Vapor Intrusion Pathway Investigation Report

East Hennepin Avenue Site
Minneapolis, Minnesota

Prepared for
General Mills, Inc.

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Executive Summary

This report describes the vapor intrusion pathway (VI pathway) investigation activities completed by General Mills in Minneapolis, Minnesota. The work was completed in accordance with the *Vapor Intrusion Pathway Investigation and Feasibility Study Work Plan* (Work Plan; Barr, 2014d), as specified in the Remedial Action Plan (RAP) Modification #1 (RAP Modification #1) to the Response Order by Consent between General Mills and the Minnesota Pollution Control Agency (MPCA), dated October 23, 1984 (Consent Order). The primary purpose of this investigation was to assess volatile organic compound (VOC) concentrations in soil, groundwater, and soil gas at and in the vicinity of the 2010 East Hennepin Avenue property (Site) including impacts from off-Site sources where elevated concentrations of trichloroethylene (TCE) have been identified in groundwater. This larger area is referred to as the Study Area. The Study Area is divided into four geographical regions, including the Site, Northeast Area, Central Area, and Southwest Area.

Prior to this investigation, General Mills contractors completed sub-slab and/or indoor air sampling at 344 properties and installed mitigation systems at 188 properties in the Study Area. This work was completed in accordance with the RAP Modification #1 and is documented in the *Sub-Slab Sampling and Building Mitigation Implementation Report* (Barr, 2015b). Individual Property Summary Reports for each property also have been prepared and submitted to MPCA. General Mills' efforts resulted in a study participation rate greater than 95%. Approximately one-half of the properties sampled had reported TCE concentrations in sub-slab soil gas less than MPCA's screening value and therefore, required no further action. The mitigation systems are operating as designed and are considered by MPCA to be among the most effective vapor intrusion mitigation strategies for existing or new buildings (MPCA, 2010).

This investigation of soil, groundwater, and soil gas was performed to assess the hydrogeologic setting of the glacial deposits and distribution of VOC concentrations in these media with respect to the potential VI pathway, including impacts from off-Site sources. This investigation included:

- Installing 18 borings for investigation purposes and 56 pilot borings to construct soil vapor monitoring ports and monitoring wells from which 23 soil samples and five soil gas samples were collected for laboratory analysis;

- Installing temporary wells at 22 boring locations for groundwater sampling from which 51 groundwater samples were collected;

- Installing 38 permanent monitoring wells for groundwater sampling and to construct a sentinel monitoring network and collecting 102 groundwater samples from these and other existing wells; and

- Installing a soil gas sentinel monitoring network comprised of 30 vapor monitoring ports from which 60 soil gas samples were collected.

The highest concentrations of TCE in groundwater in the Study Area were detected northeast (up-gradient) of the Site. Multiple sources in the Northeast Area are the predominant cause of TCE concentrations in groundwater in the Study Area. In addition, multiple potential sources of chlorinated solvents, unrelated to the Site, exist throughout the Study Area. Elevated sub-slab soil gas TCE concentrations in the southwest portion of the Study Area suggest different release(s) unrelated to the Site. Extensive soil and groundwater sampling at the Site and former disposal area show no evidence of dense nonaqueous phase liquid (DNAPL) or TCE source material. The Site is not an ongoing source of TCE to groundwater at concentrations that would contribute to the VI pathway in the Study Area.

In conjunction with this investigation, General Mills prepared a Human Health Risk Assessment (HHRA) to evaluate exposures to soil, groundwater, and indoor air associated with residential and commercial uses in the Study Area. The HHRA was prepared based on the soil, groundwater, and soil gas sampling data collected in this and previous investigations and in connection with the sub-slab sampling and building mitigation response action. The HHRA concludes that the only exposure pathway in the Study Area that may be complete and of potential significance is the potential VI pathway from VOCs in the glacial drift groundwater within the Northeast Area.

1.0 Introduction

This report describes the vapor intrusion pathway (VI pathway) investigation activities completed by General Mills, Inc. in Minneapolis, Minnesota. The work was conducted in accordance with the Remedial Action Plan (RAP) Modification #1 (MPCA, 2014a) to the Response Order by Consent between General Mills and the Minnesota Pollution Control Agency (MPCA), dated October 23, 1984 (Consent Order; MPCA, 1984). Investigation activities were guided by the *Vapor Intrusion Pathway Investigation and Feasibility Study Work Plan* (Work Plan; Barr, 2014d), approved by MPCA in its letter, dated September 18, 2014 (MPCA, 2014c). This investigation follows numerous soil, groundwater, and soil gas investigations completed in connection with the property at 2010 East Hennepin Avenue, as well as 25 years of groundwater remediation performed by General Mills pursuant to the Consent Order.

The Consent Order uses the term "Site" to refer to the former General Mills property at 2010 East Hennepin Avenue (Figures 1 and 2). This terminology is retained in this report, and thus references to the Site are intended to refer only to the property at 2010 East Hennepin Avenue. General Mills investigated soil, groundwater, and soil gas at the Site and at locations northeast, south, and southwest of the Site. These areas are collectively referred to in this report as the Study Area as shown on Figure 2.

The primary purpose of the investigation was to assess volatile organic compound (VOC) concentrations in soil, groundwater, and soil gas in the Study Area with respect to the potential VI pathway, including those due to up-gradient sources where the highest trichloroethylene (TCE) concentrations in the Study Area have been measured in groundwater. The results of this investigation, together with previous investigations and additional information made available from MPCA files, confirm that multiple sources of TCE are impacting groundwater and soil gas conditions throughout the Study Area. No current TCE source areas have been found on the Site.

1.1 Study Area Background

TCE, a widely used industrial and commercial solvent, is variably present in groundwater throughout the Study Area with the highest concentrations detected up-gradient of the Site. The 700-acre Mid-City Industrial neighborhood occupies the northeast portion of the Study Area. The remaining portions of the Study Area include primarily residential properties intermixed with industrial and commercial properties.

The sub-slab soil gas sampling and investigation work completed by General Mills in 2013 through 2015 provided an extensive data set that measured sub-slab and groundwater TCE concentrations at locations throughout the Study Area. The data confirms multiple sources of TCE are impacting groundwater and soil gas conditions throughout the Study Area.

Separately, in recognition that other sources of chlorinated solvents up-gradient and side-gradient of the Site exist, MPCA is conducting sub-slab soil gas sampling in connection with a newly established project area named the Southeast Hennepin Area Groundwater and Vapor Site (SA249), the boundaries of which include portions of the Study Area. In early 2015, MPCA completed a Comprehensive Environmental

Response, Compensation, and Liability Act (CERCLA) pre-screening assessment for the purposes of listing SA249 on Minnesota's Permanent List of Priorities to conduct further groundwater and soil gas investigations.

1.2 Investigation Activities

In accordance with RAP Modification #1, the scope of work for the VI pathway investigation set forth in the MPCA-approved Work Plan, included the following tasks:

1. Further assessing the hydrogeologic setting of the glacial drift and the VOC concentrations in shallow groundwater, including impacts from off-Site sources;
2. Placing additional borings at the Site;
3. Establishing a sentinel groundwater and soil gas monitoring network; and
4. Reporting results and presenting approaches to subsequent stages of investigation and feasibility study activities, as necessary.

1.3 Report Organization

Following this introductory section, Section 2.0 summarizes the background information about the Site and off-Site areas as context for the investigation. The investigation methods are described in Section 3.0. A description of the physical setting is detailed in Section 4.0. A discussion of the sampling results is presented in Section 5.0. The site conceptual model (SCM) is described in Section 6.0. Investigation conclusions are summarized in Section 7.0. Recommended next steps are presented in Section 8.0. References are in Section 9.0. Additional details regarding investigation procedures and documentation are in the appendices to this report.

2.0 Background Information

This section summarizes the investigation and response action history of the Site. It defines the Study Area and presents an overview of information generated through limited regulatory reviews and from investigation and response action work completed in the Study Area from the early 1980s to the present.

2.1 Response Action History

Section 2.1.1 provides an overview of the investigations and response actions completed by General Mills with respect to the former disposal area at the Site. Section 2.1.2 provides a summary of the recent sub-slab soil gas sampling and mitigation project completed in the Study Area.

2.1.1 Site History

Multiple investigations have been conducted with regard to a former disposal area at the Site since the early 1980s to characterize soil and groundwater conditions at and near the Site. The early investigations detected VOCs, primarily benzene, toluene, ethyl benzene, and xylenes (BTEX) and, to a lesser extent, chlorinated VOCs (cVOCs) including TCE, tetrachloroethylene (PCE), and 1,1,1-trichloroethane (1,1,1-TCA) in soil and shallow groundwater in the southeastern corner of the Site. In contrast, further from the former disposal area, TCE was the predominant constituent detected in groundwater (Barr, 1983).

Early investigations determined that shallow groundwater flowed in a southwesterly direction. No investigation of the glacial drift was conducted up-gradient of the Site during these investigations. Well 1, placed in the northeast corner of the Site, was believed at the time to be up-gradient of the former disposal area and showed only low levels of TCE in shallow groundwater. No water table wells were installed northeast of the Site.

General Mills agreed to install and operate a groundwater extraction and treatment system beginning in 1985 to limit the migration of TCE. The system was installed, operated, and monitored as a groundwater remedial action under the Consent Order (Barr, 1985).

Additionally, several types of institutional controls (ICs) have been implemented for protection of public health and the environment, limiting access to impacted soil and/or groundwater at the Site and the Study Area to assure long-term protectiveness. Specifically the following controls are currently in place:

Institutional Controls (IC) Summary Table adapted from 2014 5-Year Review (MPCA, 2014d)

Media, Engineered Controls, & Areas that Do Not Support UU/UE[(1)] Based on Current Conditions	IC Objective	Title of IC Instrument Implemented
Soil greater than 4 feet below ground surface (bgs)	Soil Impacted Area shall be used for industrial/commercial purposes only; No disturbance or alteration that would expose or disturb the subsurface soils (>4 feet bgs)	Declaration of Restrictions and Covenants and Affidavit Concerning Real Property Contaminated with Hazardous Substances Document #8471566 as recorded by the Hennepin County Recorder Office.
Groundwater	No disturbance or dewatering of groundwater is to take place beneath the Groundwater Impacted Area without prior authorization from the MPCA.	Declaration of Restrictions and Covenants and Affidavit Concerning Real Property Contaminated With Hazardous Substances Document #8471566 as recorded by the Hennepin County Recorder Office.
Groundwater	Requires notification of proposed construction of a groundwater supply well to the commissioner	Minn. Rules 4725.1820 Notification for Construction of Water Supply Wells
Groundwater	Requires notification of proposed construction of a groundwater well to the commissioner	Minnesota Statute 1031.205 Well Construction
Groundwater	Requires MDH commissioner approval for construction and modification of wells and borings within Special Well and Boring Construction Areas (SWCAs)	Minnesota Rule 4725.3650 Special Well and Boring Construction Areas - Twin Cities Army Ammunition Plant

Notes:
(1) Unlimited use and unrestricted exposure

The groundwater treatment system operated for 25 years. Annual groundwater sampling and reporting was completed over that period. General Mills agreed to periodically modify the groundwater monitoring network and the groundwater extraction and treatment systems several times during the period of operation, as requested by MPCA.

After achieving the remedial action objectives set forth in the Consent Order, MPCA suggested and then approved shutting down the groundwater extraction and treatment systems in 2010. TCE concentrations remain stable and no significant rebound in TCE concentrations has been observed following the shutdown of the pump-out system.

Once the remedial action objectives were met, steps toward delisting the Site were initiated, including vapor intrusion, potable water well, and surface water pathway evaluations. From 2011 into 2013, General Mills conducted phased investigations of shallow groundwater and soil gas in accordance with MPCA-approved work plans (Barr, 2012a; 2012b; 2013c; 2013d; 2013e).

In November 2013, General Mills began implementing the *Sub-Slab Sampling and Building Mitigation Work Plan* (Barr, 2014a) under MPCA oversight. General Mills collected sub-slab soil gas samples at 339 properties and installed building mitigation systems at 188 properties from November 2013 to April 2015 (see Section 2.1.2). The sub-slab soil gas sampling results pointed to the likely existence of one or more TCE sources unrelated to the Site.

In April 2014, as part of its ongoing evaluation of the VI pathway, General Mills also conducted soil, groundwater, and soil gas sampling to evaluate areas northeast, south, and southwest of the Site (Barr, 2014b). TCE was detected in groundwater and soil gas at multiple locations northeast of the Site, providing further evidence of the presence of off-Site TCE sources including sources up-gradient of the Site.

In response to a May 2014 request from MPCA, General Mills conducted an additional investigation of the former disposal area (Former Disposal Area Investigation). The work included installing borings at the Site in and around the former disposal area to characterize current soil and groundwater conditions (Barr, 2014c). The investigation found no TCE in soil samples collected in the upper 30 feet of the former disposal area. Only low levels of TCE (less than 1 part per million) were found in soil samples at depths between approximately 40 and 53 feet bgs in the former disposal area. The results of this investigation showed no evidence of source material at the former disposal area that could act as a continuing source of TCE to shallow groundwater.

The August 2014 Work Plan was developed as the sub-slab soil gas sampling and initial 2014 investigation activities were in progress. New information from MPCA files, previously unknown to General Mills, also became available. These files included data from as far back as the mid-1990s documenting the presence of TCE in soil and groundwater at multiple off-Site sources in and near the Study Area and up-gradient and side-gradient of the Site (see Section 2.2). The Work Plan considered the initial 2014 investigation results, as well as the information from MPCA files regarding TCE soil and groundwater concentrations off-Site, to design an investigation that extended to the northeast of the Site to evaluate impacts from off-Site sources.

2.1.2 Sub-Slab Soil Gas Sampling and Building Mitigation

The sub-slab soil gas sampling and building mitigation project was conducted by General Mills from November 2013 to April 2015. The work was completed in accordance with the *Sub-Slab Sampling and Building Mitigation Work Plan* (Barr, 2014a), dated February 2014, as specified in RAP Modification #1. The primary purpose of this work was to collect sub-slab soil gas samples from occupied buildings on properties in the vicinity of the Site and to analyze the samples for TCE to determine whether building mitigation (sub-slab depressurization (SSD) systems) would be offered.

The work included the following tasks:

- Collecting sub-slab soil gas samples;
- Collecting indoor air, outdoor air, and paired sub-slab soil gas samples at certain properties;
- Installing building mitigation systems; and
- Conducting post-mitigation indoor and outdoor air sampling at certain properties.

Of the 361 properties where participation was requested:

- 344 properties participated in the study;
- 339 properties participated in sub-slab sampling; and
- 188 properties had mitigation systems installed.

A study participation rate greater than 95% was achieved. No further action was necessary at approximately one-half of the properties studied because these properties had reported TCE concentrations in sub-slab soil gas less than MPCA's conservative screening value[1]. Mitigation systems were offered, and if accepted, installed at properties with reported TCE concentrations in sub-slab soil gas greater than the conservative MPCA screening value. In general, this area is referred to as the Soil Gas Monitoring Area (see Figure 2). Mitigation systems were also offered, and if accepted, installed at select properties within the Soil Gas Monitoring Area with reported TCE concentrations in sub-slab soil gas less than the conservative MPCA screening value based on their proximity to properties with elevated TCE concentrations. Building mitigation system locations are shown on Figure 3. The SSD systems have been demonstrated to be effective and are operating as designed (Barr, 2015b). The SSD systems are considered by MPCA to be an effective vapor intrusion mitigation strategy for existing or new buildings (MPCA, 2010).

2.2 Study Area Overview

The following sections of the report divide the Study Area into four geographical regions, which are shown on Figure 2 and defined as follows:

1. Site – 2010 East Hennepin Avenue property
2. Northeast Area – Outside of and generally hydraulically up-gradient from the Soil Gas Monitoring Area and the Site with respect to glacial drift groundwater;
3. Central Area – Properties generally within the Soil Gas Monitoring Area, excluding the Site; and

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[1] The sub-slab screening value of 20 micrograms per cubic meter ($\mu g/m^3$) was derived by MPCA as the concentration of TCE in sub-slab soil gas that would not result in an indoor air concentration of TCE that exceeded a screening value of 2 $\mu g/m^3$. The indoor air screening value of 2 $\mu g/m^3$ is protective for a hazard index of 1 assuming continuous exposure to the indoor air (i.e., 24 hours per day), 365 days per year, over a 30-year period. The sub-slab soil gas screening level was derived by applying a conservative 0.1 sub-slab soil gas to indoor air attenuation factor to the indoor air screening value of 2 $\mu g/m^3$. The 0.1 attenuation factor used by MPCA is over three times more conservative than the 95th percentile attenuation factor of 0.03 recommended by the U.S. Environmental Protection Agency (EPA) based on its vapor intrusion guidance (EPA, 2015).

4. Southwest Area – Outside of and generally hydraulically down-gradient from the Soil Gas Monitoring Area with respect to glacial drift groundwater.

The Soil Gas Monitoring Area is surrounded by a network of wells and vapor ports installed for the purpose of assessing TCE concentrations in groundwater and soil gas at the perimeter of the area where most of the building mitigation work occurred.

The Site is located at 2010 East Hennepin Avenue and is a 6.7–acre wedge-shaped parcel located on the south side of East Hennepin Avenue. The Northeast Area includes a portion of the 700-acre Mid-City Industrial neighborhood located north of East Hennepin Avenue and residential properties east of the Site that are outside of the Soil Gas Monitoring Area. The Central Area includes primarily residential properties along with some commercial and industrial properties in and side-gradient to the Soil Gas Monitoring Area. The Southwest Area includes a mix of industrial, commercial, and residential properties and Van Cleve Park on 15th Avenue SE.

TCE is present in the glacial drift groundwater at various locations and concentrations throughout the Study Area. TCE was a commonly-used industrial and household solvent between the 1930s and the 1990s, and remains in use today. The largest use by volume of TCE was to clean and degrease metal parts. TCE continues to be used by industry, automotive repair shops, and do-it-yourselfers to perform vehicle and household equipment maintenance and repairs (Williams, 2014). The presence of consumer products known to contain TCE was documented in homes and basements during the sub-slab soil gas sampling project (Barr, 2015b).

A review of city directories and a regulatory database search for potential TCE users in the Study Area identified over 70 businesses in the city directory listings and 380 facilities on the regulatory database listings that were or are potential solvent users (EDR, 2013; EDR, 2014a; EDR, 2014b). The following sections summarize land use and potential contaminant sources at the Site and in the Northeast, Central, and Southwest Areas based on regulatory records, fire insurance maps, Site environmental reports, city directories, and a limited review of MPCA files.

2.2.1 Site – 2010 East Hennepin Property

Most of the current buildings at the Site were constructed between 1930 and 1934 (HIG, 2013; HIG, 2014a; HIG, 2014b). The BNSF railway corridor borders the Site on the south and west and has been present since the Site buildings were constructed in the 1930s. Buildings on the Site historically have been used for a variety of activities, including, but not limited to, laboratories and related uses, pilot plants, and offices. A review of city directories identified more than 150 businesses that have operated at the Site (EDR, 2013; EDR 2014a). The Site is currently occupied by a variety of commercial businesses with reported residential use at the top floor of one building.

From approximately 1930 until the 1970s, General Mills and, later, General Mills Chemicals, Inc. operated a technical center and research laboratory at the Site. For part of this time period, laboratory wastes reportedly were disposed in a disposal area in the southeast portion of the Site. In 1977, Henkel, Inc.

(Henkel) acquired General Mills Chemicals, Inc. and, with it, the property at 2010 East Hennepin Avenue. Henkel continued much of the research and chemical business at the Site. Into the 1980s, Henkel continued to generate, treat, and store hazardous waste on the Site.

The former disposal area in the southeastern portion of the Site was used from approximately 1947 to 1962, to manage wastes in a manner that was generally consistent with industry practices at the time. Liquid wastes were reportedly placed into a conveyance feature constructed using three empty 55-gallon drums that were perforated, stacked one on top of another, and buried with the top of the deepest drum approximately 10 to 12 feet bgs (Barr, 1983). The wastes were a mixture of waste solvents, likely varying in composition on a daily basis. It is unclear whether the wastes were an aqueous mixture or separated phases prior to disposal. General Mills preliminarily estimated that approximately 1,000 gallons of waste organics and solvents per year (or about 19 gallons per week) may have been disposed in the former disposal area (GMI, 1981). No records are available to accurately determine the quantity of solvents that were disposed; however, chemical analyses suggest that the volume of solvents disposed was much lower than the early estimate (Barr, 1983). Site characterization work associated with the former disposal area began in 1981. The drums were reportedly excavated in 1981, and the bottom of the excavation is believed to have been about 12 feet deep (Barr, 1983).

Above-ground storage tanks were located on the western and southern portions of the Site in the 1970s and 1980s. Various chemical storage areas and underground fuel oil tanks existed on the Site. The fuel oil tanks were reported to have been removed in the 1980s and 1990s (EDR, 2014b).

2.2.2 Northeast Area

The Northeast Area is hydraulically up-gradient from the Site, Central, and Southwest Areas. The Northeast Area includes a portion of the Mid-City Industrial neighborhood which was developed as early as 1934, based on aerial imagery, and is bounded by Interstate I-35W to the north, Highway 280 to the east, Johnson Street to the west, and East Hennepin Avenue to the south. Early topographic maps indicate that roads and rail spurs were constructed in the southern and eastern portions of the Mid-City Industrial neighborhood as early as 1896 with the north, central and western areas occupied by wetlands along a steep hillside trending northwest to southeast. A large gravel pit operated on the northern portion of the Mid-City Industrial neighborhood between 1934 and 1977. Development of the Mid-City Industrial neighborhood continued through the mid-1970s. Based on historic topographic maps, the industrial properties along East Hennepin Avenue were the first to be developed and development expanded rapidly to the north after 1977, when operations at the gravel pit ceased.

A limited review of MPCA files for properties located in the Northeast Area documents TCE releases to groundwater at several properties along and north of East Hennepin Avenue since at least 1994. The locations of these sites are shown on Figure 4 and are summarized below:

Site Name	MPCA File Number	TCE Concentration in Shallow GW	Sample Date	Reference
AmeriPride Services Inc. 700 Industrial Blvd NE	VP 24750 LUST 16906	7.2 µg/L	2009	Delta, 2009
Northwestern Warehouse 3255 Spring Street NE	VP 13100 VP 13101	610 µg/L	2000	Braun Intertec, 2000
Sears/former Scott-Atwater Manufacturing 2700 Winter Street NE	LUST 7043 LUST 7095	290 µg/L	1995	Groundwater Technology, 1996
Anne Gendein Trust Property/Lend Lease Trucking/former Scott-Atwater Manufacturing 359 Hoover Street NE	VP 13270 LUST 6600	3,600 µg/L	2001	Peer, 2001
2400 Traffic Street	VP 22300 VP 23301 VP 23302	41 µg/L	2006	Vieau Associates Inc., 2006
Office/Warehouse 2301 Traffic Street	VP 27480	2.7 µg/L	2011	Pinnacle Engineering, 2011
Frank's Auto Repair 2314 Hennepin Ave E	LUST 17726	1,620 µg/L	2009	Thatcher, 2009; AECOM, 2012
East Hennepin Auto Service Inc. 2100 Hennepin Ave E	LUST 2477	24 µg/L	1994	AET, 1994
Como Student Community 1024 27th Avenue SE	VP 24930	10.7 µg/L	2009	DPRA, 2009
LUST – Leaking underground storage tank site VP – Voluntary investigation and cleanup site µg/L – microgram per liter				

As shown in the table above, investigation at the Frank's Auto Repair and Anne Gendein Trust/Scott-Atwater Manufacturing Company sites, have documented high TCE concentrations in shallow groundwater. The concentrations at these sites are approximately an order of magnitude higher than TCE concentrations reported south of East Hennepin Avenue at the Site and in the Central Area. In addition, TCE was detected in soil samples collected in the vadose zone (soil above groundwater) on the Anne Gendein Trust Property (Peer, 2001).

The Scott-Atwater Manufacturing Company, manufacturers of outboard marine motors, operated in the Northeast Area from 1938 to approximately 1966. During this time, the Scott-Atwater Manufacturing Company property included what later became the Anne Gendein Trust Property, Lend Lease Trucking, and Sears properties. It started as a small tool making and punch press operation and became the second largest outboard boat motor manufacturer in the U.S. in 1941. A 1952 fire insurance map identified two paint spray booths at the Scott-Atwater facility. Manufactured metal parts typically required cleaning prior to painting, which was likely done using TCE (Mercer, 2014). Disposal practices at the Scott-Atwater facility are unknown. Historic aerial photos identified possible disposal areas on properties in the Northeast Area that Scott-Atwater acquired circa 1953. These disposal areas may have been used for waste disposal as early as the 1930s, based on the presence of dirt roads leading from the Scott-Atwater facilities to the possible disposal areas (Peer, 2001; Mercer, 2014). The potential sources of TCE in the Northeast Area are based in part on historical aerial imagery and fire insurance maps included in Appendix A.

Frank's Auto Repair operated as an automotive repair facility for more than 40 years at 2314 East Hennepin Avenue (Thatcher, 2009). TCE concentrations were reported in soil samples collected from four out of five borings completed by Thatcher in 2009. Thatcher concluded it appeared likely that products had been either improperly stored or dumped in the small gravel area on the west side of the Frank's building.

In addition to the TCE groundwater concentrations identified above, a review of various references including city directories, fire insurance maps, and regulatory database reports identified the locations listed below as potential solvent users and possible sources of additional TCE releases in the Northeast Area. The approximate locations of these additional potential solvent sources are shown on Figure 4.

Site Name	Address	Reference
Twin City Plating	641 Hoover St NE	Regulatory database report (LUST 7105, VP 4330)
Excel Metal Finishing Inc.	2501/2503 Winter St NE	Regulatory database report
Glidden Paint	1901 Hennepin Ave E	City directory
Minneapolis Casket Company	2125 E Hennepin Ave	City directory

2.2.3 Central Area

The Central Area includes primarily residential properties and some commercial and industrial properties generally within the Soil Gas Monitoring Area and is located down-gradient from the Northeast Area. Based on features identified on an 1867 plat map, it appears the Central Area was first developed between 1867 and 1896 (Kestrel, 2006). Land use in the Central Area has not changed significantly over the past 75 years.

A review of various resources including city directories, fire insurance maps, and regulatory database reports identified the locations listed below as potential solvent users and potential releases within the Central Area. The approximate locations of these sites are shown on Figure 4.

Site Name	Address	Reference
Pitcher Mfg Co./United Chemical	21st Ave SE & Como Ave SE	Fire Insurance Map
Amar's Auto Service	2101 Como Ave SE	City directory, Fire Insurance Map
Bowen Products	983 17th Ave SE	Fire Insurance Map
Stahl Mfg/M&M Wire Clamp Co.	983 17th Ave SE	Fire Insurance Map
Joe's Market (former dry cleaner)	1820 Como Ave SE	City directory, property inspection, interview with owner, historical reference
Joe Baker's Auto	1721 Como Ave SE	Regulatory report

As with most residential neighborhoods of this size and history, various commercial services have existed over time in the neighborhood to meet the needs of the area. Typical commercial services include grocery stores, dry cleaners, automotive repair shops, gasoline stations, and restaurants. The occupants and services provided in many of the buildings have changed over time. Joe's Market is an example of a property where use has evolved and changed over the years. From at least the 1950s to the late 1980s, it operated as a dry cleaner and remains a laundromat today. In 2014, three one-gallon containers of Zep Top Solv liquid solvent degreaser (90-100% TCE by weight) were present in the basement of the building during the sub-slab soil gas sampling work. As another example, operations at the property at the northeast corner of 21st Avenue SE and Como Avenue included a gas station, auto repair, and various industrial operations. Additional consumer products containing various solvents were observed in several properties within the Central Area during the sub-slab soil gas sampling work.

2.2.4 Southwest Area

The Southwest Area is hydraulically down-gradient from the Soil Gas Monitoring Area. The Southwest Area includes a railroad corridor south of Elm Street SE that has been present since at least 1892, based on a review of fire insurance maps. Commercial and industrial properties have been present on either side of the rail corridor since at least 1912. The area includes a mix of multi- and single- unit student housing, private residences, Van Cleve Park and recreation center, and commercial businesses such as Gorshe Auto Repair. Van Cleve Park is located north of the rail corridor. Residential properties are located to the southwest of the commercial and industrial properties that are present on either side of the rail corridor.

A review of various sources, including city directories, fire insurance maps, and regulatory database reports, identified the locations listed below as potential solvent users or properties with documented TCE in groundwater within the Southwest Area; the approximate locations of these sites are shown on Figure 4.

Site Name	Address	Reference
Kozebar Co./Cozy Baby Carriage Co.	910 13th Ave SE	Fire Insurance Map
Jewel Coal Company	1410 Rollins Ave SE	City Directory
Unnamed Repair Shop	15th Ave SE & Rollins Ave SE	Fire Insurance Map
Cargill / International Sugar	820 / 830 15th Ave Se	Fire Insurance Map
Warner MFG Co.	801 16th Ave Se	Fire Insurance Map
CNW East Minneapolis Yard	2000 East Elm St	Regulatory database report (VP5812, VP5810, VP5811, LUST1671)
MN Tank Co.	8th St SE and 15th Ave SE	Fire Insurance Map
Gorshe Auto Repair	800 14th Ave SE	Regulatory report
Shop & Storage	8th St SE and 15th Ave SE	Fire Insurance Map
Postcard Builder	815 14th Ave SE	MPCA file review (VP30090)
15th Street Student Housing	700 Block between 14th Ave SE and 15th Ave SE	MPCA file review (VP30330)

Consumer products containing various solvents, specifically Zep 45 penetrating lubricant (30-60% TCE by weight) and Zep Erase graffiti remover (40-50% PCE by weight), were observed in buildings in the Southwest Area during the recent sub-slab soil gas sampling work.

2.3 Utilities

The City of Minneapolis provides water, sanitary sewer, and storm sewer services to the Study Area. During the development of the Work Plan, subsurface utilities corridors, including water, sanitary sewer, and storm sewer lines, were evaluated for potential preferential pathways for vapor migration. Extensive well surveys of the surrounding area have not identified wells used for drinking water or other purposes (Barr, 1997; Barr, 2013a). Vapor migration through preferential pathways can occur via natural and man-made pathways in the subsurface (e.g., buried lines) that provide an enhanced (more direct) transmission route from a source to a receptor. Preferential migration through utility bedding and backfill was determined to be unlikely since these materials are similar to the native sandy soils. In addition, no preferential pathways were identified based on the results of the sub-slab soil gas sampling performed throughout the Study Area.

3.0 VI Pathway Investigation

This section describes the investigation and sampling activities completed in accordance with the Work Plan. Additions and minor deviations from the Work Plan are described in Section 3.6. Investigation and sampling activities were conducted between October 13, 2014, and March 12, 2015.

3.1 Investigation Activities

A total of 18 borings for investigation purposes and 56 pilot borings were installed as part of this investigation and included:

- A total of 12 investigation borings (DP-060 to DP-071), three pilot borings for vapor monitoring ports (SVP1, SVP2, SVP30), and three pilot borings for monitoring wells (SMW1, 308, and 311) advanced at the Site.

- A total of five investigation borings (DP-072 to DP-076) and eight pilot borings for monitoring wells (301, 302, 303, 304, 305, 306, 307, and 310) advanced in the Northeast Area.

- A total of 27 investigation borings for vapor monitoring points (SVP3 to SVP29) and 12 pilot borings for monitoring wells (309, 312, 313, 314, 315, SMW3, SMW6, SMW10, SMW16, SMW19, SMW22, and SMW25) advanced in the Central Area. The Central Area includes the monitoring wells and vapor monitoring ports that comprise the sentinel monitoring network.

- One investigation boring (DP-077) and three pilot borings for monitoring wells (316, 317, and 318) advanced in the Southwest Area.

A summary of soil boring information including locations, depths, and field screening information is provided in Table 1. Investigation locations completed as part of the VI pathway investigation are shown on Figure 5. The previous and new investigation locations in the Study Area are shown on Figure 6 and for the Site on Figure 7.

Encroachment and right-of-way access permits were secured from the City of Minneapolis for the installation of permanent monitoring wells and vapor monitoring ports. Right-of-way access permits were secured from the City of Minneapolis for direct-push drilling activities including temporary well, temporary soil gas, and soil boring installation.

Temporary wells were installed at the investigation boring locations for the purpose of collecting groundwater and/or soil gas samples. Following groundwater sample collection, the temporary wells were removed, and the soil borings were sealed in accordance with MDH requirements. Soil boring logs and MDH Well and Boring Sealing Records are in Appendix B.

Pilot borings and wells were installed using a combination of direct-push and hollow-stem auger methods to sample and log soils and verify planned monitoring well screen intervals. Permanent monitoring well and/or soil vapor monitoring point installation generally occurred after the pilot borings were completed.

Temporary wells were installed at four pilot boring (301, 303, 304, and 305) locations for the purpose of collecting groundwater samples prior to permanent monitoring well installation. Soil gas samples were collected from temporary sampling ports placed in borings adjacent to wells 313, 314 and 315, following the installation of the permanent monitoring wells.

A total of 38 permanent monitoring wells were installed during this investigation for the purpose of collecting groundwater samples from the glacial drift and sentinel monitoring networks. The glacial drift groundwater monitoring network consists of 30 new wells (the 300 series wells) and 13 previously existing glacial drift monitoring and pump-out wells (2, 109, 110, 111, 112, 113, B, Q, S, T, V, W, and X). The sentinel monitoring network consists of eight new wells (SMW series) and five wells from the glacial drift groundwater monitoring network (wells 309GS, 312GS, 111, 112, and 113). Nested wells were installed at 12 of the 38 glacial drift monitoring well locations with one well screened at the water table and one screened at the base of the glacial drift.

Wells were installed by a licensed well contractor and were constructed in accordance with MDH well code. Monitoring well construction details are in Table 2 and on the boring logs in Appendix B. The wells were developed a minimum of three days after the wells were installed by a combination of surging and pumping to remove fines from the well screen. Well stabilization forms are in Appendix B.

A total of 30 vapor monitoring ports were installed for the purpose of collecting soil gas samples from the sentinel monitoring network. The vapor monitoring port construction details are in Table 3 and Appendix B.

3.2 Sampling Activities

Soil, groundwater, and soil gas samples were collected for laboratory analysis in general accordance with the Work Plan. Laboratory analytical services were provided by Pace Analytical of Minneapolis, Minnesota (Pace) in accordance with the *Quality Assurance Project Plan* (QAPP; Barr, 2014f). Soil and groundwater samples were analyzed for VOCs using EPA Method 8260. Soil gas samples were analyzed for the Minnesota Soil Gas List using EPA Method TO-15. Laboratory reports are included in Appendix C. The data quality assurance/quality control review is in Appendix D.

3.2.1 Field Screening

Soil at soil borings was continuously sampled for geologic characterization and field screened for organic vapors with a photoionization detector (PID) equipped with an 11.7-eV lamp. Soil samples were screened using the visual-manual procedures of ASTM Standard D2488 for guidance, which is based on the Unified Soil Classification System. Soil sampling was not completed at two investigation locations. Soil vapor port SVP1 and monitoring well nest 306 were constructed based on the lithology observed at borings SMW1 and DP-072, respectively, based on their proximity to these locations.

Field screening results from soil samples collected in the vadose zone included:

- At the Site, no elevated headspace readings (above background of two parts per million [ppm]) were measured in samples from six borings (DP-060, DP-062, DP-063, DP-066, SMW1, and SVP6). A sheen was observed in samples from boring 311 from a depth of 10 to 20 feet bgs and boring DP-061 from 5 to 7 feet bgs. Headspace readings were above background in samples from 11 borings (DP-061, DP-064, DP-065, DP-067, DP-068, DP-069, DP-070, DP-071, 308, 311, and SVP2) with readings ranging from 2.1 to 1,733 ppm.

- In the Northeast Area, no elevated headspace readings were measured in samples from nine borings (DP-072, DP-076, 301, 302, 303, 304, 305, 307, and 310). A sheen was observed in samples from boring 310 at the soil/groundwater interface. Headspace readings were measured above background in samples from three borings (DP-073, DP-074, and DP-075) with readings ranging from 2.7 to 6.1 ppm.

- In the Central Area, no elevated headspace readings were measured in the samples from 39 borings. A sheen was observed in samples from borings SVP26 from a depth of 6 to 9 feet bgs but no headspace readings were above background at that location (i.e., 2.0 ppm).

- In the Southwest Area, no elevated headspace readings were measured in any of the samples from the borings.

Field screening results for samples from below the groundwater table included:

- At the Site, no elevated headspace readings were measured in samples from eight borings (DP-060, DP-061, DP-062, DP-068, DP-069, SVP2, SVP30, and SMW1). Sheen was observed in soil samples from borings DP-070 from a depth of 18 to 22 feet bgs and 311 from a depth of 20 to 25 feet bgs. Headspace readings were measured above background in samples from nine borings (DP-063, DP-064, DP-065, DP-066, DP-067, DP-070, DP-071, 308, and 311) with readings ranging from 2.1 to 1,352 ppm.

- In the Northeast Area, no elevated headspace readings were measured in samples from three borings (302, 307, and 310). Sheen was observed in soil samples from boring 310 at depths of 26 to 28 feet bgs and 30 to 32 feet bgs. Headspace readings were measured above background in samples from nine borings (DP-072, DP-073, DP-074, DP-075, DP-076, 301, 303, 304, and 305) with readings ranging from 2.1 to 48.9 ppm.

- In the Central Area, no elevated headspace readings were measured in samples from 30 borings (312, SMW10, SMW19, and SVP3 to SVP29). Headspace readings were measured above background in soil samples from nine borings (309, 313, 314, 315, SMW3, SMW6, SMW16, SMW22, and SMW25) with readings ranging from 2.2 to 48.9 ppm. No sheen was observed in saturated soil samples from borings in the Central Area.

- In the Southwest Area, no elevated headspace readings were measured above background and no sheen was observed in the soil samples from the four borings placed in this area.

3.2.2 Soil Samples

A total of 23 discrete soil samples were collected from 18 borings installed at the Site and in the Northeast and Central Areas. A summary of soil samples collected is in Table 4.

A total of 13 soil samples were collected from locations in the vadose zone and included:

- Nine soil samples from the Site where headspace readings were above background and one soil sample where elevated headspace readings and sheen were observed.
- Two soil samples from the Northeast Area where headspace readings were above background.
- One soil sample from the Central Area where a light sheen was observed.

Ten soil samples were collected from locations below the water table where headspace readings were above background and included:

- Two soil samples at the Site from the glacial till unit underlying the glacial drift.
- Three glacial drift samples from the Northeast Area.
- Five soil samples from the Central Area in the glacial till layer.

No discolored soil, odors, sheens, or elevated headspace readings were observed in samples from borings placed in the Southwest Area; therefore, no soil samples were collected for chemical analysis. Soil sample analytical results are presented in Table 5 and TCE results are shown on Figure 8.

3.2.3 Groundwater Samples

A total of 51 groundwater samples were collected from temporary wells installed in selected borings at the Site and in the Northeast and Southwest Areas. Groundwater samples were collected at the water table and at the base of the glacial drift from temporary wells. In some cases, a third sample was collected based on field screening results. A summary of the groundwater sampling is provided below:

- Groundwater samples were collected from temporary wells installed in 12 investigation borings (DP-060 to DP-071) at the Site.

- Groundwater samples were collected from temporary wells installed in five investigation borings (DP-072 to DP-076) and four pilot borings (301, 303, 304, and 305) in the Northeast Area.

- Groundwater samples were collected from temporary wells installed in boring DP-077 in the Southwest Area.

A total of 102 groundwater samples were collected from permanent monitoring wells in the Study Area. This included sampling at existing wells and at wells installed as part of this investigation. Groundwater samples were collected from each monitoring well in December 2014 and March 2015. A summary of the groundwater sampling is provided in Table 6 and included:

- At the Site, groundwater samples were collected from five monitoring wells installed during this investigation (308GS, 308GD, 311GS, 311GD, and SMW1) and two existing monitoring wells (109 and B).
- In the Northeast Area, groundwater samples were collected from 12 monitoring wells installed during this investigation (301GS, 301GD, 302GS, 303GS, 304GS, 305GS, 305GD, 306GS, 306GD, 307GS, 307GD, and 310GS).
- In the Central Area, groundwater samples were collected from 17 monitoring wells installed during this investigation (309GS, 309GD, 312GS, 312GD, 313GS, 313GD, 314GS, 314GD, 315GS, 315GD, SMW3, SMW6, SMW10, SMW16, SMW19, SMW22, and SMW25) and nine existing monitoring wells (2, 110, 111, 112, 113, Q, S, T, and X).
- In the Southwest Area, groundwater samples were collected from four monitoring wells installed during this investigation (316GS, 316GD, 317GS, and 318GS) and two existing monitoring wells (V and W).

Temporary and permanent monitoring well groundwater analytical results are presented in Tables 7 and 8, respectively, and are shown on Figures 9 and 10, respectively. Temporary well groundwater sample TCE results from previous investigations in 2012, 2013, and 2014 are shown on Figure 11.

Groundwater elevations were measured at each well in the monitoring network during the December 2014 and March 2015 sampling events and the results for each event are in Table 9.

3.2.4 Soil Gas Samples

Five soil gas samples were collected from temporary vapor ports installed in soil borings and 60 soil gas samples were collected from permanent vapor monitoring ports at the Site and in the Central Area. Soil gas samples were collected from each permanent vapor port in December 2014 and March 2015. Soil gas sampling included:

- At the Site, soil gas samples were collected from two temporary vapor ports (DP-070, DP-071) and three permanent vapor ports (SVP1, SVP2, SVP30).
- In the Central Area, soil gas samples were collected from three temporary vapor ports (313, 314, and 315) and 27 permanent vapor ports (SVP3 to SVP29).

Soil gas results are presented in Table 10 and shown on Figure 12. Soil gas results and groundwater sampling TCE results for the Southwest Area are shown on Figure 13.

3.3 Analytical Quality Control Summary

Quality control data were reviewed to assess the integrity and validity of the analytical data obtained from the analyses of the soil, groundwater, and soil gas samples collected as part of the VI pathway investigation.

The analytical data were reviewed in accordance with Barr's data validation standard operating procedures (SOPs) which are based on the U.S. EPA Contract Laboratory Program National Functional Guidelines for Organic and Inorganic Data Review and in general accordance with U.S. EPA Methods 8260 and TO-15 as specified in the QAPP (Barr, 2014f).

Barr performed full data validation on at least 10% of the data packages as described in the QAPP. The data validation occurred in a timely manner as described in the QAPP.

In general, the areas covered by the validation process included:

- Holding times, preservation and storage
- Blank sample analysis
- Accuracy data
- Precision data

Overall, the quality control information collected for this investigation demonstrated compliance with the project's data quality objectives as measured by the quality control samples. The data reported by the laboratory are considered useable subject to the data qualifiers assigned during the data evaluation process. The details of the analytical quality control review are provided in Appendix D.

3.4 Other Activities

The following other activities were completed during implementation of the Work Plan.

3.4.1 Investigation-Derived Waste Disposal

Soil cuttings generated from the investigation activities were either thin-spread at the Site or containerized in poly-lined roll-off containers, as described in the Work Plan. A waste characterization sample was collected and analyzed and the results were submitted for approval to the Vonco II Landfill in Becker, Minnesota. The soil profile was accepted by the landfill and three roll-off containers (approximately 30 cubic yards of soil) were disposed in accordance with federal, state, and local regulations. Investigation-derived waste disposal documentation is provided in Appendix E.

Well development water and water used for decontamination of equipment was containerized in a portable tank. A waste characterization sample was collected and analyzed and the laboratory results were submitted to Metropolitan Council Environmental Services (MCES). A special discharge permit (#3325) was approved in a letter dated November 25, 2014, and is provided in Appendix E. Approximately 5,100 gallons of water were disposed at the Metropolitan Liquid Waste Receiving Facility under this permit.

3.4.2 Surveying

Soil boring, monitoring well and vapor monitoring port locations were surveyed in the field using Real-Time Kinematic (RTK) Global Positioning System (GPS) methods. The survey information for each soil boring location is summarized in Table 1. In addition, the elevation of the top of riser and the ground elevation for each well and vapor monitoring port were measured to the nearest 0.01 foot above mean sea level (MSL) using typical survey methods and is summarized in Tables 2 and 3, respectively. The NGVD29 vertical datum was used.

Previously existing wells were surveyed using the vertical datum NGVD88. To maintain consistency, all older wells that are part of the glacial drift monitoring network were resurveyed using vertical datum NGVD29. For this reason, some data tables in previous reports may indicate slightly different reference elevations, typically within plus or minus 0.2 feet.

3.5 Safety

The safety goal for the VI pathway investigation was zero incidents. This goal was accomplished through careful planning and implementation of the work. Work was performed in accordance with the Project Health and Safety Plan (PHASP, Barr 2014g). All workers on the project were required to read and sign the PHASP prior to starting work. The PHASP was maintained at the work area whenever work was occurring. A Field Risk Assessment Form was completed prior to commencing work. General Mills and appropriate property owners were notified before work began. Safety tailgate meetings were conducted prior to the start of work each day and contractors were required to have an orientation to familiarize their workers with the work areas and daily safety meetings. The buddy system was implemented at all times for this work.

3.6 Additions and Deviations from Work Plan

Investigation and sampling activities were conducted in general accordance with the Work Plan except for the additions and minor deviations listed below. None of the additions or deviations had a negative impact on the investigation results.

- Pilot borings were advanced to bedrock prior to installing wells and soil vapor monitoring ports to more fully characterize the geology in the Study Area. Where the pilot boring extended 10 feet deeper than the bottom of the well, the borehole was grouted to the well depth.

- A total of six additional direct-push soil borings were completed outside of the scope of work described in the Work Plan. Five borings (DP-072 to DP-076) were installed on the east side of 23rd Avenue SE, just south of East Hennepin Avenue, to help determine the location of monitoring well nest 306GS/GD. One boring (DP-077) was placed on the Van Cleve Park property to help determine the location of monitoring well nest 316GS/GD.

- A third well was considered for installation in the glacial till underlying the glacial drift at the location of well nest 311GS/GD, at the former disposal area. MPCA and Barr jointly determined that the installation of a third well was not necessary or technically practical as the glacial till would likely not produce water and no evidence of impacts (discoloration, odor, sheen, organic vapors) was observed in soil samples from pilot boring 311.

- Soil gas samples were collected from the locations of wells 313, 314 and 315 after the permanent monitoring wells were installed, rather than prior to installing the pilot borings as described in the Work Plan.

4.0 Physical Setting

This section summarizes the surface topography and surface water features, geology, and hydrogeology of the Study Area based on information generated during the VI pathway and previous investigations.

4.1 Surface Topography and Surface-Water Features

The surface elevation of the Study Area is approximately 885 feet above MSL in the Northeast Area and slopes to the southwest to approximately 830 feet above MSL in the Southwest Area. The Mississippi River is the nearest surface water feature and is located approximately three-fourths of a mile to the southwest of the Study Area. The surface water elevation of the Mississippi River at that location is approximately 725 feet above MSL. Surface water features and topography have not significantly changed since the area was developed in the late 1800s and early 1900s (HIG, 2014c).

4.2 Geology and Hydrogeology

The uppermost stratigraphic units within the Study Area consist of primarily sand, underlain by clay (glacial till) and bedrock (primarily Decorah Shale). Fill and in some cases peat overlie the sandy materials. Geologic cross sections across the Study Area are shown on Figures 14 and 15. The geology and hydrogeology data collected for this investigation focused on the glacial deposits. Borings completed as part of this investigation were advanced to the top of the uppermost bedrock surface. The bedrock topography and uppermost bedrock unit were updated as part of this investigation and are shown on Figure 16. Descriptions of bedrock geology are summarized from previous investigations.

4.2.1 Glacial Deposits

Glacial deposits in the Study Area generally consist of between 12 (boring DP-033) to 80 feet (well 201) of heterogeneous fine- to medium-grained sand, with lesser amounts of coarse sand and gravelly sand. The sand and gravel are associated with glacial outwash in the Northeast Area and glacial-fluvial terrace deposits in the Central and Southwest Areas. In some locations, the sand and gravel deposits are overlain by up to 20 feet of fill or peat. A discontinuous glacial till is present below the sand and gravel and above the underlying bedrock within portions of the Study Area. The thickness of the glacial till is generally 5 to 15 feet (where present). In some areas, for example in the area immediately southwest of the intersection of 17th Avenue SE and Rollins Avenue SE, the glacial till is greater than 20 feet thick. The glacial till is generally absent in the Northeast Area. The glacial outwash and terrace deposits have collectively been referred to as the "glacial drift" in historic reports and that nomenclature is used in this report for consistency.

Groundwater flow within the glacial drift is primarily through the sand and gravel deposits. The water table occurs primarily within the sand and gravel deposits at depths ranging from approximately 10 to 25 feet bgs within the Study Area (Table 9). The base of the glacial drift, either the top of the glacial till (where present) or the top of the uppermost bedrock, is shown on Figure 17. Based on over 70 groundwater level monitoring events over the last 30 years, the regional horizontal groundwater flow direction in the glacial drift across the Study Area has been consistently to the southwest, both during and following operation of the pump-out wells (Barr, 2013b), with little to no seasonal variation. Water table contours interpreted from measured water levels in December 2014 and February 2015 are shown on Figures 18 and 19, respectively. No appreciable differences in water levels or flow directions are noted between measurement dates. Hydrographs of water level data from the glacial drift monitoring wells show stable water level trends (Barr, 2013b).

Local variations in groundwater flow direction are influenced by changes in the saturated thickness of the glacial drift. Figure 20 shows the saturated thickness of the glacial drift based on the distance between the water table elevation (from February 2015, Figure 19) and the top of the glacial till (where present) or the top of the uppermost bedrock (Figure 17). Localized changes in flow direction interpreted from water table contours (Figures 18 and 19) show a strong correlation with changes in saturated thickness. Groundwater flows around areas of reduced saturated thickness (reduced transmissivity) or flows toward areas of increased saturated thickness (increased transmissivity). This is most evident on Figures 18 and 19 near 24th Avenue SE and Talmage Ave SE; at the 2010 East Hennepin property; and at Rollins Avenue and 17th Avenue SE. Local changes in flow direction are also possible due to areas of lower or higher hydraulic conductivity within the glacial drift.

Local flow variations within the glacial drift influence the transport of impacted groundwater from potential source areas in the Northeast to the Central Area and Site. Transport of groundwater may also be influenced by preferential flow through areas of higher hydraulic conductivity within the glacial drift at scales smaller than the monitoring well network used in this study are able to address. Other transport mechanisms such as diffusion, dispersion, and retardation can also affect the transport and distribution of contaminants in the glacial drift.

The hydraulic conductivity of the glacial drift was estimated to be 2×10^{-3} centimeters per second (cm/sec) based on a pumping test conducted at pump-out well 109 in 1985 (Barr, 1985). Horizontal hydraulic gradients in the glacial drift range from 0.0023 feet per feet (ft/ft) to 0.018 ft/ft within the Study Area based on the water levels measured during the VI pathway investigation. Variations in groundwater flow velocity across the Study Area would be expected based on the heterogeneity of the glacial deposits.

Potentiometric head differences between the glacial drift and wells completed in the underlying bedrock indicate that, where present, the glacial till and/or the Decorah Shale acts as a confining unit, restricting vertical groundwater flow between the glacial drift and lower bedrock units (Barr, 1983; Runkel et al., 2003). Hydraulic heads in the glacial drift are typically 5 to 15 feet higher than in the upper bedrock units below the Decorah Shale. Runkel and others recognize that the Decorah Shale is an effective confining bed, even in shallow bedrock conditions. They estimate that the bulk vertical hydraulic conductivity of the Decorah Shale ranges between 10^{-5} and 10^{-4} meters per day (m/day).

4.2.2 Bedrock

The depth to bedrock ranges from 35 to 80 feet bgs in the Study Area. The Decorah Shale is the uppermost bedrock unit over most of the Study Area. The unit varies in thickness from zero to 35 feet and is divided into two members: an upper unnamed member and the lower Carimona Member (Mossler, 2008; Mossler, 2013). The upper member is primarily a fossiliferous shale and is generally about four feet thick in the Study Area. The lower Carimona Member is a thin-bedded limestone with interbedded shale and is generally four to seven feet thick in the Study Area. A thin, two- to five-inch thick bentonite bed is typically present near the base of the Carimona Member (Barr, 1983).

A bedrock valley is present in the Central and Southwest Areas, where a change in bedrock elevation of approximately 20 feet is interpreted to be present (Figure 16). Bedrock elevations along the axis of the bedrock valley are at approximately 800 feet above MSL and bedrock elevations in the Northeast Area are greater than 820 feet above MSL.

The underlying Platteville Formation consists of the Magnolia, Hidden Falls, Mifflin, and Pecatonica members (Barr, 1983; Mossler, 2008), which have a combined thickness of about 23 feet in the Study Area. The Platteville Formation is generally comprised of limestone and is both an aquifer and an aquitard (Anderson et al., 2011; Runkel et al., 2011).

Below the Platteville is the remaining sequence of bedrock units including the Glenwood Formation, St. Peter Sandstone, Prairie du Chien Group, Jordan Sandstone, St. Lawrence Formation, Tunney City Group, Wonewoc Sandstone, Eau Claire Formation, and Mt. Simon Sandstone (Mossler, 2008; Mossler 2013).

5.0 Discussion

This section summarizes and discusses the results of the VI pathway investigation at the Site and in the Northeast, Central, and Southwest Areas. TCE is the primary constituent of concern as identified in RAP Modification #1. This section discusses VOC results at the Site and primarily TCE results in the other portions of the Study Area.

5.1 Geology and Hydrogeology

Glacial drift in the Study Area generally consists of heterogeneous fine- to medium-grained sand, with lesser amounts of coarse sand and gravelly sand. The glacial drift is underlain by discontinuous glacial till and/or shale at the Site and portions of the Study Area which together act as a confining unit. Across the entire Study Area, hydraulic gradients and groundwater flow direction within the glacial drift are influenced by the geometry and saturated thickness of the unit, which are defined by the water table above and top of glacial till and/or bedrock below. Groundwater flow is consistently to the southwest, with little to no seasonal variation. Minor local variations in flow direction exist in each of the areas, as expected, based on the variable geometry and saturated thickness of the glacial drift, variations in hydraulic conductivity, and the size of the Study Area.

5.2 Site – 2010 East Hennepin Avenue Property

The results of extensive sampling at the Site show no evidence of dense nonaqueous phase liquid (DNAPL) or TCE source material in soil at the Site. The Site is not an ongoing source of TCE to groundwater that would contribute to the potential vapor intrusion pathway in the Study Area. The magnitude of TCE concentrations in groundwater that flows into the Central Area and the Site from the Northeast Area demonstrate that the Site is impacted by up-gradient sources.

As discussed in Section 2.0, buildings on the Site historically have been used for a variety of activities, including laboratories, pilot plants, offices, and other commercial uses. Exterior areas near Buildings 10, 11, 12, and 14, the western exterior storage area, and the former disposal area were further evaluated as a part of the VI Pathway investigation. Numerous soil, groundwater, sub-slab soil gas, and indoor air samples have been collected at the Site during this and previous phases of investigations between 2012 and 2014. Groundwater samples have been collected from the network of seven active glacial drift wells, 24 soil samples have been collected from borings, and 104 sub-slab soil gas and 23 indoor air samples have been collected from the 13 buildings. The results of these investigations are discussed below.

5.2.1 Buildings 10, 11, 12, and 14

As described below, a completed VI pathway does not exist at Buildings 10, 11, 12, and 14, based on the indoor air sampling results at these buildings. In addition, the lack of elevated TCE concentrations in soil from the vadose zone and groundwater at the water table support that the risks are sufficiently low and that no additional action with regard to soil, groundwater, or soil gas is necessary in this area.

Exterior areas adjacent to Buildings 10, 11, 12, and 14 were targeted for investigation based on elevated TCE concentrations in sub-slab soil gas below these buildings. Eight investigation soil borings were installed in this area. The indoor air results, coupled with the VI pathway investigation data demonstrate that the vapor intrusion pathway is incomplete. The soil, groundwater, soil gas, and indoor air results from this and previous Barr investigations near these buildings are highlighted below:

- No VOCs were detected above the laboratory reporting limits in soil samples collected from the vadose zone around Buildings 10, 11, 12 and 14. TCE was detected in only two soil samples collected from below the water table in boring DP-066. Boring DP-066 is located at the south end of Building 14 and TCE concentrations in soil samples from this boring were 1,290 and 2,080 µg/kg at 44 feet and 52.5 feet bgs, respectively.
- Groundwater TCE concentrations at the water table ranged from 9.6 µg/L at boring DP-060 to 149 µg/L at boring DP-064. Boring DP-064 is located east of Building 14.
- Sub-slab soil gas and indoor air sampling was conducted at these four buildings (Barr, 2015b). Sub-slab soil gas TCE measurements ranged from 5.7 to 3,320 µg/m^3 and were highest beneath Building 12. Indoor air sampling results from two rounds of sampling conducted in Buildings 11, 12, and 14 and one round of sampling in Building 10 were all below the applicable ISVs, with the exception of methylene chloride, which was attributed to lab contamination, and naphthalene, which exceeded the ISV in a field duplicate but not in the original sample (Barr, 2015a; Barr, 2015b).

5.2.2 Western Exterior Storage Area

Low concentrations of VOCs in soil and groundwater and limited soil gas impacts support that the Western Exterior Storage Area is not a source for vapor intrusion to Site buildings or residential properties in the Central Area. TCE was not detected above the applicable 10xISV in soil gas in and around this area (Buildings 1, 2, 9 and 15) demonstrating that the VI pathway from the low-level impacts in the Western Exterior Storage Area is incomplete. Therefore, no additional action with regard to soil, groundwater, or soil gas is necessary at the Western Exterior Storage Area.

Historical land use in the Western Exterior Storage Area included the former presence of Building 13, and chemical and drum storage as documented in photographs taken during Henkel's ownership and operation of the property. Four investigative borings were placed in this area. Boring DP-068 targeted a former solvent storage area, boring DP-069 targeted former Building 13, and borings DP-070 and DP-071 targeted a former drum storage area near an existing concrete pad. The soil, groundwater, and soil gas results from investigating this area are summarized below:

- No VOCs were detected above the reporting limits in soil from these borings, with the exception of chlorobenzene at a concentration of 4,420 µg/kg in boring DP-068 at 12 feet bgs near the former drum storage area.

- Although elevated organic vapor readings were measured at borings DP-070 and DP-071 (171 to 1,226 ppm) at the soil/groundwater interface, no TCE was detected in groundwater collected from these borings. Laboratory results showed only minor amounts of petroleum constituents and other VOCs, including 1,1,2-trichloroethane, 1,1-dichloroethane, and methyl isobutyl ketone in groundwater samples from these borings.

- Only low TCE concentrations were detected in groundwater samples from borings DP-068 and DP-069. In boring DP-068, TCE was detected at 0.42 µg/L at the water table and at 4.6 µg/L at 36 to 38 feet bgs. In boring DP-069, TCE was detected at 0.41 µg/L at 33 to 35 feet bgs. Other VOCs were not detected with the exception of 1,1,1- trichloroethane at concentrations ranging from less than detection limits to 4.4 µg/L at both locations and chloroform at 2.2 µg/L at boring DP-068 at the water table.

- 1,2-Dichloroethane (1,2-DCA) was the only constituent detected in soil gas at concentrations that exceeded 10x the industrial ISV at borings DP-070 and DP-071. 1,2-DCA was not detected in groundwater. Concentrations of VOCs did not exceed 10x the industrial ISVs in sub-slab soil gas samples collected from nearby Buildings 1, 2, 9 and 15 (Building 6 had a limited access crawl space and was not sampled) and in soil gas samples collected from nearby vapor port SVP-2. In addition, concentrations of VOCs in soil vapor ports SVP-3 and SVP-4, immediately down-gradient of the Western Exterior Storage Area, did not exceed 10x the residential ISV for 1,2-DCA.

5.2.3 Former Disposal Area

Data gathered in the Former Disposal Area Investigation (Barr, 2014c) and this investigation showed no evidence of DNAPL or TCE source material in soil at the former disposal area. Multiple investigations have been conducted in and near the former disposal area since the early 1980s to characterize soil and groundwater conditions, including more than 20 soil borings and seven glacial drift wells. This extensive data set in this limited area demonstrates that there is no evidence of source material that would act as an ongoing TCE source to groundwater in the Study Area.

As part of the VI Pathway investigation, historical information was used to place well nest 311GS/GD at the location of the former disposal area drums. During installation of the 311 pilot boring, the maximum organic vapor reading (1,733 ppm) was at the soil/groundwater interface (approximately 20 feet bgs). Elevated concentrations of VOCs, primarily associated with petroleum hydrocarbons, were detected in a soil sample collected from the boring at 17.5 feet bgs. Notably, no TCE was detected in this sample. This is consistent with and confirms the results of the Former Disposal Area Investigation (Barr, 2014c). During that investigation, no cVOCs were detected in the vadose zone from four soil samples collected in the former disposal area (DP-054 through DP-057).

The soil, groundwater, and soil gas results from the VI pathway investigation, the Former Disposal Area Investigation, and sub-slab sampling activities at and near the former disposal area are summarized below:

- No TCE was detected in vadose zone soil samples collected from five borings placed in the vicinity of the former disposal area. Only low TCE concentrations (near the laboratory reporting limit) were measured in saturated zone soil samples collected from the top of the confining glacial till layer during the Former Disposal Area Investigation (Barr, 2014c). TCE was detected at less than 1 mg/kg in the soil sample collected directly above the Decorah Shale at boring DP-056.
- A TCE concentration of 172 µg/L was measured in the glacial drift groundwater at the former disposal area (well 311GD). This is more than an order of magnitude lower than the highest TCE measured in the Northeast Area at well 301GD. The highest TCE concentration in groundwater measured during the VI pathway investigation on the Site (temporary well DP-064 at a depth of 52.5 to 54.5 feet bgs at 629 µg/L) is located at the east property boundary, up-gradient of the former disposal area and down-gradient from known releases of TCE in groundwater in the Northeast Area.
- Other constituents in the glacial drift groundwater near the former disposal area include petroleum constituents, other cVOCs, and other VOCs (acetone, bromobenzene, and methyl isobutyl ketone). As described in Section 5.2.1, none of these constituents were above their applicable ISVs in the indoor air of Buildings 10, 11, 12, and 14.
- Soil gas samples were not collected from the former disposal area during the VI pathway investigation. One soil gas sample was collected at boring DP-054 from 16.4 feet bgs during the Former Disposal Area Investigation. Boring DP-054 was placed approximately four feet from well 311, which was installed at the location of the former disposal area. Although TCE was not reported in this soil gas sample, the TCE reporting limit was elevated at 4,900 µg/m^3 due to the presence of other VOCs, primarily petroleum hydrocarbons, at elevated concentrations. Vinyl chloride was reported in the soil gas sample at a concentration of 15,700 µg/m^3. However, vinyl chloride was not detected in sub-slab soil gas or indoor air samples collected from nearby buildings (Buildings 10, 11, and 14) or the tunnel connecting Buildings 11 and 14 (Barr, 2015a).
- Only low concentrations of TCE were measured in glacial till, headspace readings were less than 10 ppm, and no evidence of impacts (discoloration, odor, sheen) were observed during field observations of the glacial till layer in soil samples from pilot boring 311 and borings DP-54 through DP-57. Therefore, the occurrence of back diffusion of TCE from the glacial till is not a significant long-term source of TCE to the Study Area.

During the initial disposal area investigations in the 1980s, TCE represented only a minor percentage of the total VOCs detected in soil and groundwater samples. This is consistent with the results from the groundwater samples collected in 2014 and 2015. The concentrations of TCE in groundwater on and southwest of the Site have decreased significantly over time. Well 109 was installed in the early 1980s and was sampled in 2014 as part of the VI pathway investigation. There has been an 87% reduction in the TCE concentration in this well from the 1980s to the present. Historical TCE results over time from wells on and near the Site are shown on Figure 21.

In summary, based on the extensive investigation, no evidence of DNAPL or other source material has been found at or emanating from the Site. TCE is not detected in the unsaturated soils at the Site. Only low concentrations of TCE (less than 1 mg/kg) are reported in the soil below the water table at the Site and are not an ongoing source to groundwater at concentrations that would contribute to the VI pathway in the Study Area. TCE concentrations in groundwater at the Site are lower than at locations directly up-gradient from the Site and demonstrate that TCE from source areas in the Northeast Area has and continues to migrate into the Central Area and the Site.

5.3 Northeast Area

The Northeast Area is hydraulically up-gradient from the Site and the Central Area and the highest TCE concentrations in groundwater measured during this investigation are at the furthest up-gradient sampling location in this area (well nest 301GS/GD). The sources and the full magnitude and extent of TCE impacts in soil, groundwater, and soil gas in the Northeast Area remain undefined. TCE in groundwater flows to the southwest from the Northeast Area into the Central Area and the Site. The pattern of concentrations of TCE measured in wells in the Northeast Area, at the Site, and in the Central Area shows higher concentrations in the Northeast Area (i.e., up-gradient) and lower concentrations at the Site and in the Central Area (i.e., down-gradient). This pattern supports that these impacts are the result of releases of TCE from source areas in the Northeast Area that have and continue to migrate into the Central Area and the Site.

The Northeast Area includes a portion of the Mid-City Industrial Area and historically has been the location of manufacturing and other industrial facilities since the early 1930s. Many of these facilities likely used and may continue to use chlorinated solvents. Section 2.2 identifies several potential chlorinated solvent users and documented releases in the Northeast Area, including solvent use associated with metal fabrication and auto repair facilities (i.e., including, but not limited to, the former Scott-Atwater Manufacturing Company and Frank's Auto Repair). MPCA plans to further assess the VI pathway in the Northeast Area as part of the investigation of the Southeast Hennepin Area Groundwater and Vapor Site (SA249).

The Northeast Area was included in the VI pathway investigation based on three primary factors. First, sub-slab soil gas sampling measured elevated sub-slab TCE concentrations at locations up-gradient and side-gradient of the Site where impacts could not have been Site-related. Second, recently discovered data contained in MPCA files identified high concentrations of TCE in groundwater in the Northeast Area. Third, high TCE concentrations were measured in groundwater at locations up-gradient of the Site during investigation activities completed by Barr in early 2014 (Barr, 2014b).

Twelve permanent monitoring wells and five investigation borings were installed from which five soil and 44 groundwater samples were collected in the Northeast Area as part of this investigation. This and previous investigations identified TCE impacts in the soil, groundwater, and soil gas in the Northeast Area, including the following:

- The highest TCE soil concentrations measured within the Study Area (2,600 µg/kg) were from a sample from soil boring 301 at a depth of 42 feet bgs within the glacial drift below the water table. This boring location is the furthest up-gradient boring from the Site. Soil samples collected during previous investigations at 359 Hoover Street NE (Anne Gendein Trust Property) also detected low levels of TCE in soil samples collected above the water table.

- TCE was detected in groundwater during this and previous investigations. Similar to the soil results, the highest glacial drift groundwater TCE concentrations in the Study Area were measured at the furthest sampling location up-gradient of the Site. The highest concentration was measured at the location of deep monitoring well 301GD (4,270 µg/L). This concentration is more than an order of magnitude higher than at down-gradient monitoring well locations at the Site or in the Central Area.

- Soil gas analyzed during a previous investigation in the Northeast Area identified the highest TCE concentration in soil gas in the Study Area at soil boring DP-051 (5,330 $\mu g/m^3$) located one-half block south of monitoring well 301GD (Barr, 2014b).

Groundwater from the Northeast Area flows to the southwest into the Central Area and the Site. Investigation locations in this and previous Barr investigations were installed in the street rights-of-way; therefore, it is anticipated that TCE concentrations would be higher on the properties where releases occurred rather than in the street rights-of-way. The presence of DNAPL or other source material in the Northeast Area is unknown. The factors discussed above demonstrate that the predominant source(s) of TCE in groundwater throughout the Study Area originates up-gradient of the Site.

5.4 Central Area

The extent of groundwater impacts, potential presence of current and historical TCE sources, and extensive soil gas sampling data collected in the Central Area suggest that multiple off-Site sources of TCE have impacted groundwater in this area. In addition, as discussed in Section 5.3, TCE concentrations in the Northeast Area are an order of magnitude higher than those measured within the Central Area, and given the flow direction, impacts from the Northeast Area extend into the Central Area.

The Central Area includes primarily residential properties with some commercial and industrial properties. The geographic area of measured concentrations of TCE in glacial drift groundwater and soil gas is generally defined by the west, south, and east boundaries of the Soil Gas Monitoring Area.

TCE concentrations measured in groundwater in the Central Area were previously attributed to a release from the former disposal area at the Site. Based on the updated data set from this and previous investigations, the magnitude and extent of groundwater impacts demonstrate that multiple releases of TCE unrelated to the Site have occurred up-gradient, side-gradient, and down-gradient of the Site. For example, TCE concentrations are elevated at locations that are side- and up-gradient of the former disposal area, such as at wells SMW25 and 309GD. In addition, the width of the impacted area is inconsistent with a single source at the location of the former disposal area due to the typically low transverse contaminant dispersion in sand and gravel aquifers (Pankow and Cherry, 1996) and due to the elevated TCE impacts found side-gradient of the former disposal area.

Potential current and historical solvent users are also present in the Central Area as discussed in Section 2.2. Unlike the former disposal area, these locations have not undergone intensive investigation or remediation. General Mills, through its operation of the groundwater extraction system, has likely removed and treated groundwater impacted by other sources.

The Central Area was the focus of the sub-slab soil gas sampling and mitigation project. Over 320 properties in the Central Area were sampled during the work completed in 2013 through 2015. Based on this extensive sub-slab soil gas sampling data set, localized sources of TCE unrelated to the Site are present in the Central Area, as discussed in greater detail below.

The soil, groundwater, soil gas, and indoor air results from this and previous investigations in the Central Area are summarized below:

- Five soil samples were collected from below the water table and the highest TCE concentration (4,230 µg/kg) was at boring SMW6 at 41 feet bgs, which is the base of the glacial drift. Boring SMW6 is located north of Como Avenue SE along 19th Avenue SE.
- The highest water table TCE concentration was measured in well 314GS (498 µg/L). This well is located directly down-gradient from a former dry cleaner. Three one-gallon containers of Zep Top Solv liquid solvent degreaser (90-100% TCE by weight) were present in the basement of the former dry cleaner building during the sub-slab soil gas sampling and mitigation work.
- Sub-slab soil gas samples were collected from more than 320 properties in the Central Area (Barr, 2015b). A small cluster of properties with elevated TCE concentrations in sub-slab soil gas were identified in the area along the east side of 18th Avenue SE, south of Como Avenue SE, and north of Fairmount Avenue SE (hydraulically down-gradient from the former dry cleaner). Within this area, there were eight properties with TCE concentrations greater than 2,000 µg/m^3 in sub-slab soil gas including one property with a concentration of 15,300 µg/m^3.

The up-gradient TCE concentrations in the Northeast Area, the wide-spread distribution of the potential source areas in the Northeast Area, the extensive width of the area of impacts east of the Site, and the sub-slab soil gas data all indicate that groundwater impacts are likely due to multiple releases of TCE up-gradient and within the Central Area. The anomalously high concentrations in sub-slab soil gas immediately down-gradient of the dry cleaner described above, suggest the existence of a source in the immediate area. Groundwater impacts in the Central Area have the potential to create sub-slab soil gas TCE concentrations that warrant vapor mitigation. In the Central Area, 178 properties were mitigated through the work completed by General Mills in 2013 through 2015.

5.5 Southwest Area

An area of low to no TCE concentrations in soil gas and groundwater between the Central and Southwest Areas is documented in the previous investigations and the sub-slab soil gas sampling (Barr, 2013c; 2013d; 2013e; 2014b, 2015b). Additional samples collected during this investigation suggest that groundwater and soil gas impacts in the Southwest Area are unrelated to General Mills' former operations at the Site.

Section 2.0 identifies several potential solvent sources in the Southwest Area. Current land use in the Southwest Area includes a mix of multi-unit and single-unit student housing, private residences, Van Cleve Park, and commercial/industrial businesses. The Southwest Area includes a railroad corridor south of Elm Street SE that has been present since at least 1892. Manufacturing and other industrial businesses have been present on either side of this rail corridor since at least 1912.

Four permanent monitoring wells and one temporary well were installed in this area as part of this investigation. The soil, groundwater, soil gas, and indoor air results from this and previous investigations in the Southwest Area are summarized below:

- No TCE or other VOC concentrations were detected in the groundwater samples from the wells and soil borings placed during this investigation. Low levels of cVOCs were detected in the groundwater samples collected from existing wells V and W.
- Groundwater concentrations suggest separately impacted areas. TCE is either not detected or detected at low concentrations (below 5 µg/L) in wells directly southwest of the Central Area.
- The sub-slab soil gas results document that the southwest boundary of the Central Area impacts is defined by the Soil Gas Monitoring Area and that a separate area of impacts is present at the properties on the north side of the railroad tracks. The TCE concentrations in soil gas from vapor ports SVP-12 through SVP-15 along the southwestern border of the Central Area ranged from not detectable to 12.8 µg/m^3. Within the Southwest Area, TCE concentrations in sub-slab soil gas were unexpectedly high at 1402/1410 Rollins Avenue SE (sub-slab at 2,340 µg/m^3) and at 823 15th Avenue SE (soil gas at 8 feet bgs in borings DP-058 at 3,270 µg/m^3 and DP-059 at 97.4 µg/m^3); these properties are located adjacent to each other.

The Central and Southwest Areas are separated by an approximately 400 foot-wide area with no detectable TCE in groundwater and TCE sub-slab soil gas concentrations of less than 20 µg/m^3. This data shows that several potential releases have caused the groundwater and vapor impacts in the Southwest Area.

6.0 Site Conceptual Model

The site conceptual model (SCM) for vapor intrusion in the Study Area has been refined with data obtained during this investigation, including the presence of multiple TCE sources that are impacting soil, groundwater, and soil gas throughout the Study Area. Information regarding documented releases to groundwater and potential vapor sources, the physical characteristics of the area, the spatial distribution of TCE, vapor transport mechanisms and migration pathways, potential receptors, and mitigation measures installed as part of response actions completed by General Mills have been incorporated into the discussion below.

6.1 Vapor Sources

As described previously, TCE was a commonly-used industrial and household solvent between the 1930s and the 1990s and is still in use today. Documented releases of TCE to shallow groundwater are present in the Northeast Area and potential users of TCE exist throughout the Study Area.

No evidence of DNAPL has been found at the Site and TCE is not detected in the unsaturated soils at the Site. Only low concentrations of TCE (less than 1 mg/kg) are present in the soil below the water table at the Site. These low concentrations are consistent with the dissolved TCE measured in the shallow groundwater and do not indicate the presence of DNAPL or source material. The Site is not an ongoing source of TCE to groundwater that would contribute to the potential vapor intrusion pathway in the Study Area.

The highest TCE concentrations in groundwater in the glacial drift are present in the Northeast Area, which is hydraulically up-gradient from the Site and the Central Area. The magnitude and northeasterly extent of TCE in groundwater in the Northeast Area is undefined.

6.2 Geology and Hydrogeology

Glacial drift is underlain by discontinuous glacial till and/or shale at the Site and portions of the Study Area. Groundwater within the glacial drift is present at depths of 15 to 25 feet bgs. The shallow groundwater flow direction is and has consistently been to the southwest, with little to no seasonal variation, since at least the early 1980s, including the periods before and during operation of the groundwater extraction system. The groundwater flow direction and gradient are influenced locally by the glacial drift's saturated thickness above the glacial till and/or bedrock and other factors (i.e., hydraulic conductivity distribution, surface topography, and drainage features such as the Mississippi River). Groundwater from the Northeast Area flows to the southwest into the Central Area and the Site.

6.3 Spatial Distribution of Contaminants

TCE is present in groundwater at various locations and varying concentrations within the Study Area. The varying distribution, presence, and concentrations of TCE within the Study Area indicates multiple sources. The highest TCE concentrations in the groundwater are in the Northeast Area. The magnitude and extent of TCE in the groundwater in the Northeast Area are undefined and the presence of DNAPL or other continuing sources of groundwater impacts in the Northeast Area is unknown. The down-gradient extent of TCE in groundwater is defined in the Central Area. The investigation results show an area of separation in groundwater and soil gas TCE concentrations between the Central and Southwest Areas. This separation, coupled with elevated soil gas TCE concentrations at 1410 Rollins Avenue SE and 823 15th Avenue SE, indicate that the TCE in the Southwest Area is unrelated to the Site.

6.4 Potential Receptors

The land use in the Study Area is primarily single-family and multi-family residential development. Some commercial and industrial properties are interspersed throughout the Study Area. Commercial and industrial properties are the primary land use at the Site and in Northeast Area north of East Hennepin Avenue. The basement floor slabs of the residential properties in the Study Area are typically 10 feet or more above the groundwater table.

6.5 Vapor Transport Mechanisms

Based on the results of the various investigations conducted to date, the primary transport mechanism for soil vapor within the Study Area is diffusion of vapors from groundwater into the shallow glacial drift. Diffusion of vapors from groundwater occurs as a result of a concentration gradient between the groundwater and the soil gas in the overlying glacial drift.

Vapor migration through preferential pathways may occur via natural and man-made pathways in the subsurface (e.g., buried utilities) such that the feature creates a pathway from a source to a receptor. Although utility plans indicate that sanitary sewers and other utilities are present, this potential pathway is unlikely since the utility bedding materials are likely similar to the native sandy unsaturated zone soils. In addition, no preferential pathways were identified based on the results of the extensive sub-slab soil gas sampling performed throughout the Study Area.

6.6 Vapor Mitigation

Mitigation systems, specifically sub-slab depressurization systems, were installed at buildings that had reported TCE concentrations in sub-slab soil gas greater than the conservative MPCA screening value or that were otherwise offered mitigation systems. The SSD systems are operating as designed and prevent completion of a vapor intrusion exposure pathway.

7.0 VI Pathway Investigation Conclusions

The investigation activities described in this report were designed to assess TCE impacts in the shallow glacial drift groundwater within the Study Area, as required in RAP Modification #1. The work was to be implemented in stages to refine and inform the scope of subsequent investigation and feasibility study activities, if necessary, based on the data collected.

The results of this investigation demonstrate the following:

- No DNAPL or TCE source material in soil was identified at or emanating from the Site;
- TCE from documented releases up-gradient of the Site are migrating from the Northeast Area into the Central Area and the Site;
- TCE concentrations in groundwater are more than an order of magnitude higher at monitoring well locations up-gradient of the Site than at the Site;
- Additional sources unrelated to the Site exist within the Northeast and Central Areas; and
- TCE impacts in the Southwest are unrelated to the Site; one or more separate releases are present in the Southwest Area.

The response actions implemented as part of General Mills sub-slab sampling and building mitigation project have been completed. As documented in the *Sub-Slab Sampling and Building Mitigation Implementation Report*, the SSD systems have been demonstrated to be effective and are operating as designed. As a result, the SSD systems have effectively removed the exposure pathway and mitigated the potential vapor intrusion risk for the properties within the Soil Gas Monitoring Area.

Although not required by RAP Modification #1, in conjunction with this VI pathway investigation, General Mills prepared an HHRA to evaluate exposures to soil, groundwater, and indoor air associated with residential and commercial uses in the Study Area. The HHRA was prepared based on the soil, groundwater, and soil gas sampling data gathered in this and previous investigations and in connection with the sub-slab sampling and building mitigation response action. The HHRA concludes that the only exposure pathway in the Study Area that may be complete and of potential significance is the potential VI pathway from VOCs in the glacial drift groundwater within the Northeast Area.

Additional response actions at the Site are not necessary to adequately protect human health or the environment. Until the extent and magnitude of the impacts associated with the documented and potential off-Site sources are defined, remedial action objectives cannot be established. Additionally, remedial alternatives, to the extent they are needed, cannot be effectively evaluated for such criteria as cost, implementability, technical practicability, or long-term effectiveness, given the potential for re-contamination from up-gradient sources.

8.0 Next Steps

8.1 Additional Sentinel Network Monitoring

Although not specifically required by RAP Modification #1, the Work Plan included installing and sampling a sentinel soil vapor and glacial drift groundwater monitoring well network. The purpose of the sentinel monitoring network is to assess TCE concentrations in groundwater and soil gas at the perimeter of the Soil Gas Monitoring Area over time. One year of quarterly sampling was included in the Work Plan.

The first two rounds of data were collected in December 2014 and March 2015, and are included and discussed in this report. The third round of data was collected in early June 2015 and the fourth is scheduled for September 2015. A sentinel monitoring report will be submitted to MCPA within 12 weeks following receipt of the complete and validated analytical data set from the one year of sampling.

The report will evaluate potential trends in TCE concentrations in soil gas and groundwater that may be indicative of contaminant migration or attenuation. Multiple lines of evidence will be considered during data evaluation to identify whether soil vapor and/or groundwater contaminants are migrating beyond the Soil Gas Monitoring Area. The sentinel monitoring report will include a proposal for future data collection and analysis, if necessary.

8.2 Reporting

Monthly progress reports were submitted to the MPCA during implementation of the Work Plan from November 2014 through June 2015. Progress reports will continue to be submitted by the 15th day of each month through submittal of the sentinel monitoring report. The progress reports describe the activities performed in the preceding month and those activities scheduled for the upcoming month.

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