTICAL DETECTION STATISTICS AND CONSTITUENTS OF POTENTIAL CONCERN DETERMINATION (CONSTRUCTION WORKER)

CAS	Chemical	Total Samples Collected[a]	Number of Detections	Detection Frequency[b] (%)	Minimum Detected Concentration (mg/m^3)	Maximum Detected Concentration (MDC) (mg/m^3)	Average Concentration (ND = 1/2PQL[c]) (mg/m^3)	Location of MDC	Range PQL[c] (mg/m^3)	LDN Screening Value (5 ft transport) (mg/m^3)	COPC Determination[d]
78-78-4	Isopentane	3186	2118	66%	0 00081 J	120000	802.1239	VMP-3	0 008 - 1100	N/A	Not a COPC - no toxicity data available
540-84-1	Trimethylpentane, 2,2,4-	3436	2555	74%	0 00032 J	13000	311 9441	VMP-16	0 0032 - 440	N/A	Not a COPC - no toxicity data available

Notes

a Samples included in the statistical analysis were collected from 4th Quarter 2009 through 4th Quarter 2016.

b Detection frequency is the number of detected samples out of total number of samples collected.

c Reporting Limits

d Per RAGS Part A (USEPA 1989), any chemical detected at a frequency less than 5% can be eliminated as a COPC.

e m,p-Xylenes screening value based on p-Xylene Tier 3 calculations.

f Calculated Tier 3 concentration exceeded the Cvsat value and was therefore adjusted to equal Cvsat value.

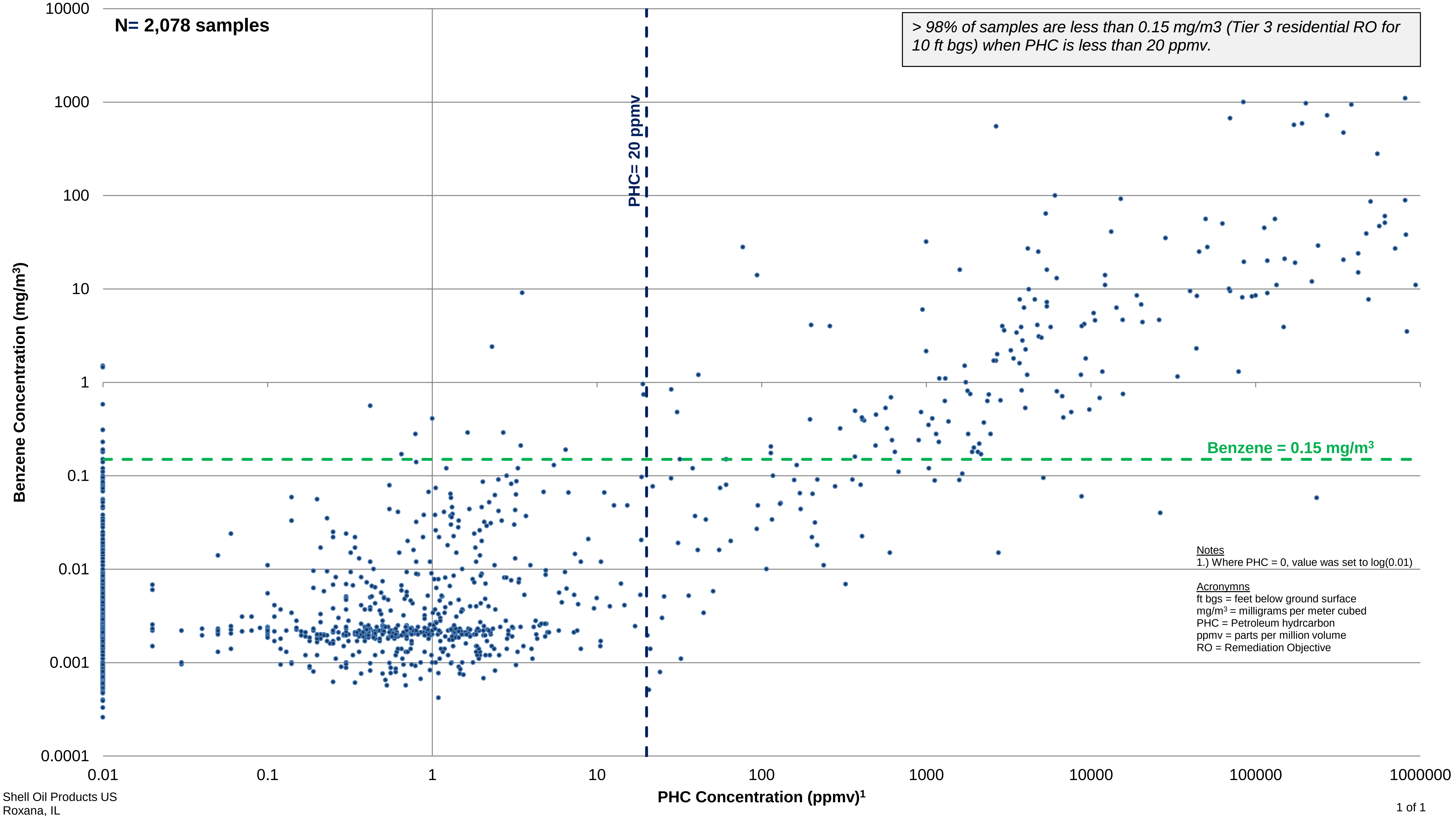
Acronyms:

CAS = Chemical Abstracts Service
COPC = Chemical of potentail concern
C_v^{sat} = Soil Vapor Saturation Limit
IAC = Ilinois Administrative Code
J = Estimated value
LDN = Little, Daisey, Nazaroff
MDC = Maximum Detected Concentration
mg/m^3 = milligrams per meter cubed
NA = not applicable; screening values and/or toxicity values are unavailable (i e., IUR or RfC toxicity data)
NC = not calculated; detection frequency <5%, therefore, Tier 3 calculation not performed
ND = non-detect
PQL = Practical Quantification Limit (Reporting Limit)
RAGS, 1989 = USEPA Risk Assessment Guidance for Superfunds, Volume I Part A, December 1989
RO = Remediation Objective
RSL = Regional Screening Level
TACO = Tiered Approach to Corrective Action Objectives (35 IAC 742)
USEPA = United States Environmental Protection Agency

Appendix 3-A. Benzene Concentration Compared to Corresponding PHC Concentration

APPENDIX 3-A

BENZENE CONCENTRATION COMPARED TO CORRESPONDING PHC CONCENTRATION



> 98% of samples are less than 0.15 mg/m3 (Tier 3 residential RO for 10 ft bgs) when PHC is less than 20 ppmv.

Notes
1.) Where PHC = 0, value was set to log(0.01)

Acronymns
ft bgs = feet below ground surface
mg/m^3 = milligrams per meter cubed
PHC = Petroleum hydrcarbon
ppmv = parts per million volume
RO = Remediation Objective