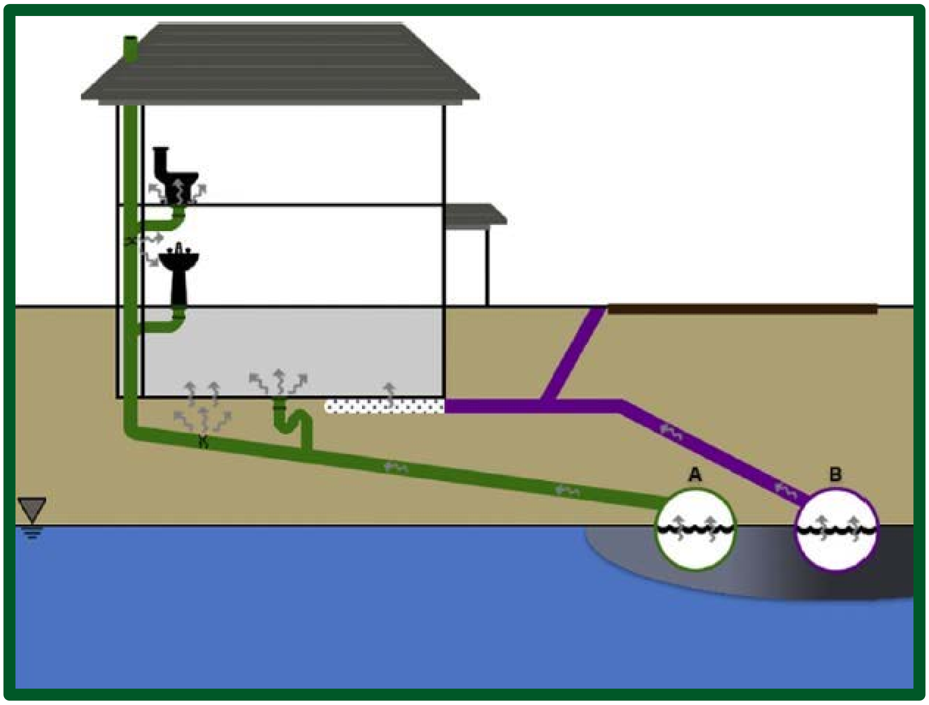
ESTCP
Executive Summary

(ER-201505)



Sewers And Utility Tunnels As Preferential Pathways For Volatile Organic Compound Migration Into Buildings: Risk Factors And Investigation Protocol

November 2018

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TECHNOLOGY CERTIFICATION PROGRAM

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-11-2018

2. REPORT TYPE
ESTCP Executive Summary

3. DATES COVERED *(From - To)*
2016-2018

4. TITLE AND SUBTITLE
Executive Summary – Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors and Investigation Protocol

5a. CONTRACT NUMBER
W912HQ-15-C-0062

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER
ER-201505

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

GSI Environmental Inc.
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Houston, TX 77098

8. PERFORMING ORGANIZATION REPORT NUMBER

4262

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program
4800 Mark Center Drive, Suite 16F16
Arlington, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
ER-201505

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A; unlimited public release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
There is growing recognition that preferential pathways can play an important role at sites affected by vapor intrusion (VI). Although this pathway is often mentioned in regulatory guidance documents, there is little information detailing the conceptual model or prevalence of this pathway. There is also limited guidance on how to assess sites for preferential pathways. As a result, preferential pathways are not currently being investigated in a consistent manner. The goal of this ESTCP project was to obtain a better understanding of sewers and utility tunnels as preferential pathways for VI. Specifically, the project involved developing a conceptual model for this pathway, identifying risk factors, and developing and validating an investigation protocol.

15. SUBJECT TERMS
Vapor Intrusion, Preferential Pathways

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASS	UNCLASS	UNCLASS	UNCLASS	26	Thomas McHugh / 713-522-6300

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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EXECUTIVE SUMMARY

Project: ER-201505

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1.0 INTRODUCTION

In the 1990s, vapor intrusion (VI) into homes and buildings was identified as a potential exposure pathway but was not routinely evaluated during site investigations because there were no accepted and validated evaluation procedures. Today, the same is true for sewer/utility VI at sites undergoing VI assessments. Although not typically tested as part of the VI investigation process, sewer/utility tunnels have been identified as important volatile organic compound (VOC) transport pathways at a small but growing number of sites.[1,2] It is likely that additional sites have sewer/utility tunnel VI that has not yet been identified.

The goal of this Environmental Security Technology Certification Program (ESTCP) project was to obtain a better understanding of sewer/utility tunnel VI. Specifically, the project involved developing a conceptual model for this pathway, identifying risk factors, and developing and validating an investigation protocol. Execution of this project involved three key tasks. Task 1 and 2 focused on field demonstrations to validate and refine the protocol. Task 3 was not part of the field demonstration program; rather, it focused on developing the conceptual model and risk factors for this pathway by utilizing data collected during the demonstration as well as literature reviews.

Based on the Task 1 field demonstration results, the protocol was refined and further validated as part of Task 2. The Final Report presents results of the overall protocol validation process completed under the first two tasks. It also includes the updated conceptual model developed under Task 3 (Final Report Appendix F) and a finalized protocol for sewer/utility tunnel VI investigations (Final Report Appendix G).

[1] Guo, Y., C. W. Holton, et al. (2015). "Identification of Alternative Vapor Intrusion Pathways Using Controlled Pressure Testing, Soil Gas Monitoring, and Screening Model Calculations." Environ. Sci. Technol. DOI: 10.1021/acs.est.5b03564.

[2] Riis, C., M. H. Hansen, et al. (2010). Vapor Intrusion through Sewer Systems: Migration Pathways of Chlorinated Solvents from Groundwater to Indoor Air. Remediation of Chlorinated and Recalcitrant Compounds—May 2010, Monterey, CA.

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2.0 OBJECTIVES

The overall objectives of this project were: i) to develop and validate an effective protocol to determine the presence or absence of sewer/utility tunnel VI during a VI investigation, ii) to determine the significance of sewer/utility tunnels at sites where this pathway has not been previously tested, and iii) to develop a detailed conceptual model for this pathway that identifies the types of sites at risk and the key mechanisms and processes involved. Key questions addressed in this study included: i) what types of samples to collect (liquid vs. vapor), ii) the significance of temporal variability, and iii) the significance of spatial variability.

To meet these project objectives, tasks were organized as follows:

- Task 1: Development of a preliminary investigation protocol and application at sites with known sewer/utility tunnel VI. The focus of this task was to determine whether the preliminary protocol would accurately identify the presence of sewer/utility tunnel VI at sites where these pathways were already known to exist based on previous investigations.
- Task 2: Application of investigation procedures to sites without known sewer/utility tunnel VI. The focus of Task 2 was to obtain a better understanding of sewer/utility tunnel VI risk at typical sites where the pathway was not already known to be important. Field testing focused on VOC attenuation between groundwater and sewers and from sewers to buildings.
- Task 3: Updated conceptual model and investigation protocol for sewer/utility tunnel VI. This task utilized the field investigation results from Tasks 1 and 2 along with results available from other sources to develop an updated conceptual model and to finalize the investigation protocol.

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3.0 TECHNOLOGY DESCRIPTION

The technology developed for this demonstration project is: i) a conceptual model for sewer/utility tunnel VI (Final Report Appendix F) and ii) a protocol to determine the presence or absence of a sewer/utility tunnel VI as part of an overall VI investigation (Final Report Appendix G). Based on results from the Task 1 and 2 field demonstrations and the Task 3 conceptual model development, the protocol includes a step-wise prioritization and decision-making process with the following key steps: i) initial desktop data review and screening, ii) field investigation, and iii) building testing or sewer mitigation.

The protocol utilizes existing sample collection and analysis methods that have been well-validated individually in other contexts. However, the protocol specifies the procedures for applying the methods in order to minimize false negative or false positive conclusions potentially resulting from spatial and temporal variability and other sources of uncertainty in the distribution of VOCs in the sewer/utility tunnel.

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4.0 PERFORMANCE ASSESSMENT

With a few exceptions, the project performance objectives were met. Performance objectives were: i) collection of quality data, ii) validation of the Investigation Protocol, and iii) evaluation of cost and implementability. The project included the collection of over 400 quantitative measurements consisting mostly of VOC concentrations and perfluorocarbon (perfluorinated) tracer (PFT) concentrations. Although the total number of measurements exceeded the project goals, fewer sewer delineation samples were collected than planned. Data quality goals were attained except for the precision goal for sewer manhole vapor samples. This was not achieved due to high matrix variability. Despite this exception, the data set was determined to be suitable for evaluation of the demonstration performance.

A total of 205 groundwater to sewer attenuation factors (AFs) were calculated from the field data generated during the demonstration. The impact of the vertical separation between groundwater and sewers was evaluated by grouping results from individual plumes into two categories: Category A (Direct Interaction [e.g., sewer below water table]) and Category B (Indirect Interaction [e.g., sewer above water table]). Median AFs are summarized in Table 1. Across the two categories, 86% of pairs showed greater than 33× attenuation.

Table 1. Groundwater to Sewer Median AFs

Site Category	No. of Plumes	No. of AFs	AF[1] (Median)	Attenuation[2] (Median)
A: Direct Interaction (Sewer Below Water Table)	6	65	7.5E-03	130×
B: Indirect Interaction (Sewer Above Water Table)	28	140	1.4E-04	7,300×

Notes: 1) AF calculated as sewer vapor concentration divided by equilibrium groundwater concentration. 2) Attenuation is the inverse of AF. It represents the concentration fold reduction from groundwater to sewer vapor. 3) Table is based on Table 6.4 of the Final Report and summarizes results from primary contaminant of concern (COC) for each site (i.e., the highest-concentration chemical in groundwater for each plume studied) and secondary site COCs (i.e., other chemicals detected a concentration of 15% or more of the primary COC concentration). At most sites, the primary COC was tetrachloroethylene (PCE) or trichloroethylene (TCE).

Sewer to building AFs were developed from the results of tracer testing. The tests indicated that concentrations decreased by factors of 20 to more than 1000 from the sewers to the buildings (see Table 2). This range was well above the 10× default in the draft protocol. The final protocol presented in the Final Report uses an AF of 0.03 (33× attenuation) as a reasonable upper-bound for the migration of VOCs in vapor from sewer/utility tunnels into buildings for use in the calculation of sewer to indoor air screening values. In addition, an overall AF of 0.001 is recommended for groundwater to sewer/utility tunnel to indoor screening values. This overall AF is based on an upper bound groundwater to sewer AF of 0.03 and an upper bound sewer to indoor air AF of 0.03.

Table 2. Sewer to Building VOC Attenuation

Building Types	Range of Attenuation
Buildings with Known Sewer/Utility Tunnel VI Issues	30 – 50×, or greater
Buildings with No Known Issues	2 of 12: 20× – 50×, or greater 10 of 12: 100×, or greater

Notes: 1) Table is based on Table 6.11 of the Final Report.

In addition to these performance metrics, data collected for this project were used to validate different aspects of the conceptual model and protocol. For the conceptual model, **background VOC concentrations** in sewers were characterized through samples collected during Task 1 and 2. These VOCs included chemicals that are common target analytes in environmental assessments (e.g., PCE, TCE, and cis-dichloroethene [DCE]; benzene, toluene, ethylbenzene, xylenes [BTEX]). The background sample results showed that VOCs commonly associated with contaminated sites are also commonly detected in sewers not located in close proximity to known VOC plumes. For the VOCs that are most commonly risk drivers at corrective action sites (e.g., benzene, PCE, TCE), the detected concentrations at background sewer locations were typically low (i.e., <20 µg/m3). The relatively high detection frequency (55%) for cis-1,2-DCE (a marker for biodegradation of TCE in the subsurface) suggests that some of the VOC detections in sewers can be attributed to unidentified subsurface sources. However, the higher detection frequency for TCE (70%) and PCE (90%) suggests that direct discharge of VOCs into sewers is another source of VOC vapors in sewers. As discussed in Section 6.3.1, this finding relies on the assumption that the cis-1,2-DCE was not formed as a result of biodegradation of TCE within the sewer line. However, the short residence time and typically aerobic conditions within sewers are unlikely to support biodegradation of TCE.

Temporal variability in VOC concentrations in sewer manholes was also characterized by sampling manholes multiple times over different time scales. Temporal variability was evaluated at chlorinated solvent plume sites; COCs included PCE, TCE, cis-1,2-DCE, 1,1-DCE, and chloroform. The evaluation was based on project demonstration results and supplemental data from Entanglement Technologies and from Arizona State University (ASU) researchers (ER-201501). Results from the field sampling and supplemental data indicate that the short-term (1-3 days) variation in concentration was low (<10× for 79% of manholes), with a median concentration range of 3.5×. However, longer-term variation (based on quarterly sampling for one year to 18 months) was much higher. Based on longer-term sampling, 88% of the Houston sanitary manholes, 81% of the Layton sanitary manholes, and 54% of the Layton land drain manholes showed >10× variation in VOC concentration, with median concentration ranges of 30×, 34×, and 11× respectively. This difference in variability is also reflected in the coefficient of variation for the datasets. The coefficient of variation (standard deviation divided by the mean) was utilized because it is a common measure of relative variability. The median coefficient of variation for the short-term datasets was 0.59 while the median coefficient of variation for the long-term datasets ranged from 1.3 to 3.7. Thus, the evaluation of temporal variability showed much higher variation in VOC concentrations over a time scale of months compared to a time scale of days. The results suggest that short-term time integrated samples (e.g., 24-hour Summas or 7-day passive samplers) would provide little benefit compared to grab samples for estimation of the long-term average VOC concentration in a sewer. In addition, small quarterly monitoring datasets provide uncertain estimates of the true long-term average VOC concentration.

Based on the groundwater to sewer AFs (described above) and risk factors identified at the supplemental sites, a classification scheme was developed to identify sites with **higher risk and lower risk for sewer/utility tunnel VI**. These risk scenarios are summarized in Figure 1.

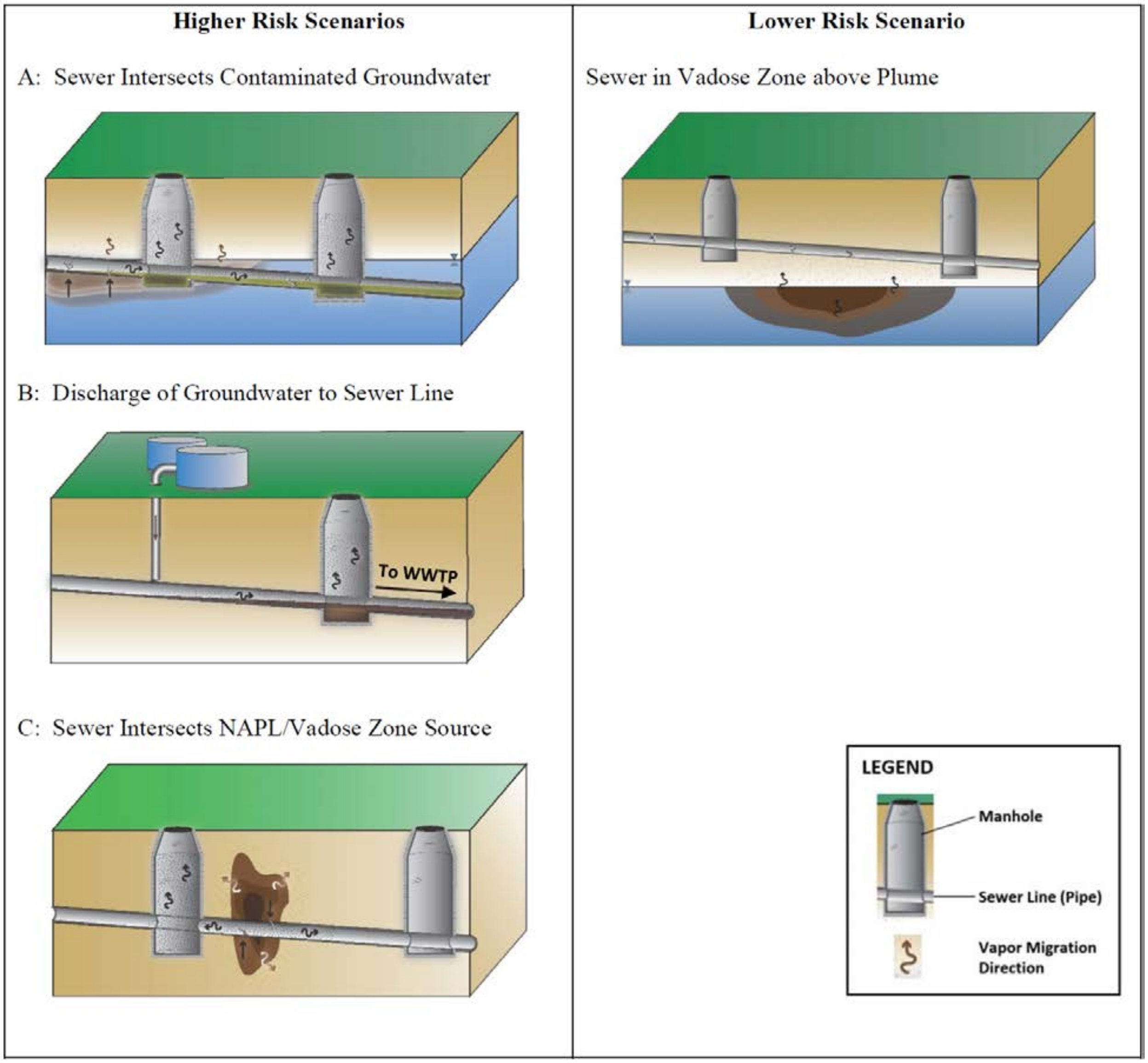

Figure 1. Higher and Lower Risk Scenarios for Sewer/Utility Tunnel VI

The protocol developed as a result of this ESTCP project (see Figure 2) recommends a stepwise desktop screening (see **Error! Reference source not found.**) and initial field sampling process (see Figure 4) that factor in the risk scenarios, AFs, and other risk factors.

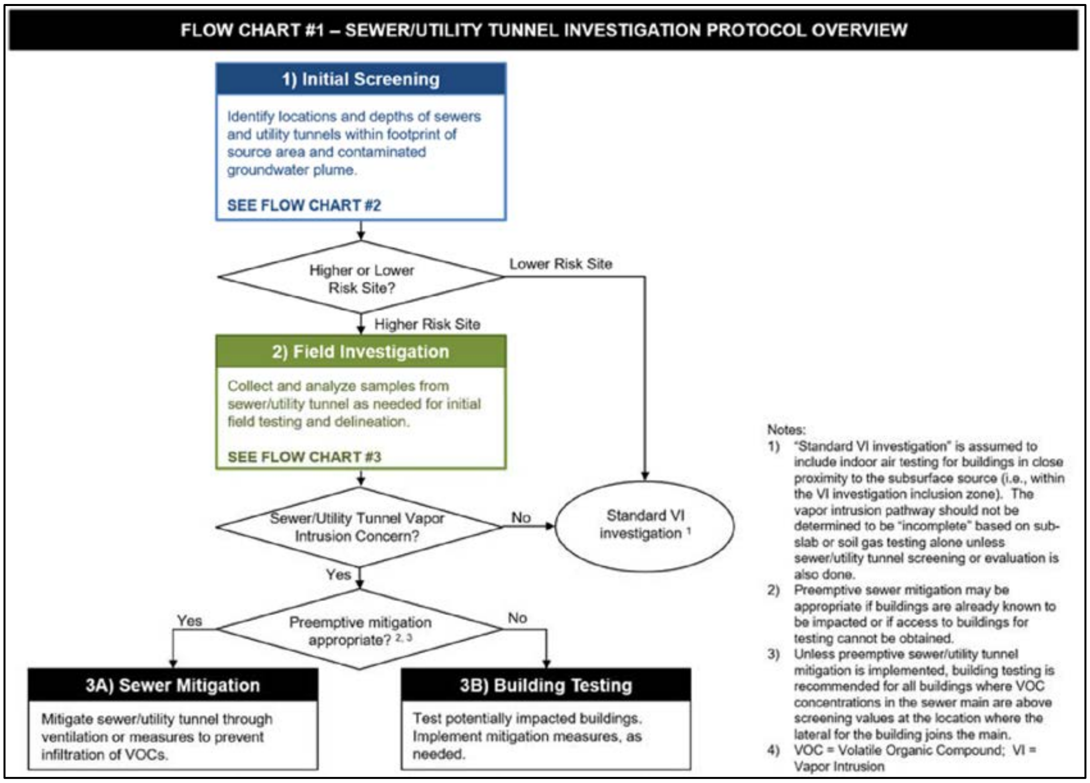

Figure 2. Overview of the Investigation Protocol

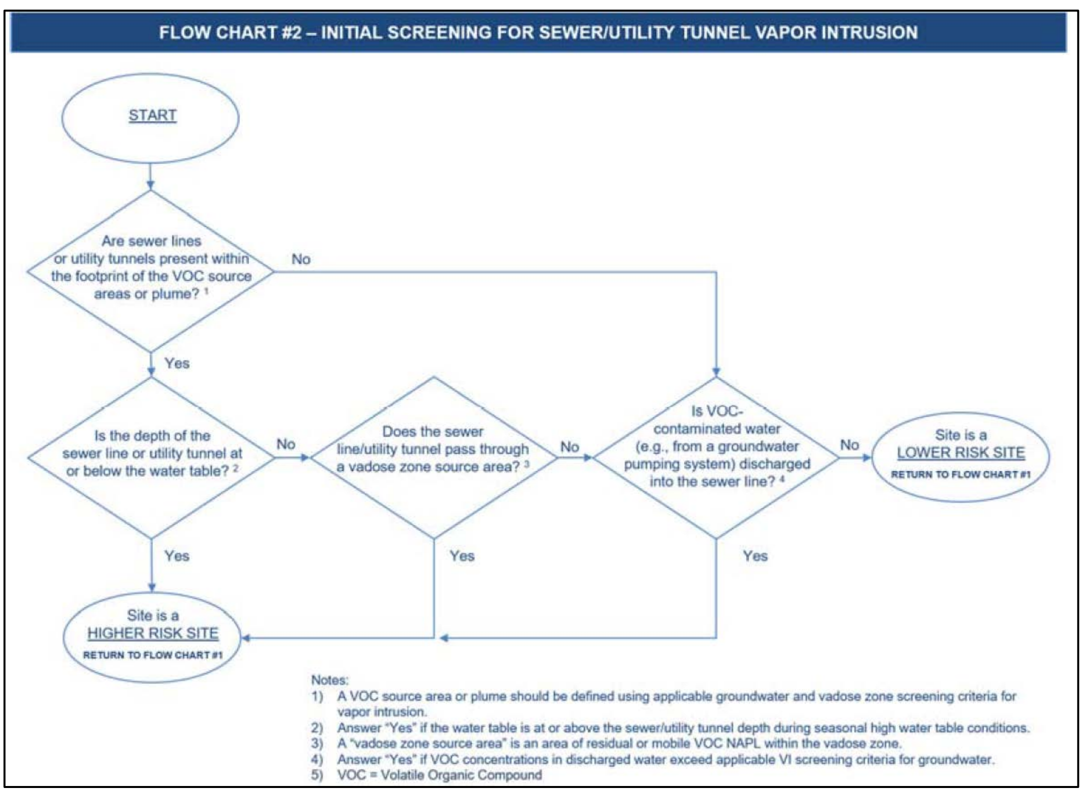

Figure 3. Flow Chart for Desktop Screening Portion of the Protocol

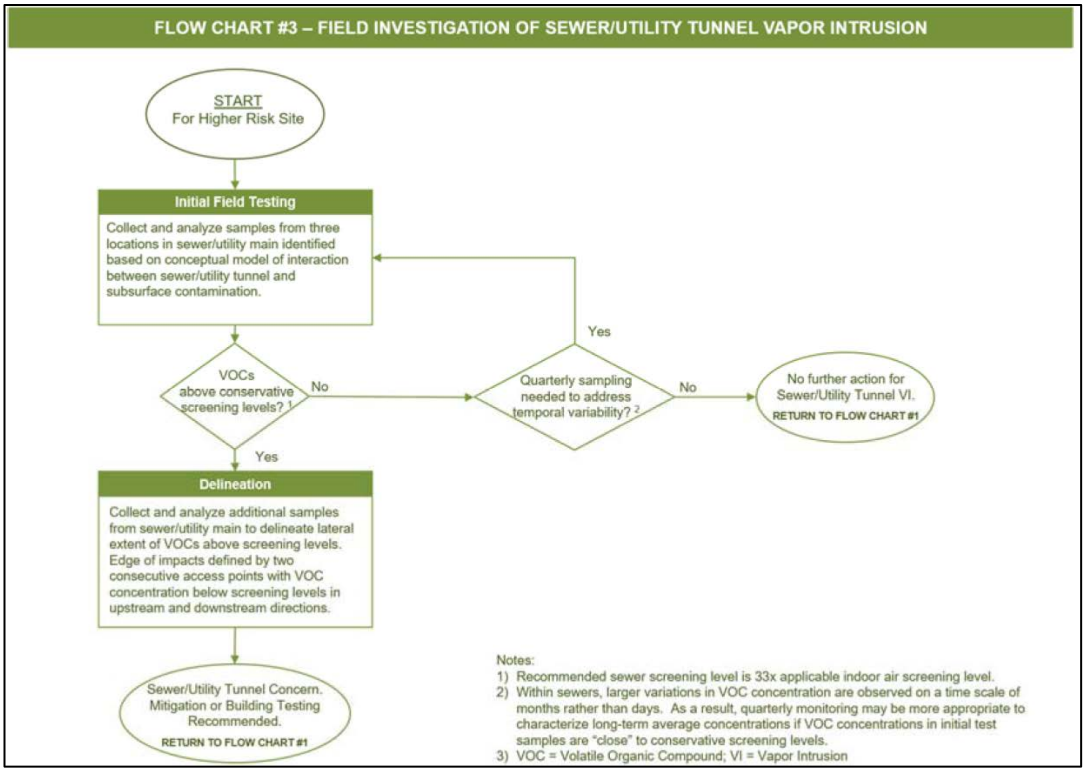

Figure 4. Flow Chart for Initial Field Sampling Portion of the Protocol

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5.0 COST ASSESSMENT

Routine implementation of the desktop screening portion of the protocol is estimated to cost about $1,000, and the initial field testing is estimated at up to about $5,000. This should increase the cost of a typical VI investigation by less than 25%. The screening step is intended to apply to all sites, and the initial field testing would apply to the subset of sites that are identified as higher risk for sewer/utility tunnel VI. It is important to recognize, however, that the cost estimates do not include any follow-up testing, for example, to delineate areas where VOCs exceed screening levels in sewers. Because the scope of any follow-up testing is site-specific, the associated costs cannot be generalized.

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6.0 IMPLEMENTATION ISSUES

The protocol is intended to supplement work plans for standard VI investigations.

Advantages:

- Provides a standardized framework for evaluating sewers/utility tunnels as potential preferential pathways for VI;
- Provides a decision logic for testing based on potential risk of the presence of sewer/utility tunnel VI; and
- Recommends sampling procedures that are practical and relatively simple to implement.

Limitations:

- Relies on indoor air testing to identify VI impacts at lower risk sites; and
- Does not provide detailed guidance on sewer/utility tunnel mitigation.

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