# SUPPLEMENTAL REMEDIAL INVESTIGATION GROUNDWATER REPORT (PART 2)

## Former York Naval Ordnance Plant
## 1425 Eden Road
## York, PA 17402

**Prepared for:**

## Former York Naval Ordnance Plant Remediation Team

**York, PA**

**August 2016**
**Revised March 2018**

**Volume 1 of 4**
**Text**

**Prepared by:**

**Groundwater Sciences Corporation**

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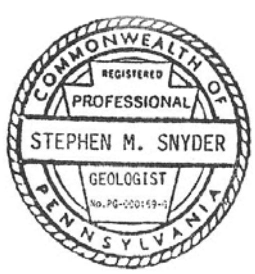


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***08/26/2016 03/21/2018***
DATE

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| %D | percent difference |
| %R | percent recovery |
| %RSD | percent relative standard deviation |
| 11DCA | 1,1-dichloroethane |
| 11DCE | 1,1-dichloroethene |
| µg/L | micrograms per liter |
| AGS | Advanced Geological Services |
| AMF | American Machine & Foundry Company |
| amsl | above mean sea level |
| B | background |
| bgs | below ground surface |
| Bldg2 | Building2 |
| Bldg3 | Building 3 |
| Bldg4 | Building 4 |
| Bldg58 | Building 58 |
| CCA | continuous casing advancement |
| CCV | continuing calibration verification |
| CEA | chloroethane |
| cfs | cubic feet per second |
| cis12DCE | cis-1,2-dichloroethene |
| CLP | Contract Laboratory Program |
| COC | constituents of concern |
| CPA | Central Plant Area |
| CR | cancer risk |
| CSM | conceptual site model |

| | |
|---|---|
| CVOC | chlorinated volatile organic compounds |
| DNAPL | dense nonaqueous phase liquid |
| DO | dissolved oxygen |
| DQO | data quality objective |
| EI | electrical imaging |
| FD1 | Footer Drain Cleanout 1 |
| FD3 | Footer Drain Cleanout 3 |
| FSP | field sampling plan |
| ft/min | feet per minute |
| fYNOP | former York Naval Ordnance Plant |
| gpm | gallons per minute |
| GPR | ground penetrating radar |
| GSC | Groundwater Sciences Corporation |
| GWTS | groundwater extraction and treatment system |
| Harley-Davidson | Harley-Davidson Motor Company Operations, Inc. |
| HHRA | human health risk assessment |
| HI | hazard index |
| IB | initial background |
| IS | internal standard |
| IWTP | industrial wastewater treatment plant |
| KCF | KCF Groundwater, Inc. |
| Langan | Langan Engineering and Environmental Services, Inc. |
| LCL | lower control limit |
| LCS/LCSD | laboratory control sample / laboratory control sample duplicate |
| Leidos | Leidos, Inc. |
| MC | methylene chloride |

| | |
|---|---|
| MF | migratory fishes |
| mg/L | milligrams per liter |
| MIP | membrane interface probe |
| mm | millimeter |
| MNA | monitored natural attenuation |
| MS/MSD | matrix spike / matrix spike duplicate |
| MSC | medium specific concentration |
| msld | mean sea level datum |
| NBldg2 | North Building 2 |
| NBldg4 | North Building 4 |
| ND | non-detected |
| NETT | North End Test Track |
| NIST | National Institute for Standards and Technology |
| NPA | North Plant Area |
| NPBA | Northern Property Boundary Area |
| NP York | NP York 58, LLC |
| PADEP | Pennsylvania Department of Environmental Protection |
| PAGWIS | Pennsylvania Groundwater Information System |
| Part 1 SRI | Part 1 Supplemental Remedial Investigation |
| Part 2 SRI | Part 2 Supplemental Remedial Investigation |
| PCE | tetrachloroethene |
| PVC | polyvinyl chloride |
| QA/QC | quality assurance/quality control |
| QAPP | Quality Assurance Project Plan |
| $Q_{7-10}$ | lowest 7-day average flow that occurs once every ten years |
| $Q_h$ | Harmonic mean flow |

| | |
|---|---|
| RAA | remedial alternatives analysis |
| RACY | Redevelopment Authority of the County of York |
| RI | remedial investigation |
| RI/FS | Remedial Investigation/Feasibility Study |
| RPD | relative percent difference |
| RQD | Rock Quality Designation |
| RRF | relative response factors |
| RUA MSC | residential used aquifer medium specific concentrations |
| RWT | Rhodamine WT |
| SAIC | Science Applications International Corporation |
| SARM | Standard Analytical Reference Materials |
| SDG | sample delivery group |
| SPA | South Plume Area |
| SPBA | Southern Property Boundary Area |
| SRB | Sulphorhodamine B |
| SW-WPL | Southwest corner of the West Parking Lot |
| TCA | 1,1,1-trichloroethane |
| TCE | trichloroethene |
| TCR | target cancer risk |
| UCL | upper control limit |
| USACE | United States Army Corps of Engineers |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| UST | underground storage tank |
| v | velocity |
| VC | vinyl chloride |

| | |
|---|---|
| VI | vapor intrusion |
| VISL | vapor intrusion screening level |
| VOC | volatile organic compounds |
| WBldg2 | West Building 2 |
| WPA | Western Property Area |
| WPL | West Parking Lot |
| WWF | warm water fishes |
| YCIDA | York County Industrial Development Authority |
| YCSA | York City Sewer Authority |
| YNOP | York Naval Ordnance Plant |

# EXECUTIVE SUMMARY

This Supplemental Remedial Investigation Groundwater Report (Part 2) (Part 2 SRI Report) presents the results of extensive groundwater remedial investigations completed at the former York Naval Ordnance Plant (fYNOP) located in York, Pennsylvania (Site) in 2012, 2013, 2014 and early 2015 and combines that information with the results of other investigations and information gained as a result of aggressive interim remedial actions since 1986. This report was prepared on behalf of Harley-Davidson Motor Company Operations, Inc. (Harley-Davidson) with review by fYNOP project team members from the United States Army Corps of Engineers (USACE).

The August 2016 draft of this report was reviewed by the United States Environmental Protection Agency (USEPA) in a letter dated January 27, 2017. As a result of the USEPA comments, this report was revised to address all comments except those relating to the Southern Property Boundary Area (SPBA) and South Plume Area (SPA), which required additional investigation. USEPA comments relating to the SPBA and SPA will be addressed in a separate future report.

This report addresses data gaps identified in the Part 1 SRI report completed in September 2011. Resolution of those data gaps was required in order to move toward a final remedial solution for the Site. **Table 3.7-1** provides a summary of each data gap, the investigations to address, and the resolution of each data gap for readers wanting more detail.

The data gaps and need for additional testing and analysis fell into five categories:

1. Nature and extent
2. Hydraulic characteristics of the karst aquifer
3. Fate and transport of chemicals of concern
4. Source area investigations
5. Interim groundwater extraction system

The first three general categories combine to cover overarching questions required to make decisions regarding short term and long term remediation at the Site. For instance, the depth of the contaminants in the carbonate aquifer (nature and extent), combined with the depth of karst conduits and the potential that there may be a deep conduit system not connected to the shallow aquifer (hydraulic characteristics of the karst aquifer) raised questions regarding the fate and transport of the Site-related constituents of concern (COCs). In addition, there was the potential concern for off-Site migration of COCs along the northern boundary of the Site (nature and extent) and, the extent of off-Site COCs was not sufficiently delineated to the south of the Site.

The fourth and fifth categories of data gaps specifically collect data that will impact future property development and selection of final remedial actions.

These data gaps were investigated and resolved by installing and sampling both deep and shallow monitoring wells and by conducting a series of passive and hydrodynamic tests on- and off-Site.

The work was divided into four phases that were generally conducted sequentially:

- Phase 1 Pre-Drilling Tasks
- Phase 2 Drilling Tasks
- Phase 3 Testing and Monitoring
- Phase 4 Data Analysis and Report

There were also data gaps regarding the performance of the interim remedial actions. As a result of investigations conducted as part of this study, groundwater extraction operations in the Northern Property Boundary Area (NPBA) and the Building 3 (Bldg3) Footer drain were shut down and are being monitored, having successfully accomplished their purposes. In the West Parking Lot (WPL) area, the effectiveness of the groundwater extraction system at capturing groundwater from deep karst conduits (greater than 200 feet below ground surface [bgs]) was demonstrated by the results of the Part 2 SRI.

An investigation to locate sources of chlorinated solvents in the groundwater in two areas of the Central Plant Area (CPA) was conducted. It was concluded that a concentrated source in both areas does not exist, or is limited in size and does not warrant a specific remedial action.

In addition to addressing the identified data gaps, an investigation was conducted to evaluate the potential for vapor intrusion of Site-related COCs into homes in the residential area south of the Site. As a result of that investigation, USEPA determined that vapor intrusion (VI) is not considered to be a significant exposure pathway for the off-site residential area down gradient of the SPBA. However, during the review of the draft Groundwater Human Health Risk Assessment

(Newfields, 2016), additional work was requested in this area, and results will be reported separately.

The carbonate aquifer underlying the west portion of the Site is composed of solution-prone bedrock through which interconnected solution channels are present within the top 200 to 250 feet of the ground surface. These interconnected channels allow groundwater flow to Codorus Creek where it is discharged through discrete springs and areas of diffuse groundwater discharges. Deeper in the aquifer (below 200 feet bgs), the aquifer is much less permeable, and, with rare but significant exception, groundwater flows through tight fractures in the bedrock. The rare solution channels below 200 feet bgs showed definitive evidence of being interconnected with the shallow solution channel network. Groundwater in the less permeable fractured portion of the aquifer flows upward into the zone of higher hydraulic conductivity, and into Codorus Creek.

The interaction of Site groundwater with Codorus Creek, which is located west of the Site, was extensively investigated. The studies determined that, under natural groundwater flow conditions (in absence of groundwater extraction system operation), Site-impacted groundwater discharges to Codorus Creek. Three springs located along both sides of Codorus Creek were discovered, and significantly contributed to the understanding of groundwater flow at the Site. The presence of shale west of Codorus Creek, forms a hydraulic barrier along the west side of the creek, causes a damming effect, since the shale is not prone to the development of solution channels. While Site-related groundwater may migrate at depth past Codorus Creek in solution channels, the shale barrier results in the groundwater discharging to the Creek. There is no indication of the existence of a deeper groundwater flow pathway (a deep karst solution channel) that does not discharge to Codorus Creek. As a result of multiple lines of evidence, the shale west of Codorus Creek was determined to be the western limit of Site-impacted groundwater from the CPA and WPL and Codorus Creek is the discharge point for all Site-impacted groundwater.

Chlorinated volatile organic compounds (CVOCs) originating in the SPBA migrate vertically downward with the groundwater through the unconsolidated materials to the underlying karst aquifer. CVOCs then migrate off-Site with the natural groundwater flow in a southwesterly direction beneath Rt. 30. The lateral extent of trichloroethene (TCE) and tetrachloroethene (PCE) exceeding Pennsylvania Department of Environmental Protection (PADEP) medium specific concentrations (MSCs) (5 µg/L) has been defined, and reaches approximately 410 feet and 770 feet, respectively, south of Rt. 30.

Natural attenuation of chlorinated hydrocarbons PCE and TCE to less toxic cis-1,2-dichloroethene (cis12DCE) occurs in the aquifers across much of the Site, and off-Site. This process occurs under anaerobic conditions (in the absence of dissolved oxygen) and therefore is frequently interrupted in the solution channels in the carbonate aquifer above 200 feet bgs because these channels receive oxygenated water from precipitation events.

The observations of the shutdown testing and the effects of reconfiguration of the groundwater extraction system, which included discontinuing pumping at CW-8 and adding CW-20, has resulted in optimization of the extraction system and a better understanding of the impacts that the various wells have on the groundwater and stream quality. After CW-8 was decommissioned, pumping at CW-20 was incorporated into the long term operation of the groundwater extraction and treatment system (GWTS).

The average concentrations of Site-related COCs in Codorus Creek at average flow conditions was determined absent the operation of the groundwater extraction system during various seasonal conditions. That information and other results from the Parts 1 and 2 SRI were used for the risk assessment process and to consider the final remedial alternatives.

Implementation of the Part 2 SRI work scope and the numerous follow-up tasks performed for the fYNOP from 2012 through October of 2015 has resulted in sufficient information to address all data gaps that were raised by the Part 1 SRI. The results, along with information from previous investigations, were used to completely characterize the various aquifers underlying the Site, with special attention given to the carbonate aquifer and the distribution of solution channels within the carbonate. The nature and extent of COCs has been determined, and the fate and transport of COCs is understood. As a result, a CSM has been developed that has been used to develop exposure scenarios for the human health risk assessment. The human health risk assessment relied on the information and conclusions of this report and other investigations referenced in this report. It is a separate companion document to this report.

Sufficient information is available as a result of this investigation to complete the remedial alternatives analysis for the Site, and it is recommended that it be completed upon review and acceptance of this report and the human health risk assessment (HHRA) by USEPA and PADEP.

After nearly three decades of investigation and remediation it is apparent that continued removal actions and continued operation of the GWTS will not result in meaningful additional improvement to the groundwater quality under the Site and flowing through the Site. Restoration of the entire aquifer to drinking water standards is not considered to be possible. Under Pennsylvania's Land Recycling (Act 2) program, there are provisions for implementation of remedial solutions that mitigate risks to receptors, without restoring the aquifer to appropriate MSCs. CERCLA's technical impracticability (TI) ARAR waiver and Alternative Concentration Limits (ACLs) are USEPA's policy mechanisms to address a similar condition, and would involve a groundwater management/containment zone (CZ). RCRA regulations allow for flexibility in setting cleanup standards and designated points of compliance. These remedies are collectively referred to as alternative endpoints. A TI ARAR waiver and a strategy involving alternate endpoints is considered to be a necessary component of the final remedy at fYNOP to deal with persistent concentrations of COCs exceeding RSLs and MSCs.

# 1 PROJECT DESCRIPTION

This Part 2 Supplemental Groundwater Remedial Investigation Report (Part 2 SRI) has been prepared by Groundwater Sciences Corporation (GSC) to provide detailed results of the groundwater investigations performed at the former York Naval Ordnance Plant (fYNOP or Site) in 2012, 2013, 2014 and 2015.

The Site is located at 1425-1445 Eden Road, Springettsbury Township, York, Pennsylvania as shown on the Site Location Map (**Figure 1.0-1**). Most of the fYNOP Site is currently occupied by the Harley-Davidson Motor Company Operations, Inc. (Harley-Davidson) facility. In mid-2012, fifty-eight acres of the 230-acre Site were sold to the York County Industrial Development Authority (YCIDA). Transfer of this property from YCIDA to the Redevelopment Authority of the County of York (RACY) was completed on November 9, 2015, with pending sale agreement between RACY and NP York 58, LLC (NP York) for development. The parcel—now addressed as 1445 Eden Road, York, Pennsylvania —extends from west of the current motorcycle production facility (Building 3) through the West Parking Lot (WPL) and is identified as the “West Campus”.

The investigations were performed to address data gaps in site characterization that were identified during Part 1 of the Supplemental Remedial Investigation Groundwater Report (Part 1 SRI), (GSC, 2011) and to fill data needs in support of the development and analysis of remedial alternatives, including preparation of Part 1 of the Remedial Alternatives Analysis (GSC, 2014f). The SRI is part of an overall Site-wide remedial investigation and feasibility study (RI/FS) being performed at the Site under the auspices of the One Cleanup Program jointly administered by the United States Environmental Protection Agency (USEPA) and the Pennsylvania Department of Environmental Protection (PADEP). The USEPA serves as the lead agency for administration of the Site under the One Cleanup Program.

The definition of Site in this document (meaning the former York Naval Ordnance Plant [YNOP] property) is contrary to the definition of site used by PADEP and USEPA, which generally means all areas impacted by the facility and requires the addressing of those areas. The definition, as stated in this document, works better because of the history of this property. It is understood, however that all impacted areas must be addressed by characterization and considered during remediation.

## 1.1 Site History

As shown on **Figure 1.1-1**, the facility is bordered on the south by Rt. 30; on the west by Eden Road, a railroad line and northward flowing Codorus Creek; and on the east and north by residential properties. The West Parking Lot (WPL), Central Plant Area (CPA), and numerous other site features are called out on this figure. The eastern third of the site is undeveloped woodlands. The central and northern areas are occupied by buildings supporting manufacturing activities. The southern and western portions of the property are parking areas. The Site Area Designations highlighted in yellow on the figure divide the Site into specific areas of study based on location, contaminant history and land use. The Western Property Area (WPA) combines the WPL, the CPA and the area west of the WPL to Codorus Creek.

The Site was initially developed in 1941 by the York Safe and Lock Company, a United States Navy contractor, for the manufacture, assembly, and testing of 40 millimeter (mm) twin and quadruple gun mounts, complete with guns. In 1944, the Navy took possession of the York Safe and Lock Company facility. The Navy owned and operated the facility as the YNOP until 1964, switching operations after World War II to overhaul war service weapons and to manufacture rocket launchers, 3-inch/50-caliber guns, 20-mm aircraft guns, and power drive units for 5-inch/54-caliber guns. In 1964, the Navy sold the YNOP to American Machine & Foundry Company (AMF), who continued similar manufacturing. In 1969, AMF merged with Harley-Davidson. In 1973, Harley-Davidson moved its motorcycle assembly operations to the AMF York facility. In 1981, AMF sold the York facility to Harley-Davidson. Harley-Davidson has continued motorcycle assembly operations at the York facility since 1981.

In 2003, Harley-Davidson built a new facility on the eastern portion of the fYNOP property, and began the process of moving all manufacturing activities to that area. In 2012, the property was subdivided into the East Campus and the West Campus, with Harley activities concentrated on the East Campus, and the West Campus being staged for redevelopment. **Figure 1.1-1** delineates the West and East campuses.

Spills, leaks and disposal practices resulted in the distribution of chlorinated solvents from metal degreasing operations and metals from plating operations in the subsurface and groundwater across the majority of the Site. Chlorinated solvents trichloroethene (TCE), tetrachloroethene (PCE), 1,1,1-trichloroethane (TCA), and their degradation products are the primary Site-related constituents of concern (COC), along with plating related substances chromium, nickel and cyanide.

## 1.2 Summary of Environmental Investigations To Date

Numerous environmental investigations and remedial efforts have been conducted at the Site over the time period 1984 to the present. They are described in the following subsections.

### 1.2.1 Pre-Site-Wide RI Activities

Starting in 1984, Harley-Davidson began an investigation of potential environmental impacts in the eastern portion of the facility. Groundwater characterization began in 1986. A groundwater extraction and treatment system (GWTS) was designed and constructed in 1990, and continues to operate as an interim remedy. Numerous soil remedial efforts have also been conducted as areas of the factory were remodeled. These pre-remedial investigation (RI) activities are summarized in Science Applications International Corporation's (SAIC) Soils RI report (SAIC, 2009).

### 1.2.2 Site-Wide Remedial Investigation

A Site-wide RI was initiated by Langan Engineering and Environmental Services, Inc. (Langan) in 1998 to evaluate potential sources of soil and groundwater impacts, determine the fate and transport characteristics of known COCs, and evaluate risks to human health and the environment (Langan, 2002). Supplemental field investigations of soil and groundwater were completed in 2007 and 2008 by SAIC as part of the Supplemental Site-Wide RI. That supplemental RI was divided into soils and groundwater reports for presentation purposes and to assist in completion and review of the documents:

1. The "Draft Supplemental Remedial Investigations Soils Report – Former York Naval Ordnance Plant", dated December 2009 (SAIC, 2009), was approved by the USEPA Region III and PADEP in a letter to Ms. Sharon Fisher on March 17, 2010.
2. The "Supplemental Remedial Investigation Groundwater Report (Part 1)" (Part 1 SRI) was completed September 2011 by GSC (GSC, 2011). That report presented a comprehensive characterization of the nature and extent of COCs in groundwater and their fate and

transport. Data gaps were identified in that report, which are the subject of the groundwater remedial investigation described in this report.

The remedial investigations particularly for soil and groundwater primarily use the latest PADEP medium-specific concentrations (MSCs) available at the time of writing as the screening value in text discussions. For on-Site soils, non-residential MSCs were used for direct contact, and for soil-to-groundwater, residential values for used aquifers with TDS $\leq$ 2500 mg/L were used. For groundwater discussions, residential used aquifer MSCs with TDS $\leq$ 2500 mg/L were used (RUA MSCs).

### 1.2.3 Soils Risk Assessment

The "Soils Risk Assessment – Former York Naval Ordnance Plant" dated March 2012 (GSC, 2012a), was approved by the USEPA Region III in a letter to Ms. Sharon Fisher on July 9, 2012. In the document, current and future potential receptors of inorganic and organic regulated substances in the soil were identified and a quantitative risk assessment process was utilized to identify the risk of exposure. Results of the assessment were that there were no unacceptable soil exposures at the Site under current or future land use assumptions, and that the risk assessment demonstrated attainment of the site-specific standard for soils for chemical constituents of potential concern.

## 1.3 Summary of Part 1 Supplemental Remedial Investigation Groundwater Report

The Part 1 SRI report summarizes environmental investigations involving groundwater completed from 1984 through 2006 and provides investigation details for work conducted from 2007 through 2010. The Part 1 SRI report was submitted to regulators on September 23, 2011 and was approved by USEPA on February 2, 2012, and by PADEP on February 3, 2012. A detailed summary taken from Section 8 of the Part 1 SRI report follows.

### 1.3.1 Physical Characteristics

The Site is located in central York County, north of the City of York, PA (**Figure 1.0-1**). This area is drained by the Codorus Creek, a tributary to the Susquehanna River with a 237 square mile drainage area above the point where it enters the Site. Hills rim the fYNOP Site on the north and east, forming somewhat of a bowl-like configuration. The eastern one third of the Site is fairly steeply sloping to the west (4 to 20%), forming an upland area to the east of the flat-lying CPA. From the base of the hills to the Codorus Creek, the land surface underlying the CPA slopes very gently (0.5%) to the west.

#### 1.3.1.1 Geology

Unconsolidated overburden materials have developed from the underlying bedrock throughout the Site. These overburden materials range in thicknesses from 15 feet to greater than 60 feet. Portions of the Site also have alluvial deposits, which include more coarse-grained sediments interspersed among the predominantly fine-grained residual soils.

Two bedrock formations underlie the site (**Figure 1.3-1**):

1. Quartzitic sandstone and phyllite underlie the more steeply sloping hills present on the eastern part of the site. A thin mantle of residual material derived from the weathering of parent material overlies the bedrock.

2. Solution-prone (karst) limestone and dolomite (carbonate) underlie the western flat-lying CPA of the site. Weathering, more specifically called karst development, has taken place within the carbonate bedrock. The high degree of variability in the elevation of the top of bedrock, called a “cutter and pinnacle” bedrock surface, and the occurrence of numerous caverns and solution channels within the bedrock at the Site indicate processes that are described as karst development. Karst development was evidenced by numerous voids encountered during the drilling of borings and monitoring wells within the carbonate bedrock. The natural (non-fill) overburden materials in the carbonate terrain range in thickness from 15 feet to 60 feet, and are comprised of silt and clay, some or all of which had formed as the residual material from carbonate bedrock weathering, and transported alluvial sediment. In addition, several sinkholes have occurred on the fYNOP property, which are a typical occurrence within areas of soluble carbonate rocks. The solution cavities and fractures often contain mud, silt, and rounded 0.5 to 2-inch quartz and limestone gravels and cobbles, as recorded in numerous boring logs from wells drilled on-Site.

The top of the carbonate bedrock surface was examined by contouring (**Figure 1.3-2**), 3-D modeling and by examining well logs. A deep broad cutter follows the contact between the quartzitic sandstone and the carbonate, underlying the CPA. The broad depression, shown as 200 to 800 feet in width, has a general north to south orientation, curving to the west at its northern extent, as the geologic contact curves to the west. The depression contains some of the localized bedrock depressions or sinking points (**Figure 1.3-3**) into which concentrated groundwater recharge has formed the deeply penetrating solution conduits which pervade the bedrock. The substantial dissolution of the bedrock surface in this area, up to a depth of 76 feet, has likely been created by corrosive groundwater recharge and storm water runoff from the Antietam Formation quartzitic sandstone and Harpers phyllite upland area in the eastern portion of the Site, flowing onto the lower-elevation carbonate bedrock area beneath the western portion of the Site.

Other depressions in the karst bedrock surface were delineated underlying the North End of Building 4 and the WPL. The lower elevation of the karst bedrock surface and solution cavities associated with these features also generally correlate with concentrated fracture trace patterns. Well locations exhibiting karst features (open or sediment-filled solution cavities) are frequent and well-distributed across the Site. For sixty-five wells examined, only thirteen had total void thickness less than 1.0 foot. Well locations with no void thickness greater than 1.0 foot appeared to be more prevalent in the southwestern corner of the fYNOP property. Of 5,702 feet of borehole penetration through carbonate rock, 888 feet penetrated voids, constituting 16% of the total volume of the aquifer. Sixty-three percent of the voids were sediment-filled, while the remainder was open (filled with water).

The depth of karst solutioning at the end of the Part 1 SRI was evident from solution channels and caverns encountered in carbonate bedrock to a depth of 217 feet. Experience with the depth of penetration of karst weathering in the mid-Atlantic area carbonate bedrock is approximately 250 feet, although exceptions are found. This would put the estimated base of the karst somewhat below the locations of the deepest known karst beneath the Site.

#### 1.3.1.2 Hydrogeology

Groundwater generally migrates from east to west, from the high topographic areas underlain by quartzitic sandstone to the limestone and dolomite that underlies the western half of the site.

Aquifer transmissivity, the property of the aquifer that describes the ease with which groundwater moves through the saturated subsurface materials, is very different between these two geologic materials. The quartzitic sandstone transmissivity is lower due to the groundwater migrating through minor partings associated with bedding planes, joints and fractures with relative higher resistance compared to the carbonate aquifer because the openings are not solution-enhanced. Because the materials of the carbonate aquifer are prone to dissolution by migrating groundwater, transmissivity in this aquifer is greatly enhanced, and groundwater moves with relative ease through the aquifer.

Water table gradients are steep (6 to 10%) in the upland regions underlain by quartzitic sandstone and diminish to a relatively flat gradient (1% or less) once the groundwater flows into the area underlain by carbonate rocks. Groundwater in the upland area flows mainly through the interconnected network of fractures, joints, and bedding planes. Once the groundwater encounters the carbonate rocks, groundwater flow is directed along fractures, dissolution cavities, interconnected conduits, and weathered zones in the rock. The regional groundwater flow through the property follows a general west-southwesterly direction. Locally, the groundwater flow through the karst bedrock is widely variable following the pathways of the karstic conduits. However, responses to pumping tests and migration pathways traced by groundwater chemistry indicate a well-connected aquifer as a result of numerous highly interconnected conduits.

The extent of the karst aquifer is limited to the north and east by phyllite, quartzite and quartzitic sandstone. These noncarbonate formations underlie the carbonate formation, dipping at angles of approximately 15 to 20 degrees toward the carbonate, and form the lower limit of the karstified aquifer in the northern and eastern portions of the industrialized area. To the south, the carbonate aquifer is laterally extensive, and the depth of karst aquifer is undetermined. Under the southern portion of the CPA and the WPL, the depth to the bottom of the carbonate aquifer is undetermined.

#### 1.3.1.2.1 Groundwater Extraction Systems

In the North Property Boundary Area (NPBA), flow directions during the Part 1 SRI were locally modified by active groundwater extraction wells; however, groundwater appears to flow off the Site to the west of MW-18 under non-pumping conditions.

In the WPL, groundwater flow is redirected locally by the system of capture wells. The operation of groundwater extraction wells appears to prevent groundwater flow from the WPL toward Codorus Creek. The combination of pumping from the extraction wells and the discharge of Site storm water to a wetland area between the western property line and the Codorus Creek may have created a divide between the creek and the Site where groundwater on the east side of the divide migrates toward the Site, and groundwater on the west side of the divide migrates westward toward the Codorus Creek. Although storm water still discharges to the wetland area, the discharge was reduced by approximately 10,000 gallons per day in 2010 when Harley-Davidson stopped discharging non-contact cooling water. This reduction may have reduced the extent of the shallow groundwater flow divide. Capture of Site groundwater and prevention of off-site migration was evaluated:

1. Comparison of extraction well pumping rates to the estimates of groundwater flowing through the aquifer that show the pumping rate equals 140% of the estimated average annual groundwater flow through the aquifer.
2. Evaluation of hydrographs of wells indicates persistent influence from the pumping wells on water levels, with piezometric levels in the creek and in wells near the creek that are consistently higher than wells onsite.
3. Groundwater piezometric levels in observation wells during operation of the groundwater extraction system indicate sufficient influence to maintain capture in the monitored portion of the carbonate aquifer, down to approximately 200 feet below ground surface (bgs).

However, because extraction wells are relatively shallow, without knowing the full depth to which groundwater flow in the karst aquifer occurs, there is no assurance that capture of all groundwater flow in the carbonate aquifer is complete.

A second concern is the loss of capture during storm events due to a condition called karst loss. A karst aquifer can experience very large and rapid influxes of storm water to the aquifer, directed to the epikarst through swallets, sinkholes, exposed karst openings in bedrock and epikarstic openings in the bedrock surface beneath the overburden. This situation could result in much larger volumes of water flowing through the aquifer for a period of hours or days following high recharge events (rainfall and snow melt) than can be extracted by the pumping system. No evidence that this occurs was observed in hydrographs of observation wells. However, the duration of these hydrographs is limited and additional monitoring for a longer duration would be necessary to properly respond to this concern.

The third and final concern is that there are concentrations of Site COCs above PADEP MSCs present in the wells installed along the east side of Codorus Creek. However, the age of the COCs was calculated to predate the start-up of the extraction system. The results of this calculation suggest that these compounds may be from residual secondary sourcing, a result of slow releases from the matrix of the aquifer which adsorbed COCs travelling with groundwater toward Codorus Creek prior to the start of pumping of the WPL wells.

#### 1.3.1.2.2 Role of Codorus Creek as a Discharge Boundary

Under natural conditions (without the operation of the groundwater pump and treat system), groundwater flowing through the Site flows westward toward and discharges to the Codorus Creek. The operation of the groundwater extraction system on the Site has likely intercepted virtually all groundwater flowing within the carbonate aquifer above a depth of 200 feet bgs. For Site related groundwater to pass under Codorus Creek to the north or west would require the existence of a large pumping center or a deep conduit isolated from the shallow aquifer (down to 200 feet). Noncarbonate rocks to the north eliminate northerly migration. The Roosevelt quarry, 12,000 feet to the west (**Figure 1.3-4**) could potentially represent a large pumping center caused by dewatering, however the occurrence of the Kinzers Shale between the creek and the quarry (**Figure 1.3-5**) would tend to prevent the influence of quarry dewatering from reaching the Codorus Creek at the fYNOP Site. Additional verification of this conceptual model may be necessary through determination of the extent of pumping from the Roosevelt Quarry, field verification of the mapping and effectiveness of the Kinzers Shale to serve as a barrier to northerly and westerly groundwater flow and/or monitoring of groundwater levels in karst conduits at various depths adjacent to the creek.

## 1.3.2 Nature and Extent of Groundwater Contamination

Chlorinated solvents PCE, TCE, TCA and degradation products of these compounds, as a group called chlorinated volatile organic compounds (CVOCs) are widely distributed in the groundwater across the Site. The solvents were released in the form of Dense Nonaqueous Phase Liquids (DNAPLs) which are, by definition, immiscible in water and exhibit a higher specific gravity than water. In addition, metal plating-related compounds, gasoline components and semi-volatiles were detected at concentrations that exceed PADEP groundwater MSCs, were delineated on Site, but the chlorinated solvents pose the majority of the concern and are the primary COCs.

Primary source areas and migration pathways were distinguished by examining normalized chemical ratios of the parent solvents and their daughter products. Chemical concentration vs. time graphs were examined and the current conditions of the groundwater quality beneath the Site were characterized. The distribution of chlorinated solvents in the groundwater was depicted on isoconcentration contour maps.

- In the higher elevation areas of the site underlain by the noncarbonate rocks, PCE and TCE are distributed in the groundwater near the northeast, east and southeast property lines. These chemicals dissolved in groundwater were pulled off site in the NPBA by former residential water supply wells. TCE and PCE also migrated offsite to the south from the southeast corner of the site.

- Source areas and high concentrations are distributed throughout areas of the carbonate aquifer known as the North End of the Test Track (NETT), CPA and the WPL.

- Concentrations of CVOCs were detected in groundwater in the wells installed off-Site on the east side of Codorus Creek.

### 1.3.3 Contaminant Fate and Transport

CVOCs in the form of DNAPLs were discharged on the ground surface and traveled vertically through the subsurface materials, leaving a trail of residual material or forming pools or accumulation zones. At the fYNOP Site, the factors affecting the transport of a DNAPL release are highly dependent on the geologic characteristics at the location of the release (**Figures 1.3-6 and 1.3-7**). In the karst aquifer, DNAPL is directed along the pinnacled bedrock surface through vertical and lateral solution channels that are open (filled with water) or filled with water-saturated residuum and sediment (sand, silt, clay, gravels and rock fragments). DNAPL is believed to have migrated vertically as deep as 200 feet in four or more areas of the site.

In the aquifer, some of the DNAPL slowly dissolved in the groundwater, undergoing a number of processes. Dissolved (aqueous) phase chlorinated solvents migrated through the aquifer transported by groundwater flow and generated a plume of dissolved CVOCs extending from the source area to the point of discharge to surface water or an extraction well. Prior to operation of the pump and treat system, groundwater in the CPA/North Plant Area (NPA)/WPL migrated generally westward toward the Codorus Creek through residuum and solution-enhanced pathways in the carbonate bedrock.

The aqueous phase chemicals diffused into the rock matrix, and adsorbed onto organic carbon or mineral surfaces. In the aqueous phase, anaerobic bacteria break down PCE and TCE to cis-1,2-dichloroethene (cis12DCE) and vinyl chloride (VC) and the TCA to 1,1-dichloroethane (11DCA) and chloroethane. TCA also abiotically transforms to 1,1-dichloroethene (11DCE).

DNAPL has likely been present in the fYNOP aquifer for 60 or more years, since vapor degreasing operations began prior to 1948 (Key Reporters, 1991). During that time, the various processes described above, enhanced by interim remedial actions, have resulted in the reduction of the DNAPL mass (**Figure 1.3-8**). Even so, a number of areas remain as probable DNAPL sources. In addition, diffusion and sorption processes have stored CVOC mass in the aquifer, which is released slowly, resulting in a tailing effect for CVOC concentrations in groundwater. Primary source areas are the Building 58-66 Area, the TCA degreaser in Building 2 (Bldg2), the North Building 2 (NBldg2) Corridor, the North Building 4 (NBldg4) Area and the southwest corner of the WPL. In these areas, concentrations increase with depth to the extent investigated (to approximately 200 feet).

### 1.3.4 Interim Remediation Progress

Over the last 20 years, CVOC concentrations in the groundwater have reduced 90 to 99% over most of the Site. The reduction is primarily a result of removal by dissolution into the groundwater that migrates from the source or is captured and removed by the pump and treat systems, natural degradation of the chlorinated solvents by bacteria and abiotically by sorption onto and diffusion of the dissolved phase into the matrix of the aquifer. Although greatly reduced, concentrations of chlorinated solvents nonetheless exceed PADEP groundwater MSCs across most of the Site. Several facts (i.e., chlorinated solvents have not been used on-Site since 1994, there has been no known release of chlorinated solvents in over 25 years, and the groundwater pump and treat systems have been operating for over 20 years) provide an indication of the persistence of the COCs in groundwater at fYNOP.

Estimates of the mass remaining in the aquifer on Site using trend analysis exceed 60,000 pounds, and may be substantially underestimated because DNAPL pools appear to be present. On the order of 2,000 pounds of this mass occurs as dissolved in groundwater. The remaining mass is adsorbed onto and diffused into the matrix of the aquifer or is in the form of suspected DNAPL pools. These undissolved sources of mass are very slowly released to the groundwater passing through the site.

### 1.3.5 Exposure Pathway Analysis

An exposure pathway analysis identifying complete exposure pathways between groundwater contaminant sources and receptors or future receptors was evaluated for four categories of human receptors, including: off-Site residents, off-Site recreators, on-Site workers, and on-Site construction workers. A complete exposure pathway consists of the following components: a source, a transport medium (*e.g.*, groundwater), a point of contact (receptor), and an exposure route (*e.g.*, ingestion, dermal, or inhalation). Source areas were examined, and potential complete pathways identified.

- Although there are no drinking water supply wells known to remain in the area, the use of groundwater as a water supply is a potential future exposure pathway for off-site residents. Vapor intrusion for off-site residents was evaluated and determined that there is no unacceptable risk.

- Off-site recreators using Codorus Creek for recreational purposes may come in contact with site COCs through dermal contact and incidental ingestion.

- On-Site workers could potentially be exposed to Site-related COCs through inhalation as a result of vapor intrusion into existing or future buildings.

- On-Site construction workers exposure to groundwater (exposure to soil was considered in the soil risk assessment) is potentially complete because excavations may reach the water table at some locations or under seasonally high conditions.

## 1.3.6 Recommendations (Identified Data Gaps)

At the conclusion of the Part 1 SRI questions regarding the Site characterization and the path forward for the eventual closure of the fYNOP site under the PADEP/USEPA One Cleanup program for groundwater were divided into five interrelated categories:

- Nature and Extent of COCs
- Hydraulic Characteristics of the Karst Aquifer
- Fate and Transport
- Source Area Investigations
- Interim Groundwater Extraction System

### 1.3.6.1 **Nature and Extent of COCs**

Several source areas were identified as requiring further lateral and/or vertical delineation. In addition, potential off-Site migration of COCs transported by groundwater had not been fully addressed for some source areas and required further characterization.

#### 1.3.6.1.1 Vertical Extent of Chlorinated Solvents in Source Areas

The depths of chlorinated solvents in the groundwater were undetermined in several source areas across the Site shown on **Figure 1.1-2**, including, the Southwest corner of the West Parking Lot (SW-WPL), the TCA Tank/Building 2 (Bldg2) Degreaser area, the Building 58 (Bldg58) area, the West Building 2 (WBldg2) Corridor, the Southeast corner of the Site, and the North Building 4 (NBldg4) area. This concern was especially important to the assessment of the effectiveness of hydraulic control of CVOC migration west of the WPL through the operation of the existing extraction wells, as further discussed in Section 1.3.6.5.4.

#### 1.3.6.1.2 Lateral Extent of Chlorinated Solvents in the NPBA

The lateral extent of COCs in the groundwater surrounding monitoring well MW-18D in the Northern Property Boundary Area (NPBA) was a data gap that required investigation during the Part 2 SRI. Concentrations of TCE drawn into MW-18D, and to a lesser extent, MW-18S, after activation of the NPBA groundwater extraction system, increased over time indicating a source is most likely to the west of the MW-18 monitoring well couplet, toward the property line, raising the concern that off-Site migration of COCs may be occurring.

#### 1.3.6.1.3 Horizontal and Vertical Extent of Off-Site Migration from the SPBA

The analysis presented in the Part 1 SRI report suggested that groundwater with dissolved COCs in the southeast corner of the Site (at well couplet MW-64S&D) appeared to migrate off-Site to the south potentially within saturated bedrock and soil south of the fYNOP property. This area of off-Site migration is referred to as the SPA. Site-related chlorinated solvents have been found in down-gradient, off-Site monitoring wells. Knowledge of the pathway and persistence of the elevated concentrations in the groundwater was incomplete. An objective of the Part 2 SRI was to determine the boundary of the lateral and vertical extent of the plume, and collect sufficient information to evaluate potential impacts of the off-Site migration.

#### 1.3.6.1.4 Potential for Migration of Site Groundwater Under and West of Codorus Creek

The presence of potential migration pathways beneath and west of Codorus Creek that might be hydraulically connected to and affected by extraction operations at a local limestone quarry or more downstream segments of Codorus Creek raised concerns that the groundwater flow, transport direction and magnitude west of the WPL required further observation, data collection, and analysis during the Part 2 SRI.

### 1.3.6.2 Hydraulic Characteristics of the Karst Aquifer

The interconnection between the surface, surface water features and the karst aquifer was not well understood. The depth of karst and the potential for a deeper karst network to be present with limited hydraulic connection to the shallow aquifer required better definition. Given the uncertain vertical delineation of chlorinated solvents in source areas and the potential migration pathways beneath Codorus Creek, two concerns were raised as a result of this data gap:

1. The effectiveness of the relatively shallow groundwater extraction system in capturing groundwater flowing at depth was undetermined.
2. If there is a deep karst network that is hydraulically separated from the shallow karst network, then the extent of contaminant migration may not have been completely understood, raising the prospect of contaminant migration under and possibly west of Codorus Creek.

Results of the Part 1 SRI indicated that the operation of the groundwater extraction system as an interim remedy likely provides sufficient influence to maintain capture in the monitored portion of the carbonate aquifer (down to approximately 200 feet bgs). However, the extraction wells are relatively shallow, and there was insufficient data during the Part 1 SRI to confirm that capture of groundwater flow in the deeper portion of the carbonate aquifer is complete.

Another concern identified during the Part 1 SRI was the potential for loss of groundwater capture during storm events due to karst loss. Karst loss is the very large and rapid influx of storm water (surface water run-off) to the aquifer, directed to the epikarst through swallets, sinkholes, exposed karst openings in bedrock and epikarstic openings in the bedrock surface beneath the overburden. This situation could result in much larger volumes of water flowing through the aquifer for a period of hours or days following high recharge events (rainfall and snow melt) than could be extracted by the pumping system. No evidence that this occurs was observed during the Part 1 SRI, but may have gone undetected because the duration of testing and level of monitoring were limited.

#### 1.3.6.3 **Fate of Site Chemicals of Concern**

**Figure 1.3-8** depicts the conceptual model of DNAPL fate and transport in the karst aquifer as published in the Part 1 SRI. CVOCs in the form of DNAPLs were discharged on the ground surface and traveled vertically through the subsurface materials at the Site, leaving a trail of residual material or forming accumulation zones. In the karst aquifer, DNAPL was directed along the pinnacled bedrock surface through vertical and lateral solution channels that are open (filled with water) or filled with water-saturated residuum and sediment (sand, silt, clay, gravels and rock fragments).

In the karst aquifer, some of the DNAPL slowly dissolves in the groundwater, undergoing a number of processes. Dissolved (aqueous) phase chlorinated solvents migrate through the aquifer transported by groundwater flow and generate a plume of dissolved CVOCs extending from the source area to the point of discharge to surface water or an extraction well. The aqueous phase chemicals diffuse into the rock matrix over time, and adsorb onto organic carbon or mineral surfaces. In the aqueous phase, anaerobic bacteria break down PCE and TCE to cis12DCE, VC, and ethene; and the TCA to 11DCA and chloroethane. TCA also abiotically transforms to 1,1-11DCE, which can subsequently degrade by reductive dechlorination to VC. These various processes described above, enhanced by interim remedial actions to control and extract contaminated groundwater, have resulted in the reduction of the mass of CVOCs at the Site.

To further understand where the Site groundwater geochemical conditions are favorable for the transformation of primary CVOCs to daughter products and supportive of an analysis of monitored natural attenuation (MNA) in the remedial alternatives analysis (RAA), analyses of groundwater for monitored natural MNA parameters was identified as a data need. Additional analyses for assessing sorption and desorption of CVOCs onto the aquifer matrix materials was also identified as a data need to allow a better assessment of the significance of this secondary source factor.

#### 1.3.6.4 **Source Area Investigations**

The locations of source areas that serve as the origin of elevated concentrations of COCs detected in the groundwater beneath the former Bldg58 area and the WBldg2 Corridor was identified as a data gap. If these locations could be further defined, then the COCs in the former Bldg58 area and the WBldg2 Corridor could potentially be more effectively remediated.

#### 1.3.6.5 **Groundwater Extraction System Effectiveness Evaluations**

The Part 1 SRI identified the need to further evaluate the apparent effects of discontinuing the operation of portions of the groundwater extraction systems initiated at the Site as interim remedies in the NPBA and the Building 3 (Bldg3) area as a component of the RAA for those areas. Subsequently, in the course of completing Part 1 of the RAA, GSC recognized the need to evaluate shutdown of the extraction system in the WPL and CPA as a component of more than one of the suggested remedial alternatives to be subjected to additional screening and analysis during Part 2 of the RAA. The data needs identified included further assessment of the lateral and vertical hydraulic effectiveness of the extraction systems and the potential off-Site migration of VOCs under non-pumping conditions. In particular, the effects of complete extraction system shutdown or operation of a more limited extraction system in the WPL on COC mass flux to Codorus Creek were identified as data needs to support the RAA. During the course of testing modifications to the groundwater extraction system, extraction well CW-8 located near the TCA Tank Area in the CPA was shut down.

#### 1.3.6.5.1 NPBA Groundwater Extraction System Effectiveness

Site-related COCs detected in off-Site residential groundwater wells located to the north of the NPBA were likely drawn to the off-Site wells by pumping of those wells for domestic water supply prior to 1986. Whether groundwater would naturally migrate northward from the NPBA to off-Site properties if the groundwater collection system were deactivated was not determined during the Part 1 SRI. Understanding this potential migration pathway is important to the analysis of remedial alternatives associated with this area that involve the shutdown of the GWTS.

#### 1.3.6.5.2 Bldg3 Groundwater Extraction System Effectiveness

Low concentrations of COCs were historically detected in the groundwater flowing to the Lift Station from the Footer Drain system beneath Bldg3 and from the toe-of-slope drain just east of Bldg3. An objective of the Part 2 SRI was to determine the feasibility of shutting down the Bldg3 Footer Drain system without water infiltrating the building facilities that it was originally installed to protect. The concern was low since the extraction well, CW-19, in the basement was never required to be activated to remove water in the history of the building.

#### 1.3.6.5.3 Impact of WPL Extraction Well Shutdown on Codorus Creek

The water quality of Codorus Creek downstream of the Site had not been investigated prior to startup of the groundwater extraction system in the WPL, which has been operating as an interim remedy since 1994. While this data need had not been identified in the Part 1 SRI, interest grew as a result of the preliminary findings of the Part 2 investigations and the implications regarding the development and analysis of alternatives under Part 1 of the RAA. The impact of Site groundwater discharging to Codorus Creek following shutdown of the extraction systems that otherwise provide hydraulic control of groundwater chemical flux to Codorus Creek would have to be observed over an extended period of time to support the analysis of the alternatives that do not include continued hydraulic plume control.

#### 1.3.6.5.4 WPL Extraction Well Capture Testing

The effectiveness of the groundwater extraction system in the WPL was well understood in the shallow and intermediate depths of the epikarst carbonate aquifer, but it was unknown whether the extraction system was effective at capturing groundwater in the deeper zones of the aquifer. Understanding the effectiveness of capture at depth would be even more important if it were determined that migration pathways existed that could transport dissolved COCs in groundwater beneath and to the west of Codorus Creek (see Section 1.3.6.1.4). The investigation of the capture response at depth in the aquifer in comparison to the depth of COCs was not listed as a specific data gap in the Part 1 SRI, but the information derived from such an investigation could also be used to more completely assess the hydraulic characteristics of the karst aquifer (see Subsection 1.3.6.2) and will be used for the future analysis of remedial alternatives under the RAA.

Another modification to the WPL extraction system that was tested during the Part 2 investigation was the addition of deep extraction well CW-20 in the SW-WPL to the groundwater extraction system in April 2014. This well was installed in 2006, but testing showed that the drawdown caused by this well in the SW-WPL was not much different than existing extraction well CW-9, and because of the costly plumbing and electrical modifications required to add CW-20, the extraction system was not modified at that time. However, interest grew regarding the impact that pumping CW-20 may have, since it was demonstrated to be connected to the karst network, and because the SW-WPL appears to be to site of DNAPL disposal. Plumbing and electrical modifications and the installation of a pump in CW-20 were accomplished, and pumping configurations that included CW-20 were tested.

#### 1.3.6.5.5 TCA Tank Area Extraction Well Shutdown

Pumping of groundwater extraction well CW-8 was initiated in November 1990 to prevent TCA migration from this release point (GSC, 2011). By 1995, TCA concentrations had reduced and TCE concentrations had increased, indicating a source of TCE had been intercepted. In the Part 1 SRI, it was concluded that "the current interim action of pumping extraction well CW-8 has served its original purpose of removing the concentrated TCA contamination at this location. Continued pumping is currently removing TCE from an unknown source." As a result of this finding, the decision was made to shut down CW-8, and use the pump and treatment plant capacity to activate the pumping of CW-20, discussed above.

### 1.3.7 SPBA Vapor Intrusion Investigation

USEPA identified an additional potential data gap while field investigations for the Part 2 SRI were being conducted. In August 2014, USEPA requested more information to determine whether vapor intrusion (VI) is a potentially complete pathway for COCs from the Site to enter neighboring residences. In 2005, USEPA issued its Documentation of Environmental Indicator Determination finding that the VI pathway in the residential area off-Site in the vicinity of the SPBA was not significant (USEPA, 2005). In 2014, the USEPA reviewed the 2005 VI assessment for the SPBA and concluded that the methodology and modeling approach that it previously approved for the 2005 VI assessment are no longer considered by USEPA to be reliable methods to estimate the potential for VI into neighboring residences. While not an identified data gap from the Part 1 SRI, this investigation was conducted under an addendum to the Part 2 field sampling plan (FSP).

## 1.4 Report Organization

This report is written as a supplement to the Part 1 SRI, and builds on the data and conclusions included in that report. It does not include all of the data and details of the first report.

1. Section 1 of this report presents the project description, including the Site history, a summary of environmental investigations to date and a summary of the findings of the Part 1 SRI, including identified data gaps which formed the basis for recommended additional studies for the Part 2 SRI.
2. Section 2, Scope and Implementation of Part 2 Investigation, summarizes the four phases of the investigation and the field efforts conducted. Where changes from the procedures described in the FSP were made, details are provided in the text or related appendices. Field notes, monitoring data, lab results and interim reports are introduced and included in tables and appendices.

3. Section 3, Results of Investigations, presents the findings and interpretations of the Part 2 investigation. Detailed descriptions and findings addressing key data gaps and needs are described. In addition, updated maps and cross sections showing groundwater chemistry distribution after incorporating newly collected data, and making use of the added data points created by the Part 2 investigation are presented in this section.
4. Section 4, Conceptual Site Model, provides a summary of the findings and conclusions of the environmental investigations and interim remedial actions involving groundwater conducted at the fYNOP located in York, Pennsylvania (Site) from 1984 through 2015. As such, this section combines the findings and conclusions of the Part 1 SRI and the Part 2 SRI.
5. Section 5, Results of Investigations to Support Remedial Alternatives Analyses, summarizes the interim remediation progress for groundwater begun in 1989, and the investigations conducted regarding the groundwater extraction systems.
6. Section 6, Conclusions and Recommendations, summarizes the accomplishments of the remedial investigation efforts and briefly discusses a path forward for fYNOP.

## 1.5 Revised Report

The August 2016 draft of this report was reviewed by the USEPA in a letter dated January 27, 2017. Proposed responses were offered in a letter from GSC on behalf of the fYNOP project team, and USEPA concurred with the approaches by email from Griff Miller dated April 7, 2017. However, subsequent submittal and review of the Groundwater Human Health Risk Assessment for this site resulted in a USEPA request for additional action in the SPBA, which is ongoing. As a result, this report was revised to address all comments except those relating to the SPBA and SPA, which will be addressed in a separate future report. Specifically, USEPA's comments requested a more complete description and illustrations of the conceptual site model of the hydrology in these areas. Notes have been added to the text areas and figures in this report that were the subject of USEPA comments related to the SPBA and SPA and were not revised. Correspondence relating to the above subject matter is included in **Appendix W**.

# 2 SCOPE AND IMPLEMENTATION OF PART 2 INVESTIGATION

Harley-Davidson and United States Army Corps of Engineers (USACE) concurred that additional studies were necessary after the completion of the Part 1 SRI report to evaluate certain identified data gaps. The USEPA and PADEP concurred with the recommendations for additional investigation activities and GSC prepared a Part 2 SRI FSP (GSC, 2012b) that was approved by USEPA and PADEP. This FSP was amended by fifteen (15) addenda prepared as the work progressed. A list of these fifteen (15) addenda is included as **Table 2.0-1**.

GSC prepared the FSP to provide details of the field activities to be performed during the Part 2 SRI at the fYNOP (GSC, 2012b). The goal of the scope of activities was to facilitate the eventual path forward for closure of the fYNOP under the PADEP / USEPA One Cleanup program. The preparation of the numerous addenda allowed the technical team to take advantage of improving or finalizing work scopes based on newly collected data. The addenda were written by GSC, and in one case, KCF Groundwater, Inc. (KCF). They were reviewed and approved by the fYNOP Technical Team, and subsequently reviewed and acknowledged or approved by PADEP and USEPA. The FSP and addenda are included in this report as **Appendix A**. The investigation, as described in the FSP was separated into four phases, summarized below and described in more detail in the following subsections:

1. Phase 1 Pre-Drilling Tasks – A number of regional and off-Site studies were performed prior to drilling. Some of these pre-drilling tasks were performed while the FSP was being finalized. The results of these initial work tasks were used to develop the scope and design of off-Site drilling and other subsequent investigation tasks.
2. Phase 2 Drilling Tasks – Drilling started with on-Site well installation in suspected source areas, and continued while some of the Phase 1 off-Site regional studies were being conducted. Off-Site drilling followed the completion of on-Site drilling in most cases. Numerous drill rig types were deployed, and as many as three drilling crews operated at the same time during portions of the investigation.
3. Phase 3 Testing and Monitoring – Stream studies, weir installation, collection and chemical analysis of surface water and groundwater samples, borehole testing, and tracer testing were conducted after the installation of wells. These Phase 3 work tasks included an 18-month long monitoring program to evaluate the effects of certain groundwater extraction operations

and shutdowns on Codorus Creek, its tributaries, springs and certain groundwater monitoring wells.

4. Phase 4 Data Analysis and Report Preparation – Data were compiled and analyzed and the findings and conclusions of that analysis were documented using text, tables, graphs and maps. This report is the product of these Phase 4 work tasks.

Phases 2 and 3 of the investigation were conducted in accordance with the Health and Safety Plan for Site Investigation and Remediation Activities (GSC, May 2012; revised August 2012) which identified and evaluated potential hazards, decontamination procedures, air monitoring during invasive procedures, personal protective equipment, and specified the emergency procedures and equipment, and the alcohol and drug use policy. The Harley-Davidson Contractor Safety Rules and Practices and Work Instructions for the York Plant were also followed during the investigation activities, on and off the Harley-Davidson property. On occasions when work was out of compliance with the procedures described in the Health and Safety Plan, a root cause analysis was investigated and corrective actions were implemented.

Prior to initiating any studies off-Site, Harley-Davidson requested permission from the property owners and building occupants to gain access to the off-Site properties. In most cases, a formal agreement was prepared between Harley-Davidson and the property owners allowing access. Where property boundaries were in question, a professional surveyor was contracted to delineate boundaries. Access to water use information and to off-Site properties was denied by some of the off-Site property owners which resulted in modifications being made to the originally proposed well locations and the inability to gather data (such as at the Roosevelt Quarry, described in Section 2.1.2).

## 2.1 Phase 1 Pre-Drilling Tasks

Phase 1 tasks were planned to be conducted prior to the drilling tasks. In a few cases the information gained was used to position wells or refine the investigation. Some planned Phase 1 tasks were delayed, but still completed later in the Part 2 investigation. Their descriptions remain in this section to maintain continuity with the FSP and associated addenda.

## 2.1.1 Field Mapping of Local Geology

The shale member of the Kinzers Formation is located west of the Site and has been mapped as shown on **Figure 2.1-1**. The shale exhibits lower hydraulic conductivity than the solution-prone carbonate bedrock beneath the Site and is likely to limit the flow of groundwater, restrict the route of potential karst conduits, and act as a western boundary to the potential deep migration of Site-related COCs. Confirmation of the existence and location of the shale during the Part 2 SRI was important for defining a potential limit of groundwater and Site-related COC migration in the westward direction across Codorus Creek. Therefore, the existence and location of the Kinzers Shale was field-verified in February 2012 by a GSC professional geologist by identifying and measuring the location and orientation (strike and dip) of rock outcrops in areas west and southwest of the Site. The geologic study area included locations near the I-83 and Rt. 30 interchange; south and west of the I-83 interchange toward Prospect Hill and the Roosevelt Quarry; north of Rt. 30 and west of Codorus Creek, including along North George Street; and southwest of the Site, including the abandoned Standard Concrete Products quarry along Sherman Street. The geologist observed and noted the rock type and composition during the field reconnaissance effort. Measurement locations were accurately recorded by a handheld GPS and rock orientation measurements were collected with a Brunton compass. The geologist's field observations are summarized in a memorandum included in **Appendix B**.

## 2.1.2 Review of Groundwater Extraction at the Roosevelt Quarry

An investigation was planned to determine whether dewatering of the Roosevelt Quarry may influence groundwater migration from the Site. The Roosevelt Quarry is located in carbonate rocks approximately 12,000 feet west of the Site as shown on **Figure 1.3-4**. Pumping operations and water elevations at the Roosevelt Quarry were to be investigated to determine the likelihood that dewatering at the quarry may cause groundwater to flow westward from the Site. Historical aerial photographs of the quarry operation were reviewed and a request was made to the quarry personnel for historical pumping/discharge records and groundwater elevation data. The quarry representatives declined to provide the information and Harley-Davidson decided not to pursue further attempts to obtain information about the Roosevelt Quarry, as other information from multiple lines of the investigation would be obtained to investigate conditions west of the Site.

### 2.1.3 Reconnaissance of Wells Located West of Codorus Creek

Groundwater elevation data were obtained for accessible wells located west of the Site and west of Codorus Creek to determine the direction of shallow groundwater flow. Indications that groundwater gradients slope downwards toward Codorus Creek from the west would add another line of evidence that groundwater from the Site is not flowing westward past Codorus Creek.

An online search was made of the Pennsylvania Groundwater Information System (PAGWIS) identifying wells west of the creek, indicating wells located at the following properties in the area of interest: North York Car Wash/T Mobile Store (1720 North George Street), Lehr's Exxon (101 Arsenal Road), Rent a Center/Northgate Shopping Center (1500 North George Street), Cars Plus (a former Sunoco facility located at 2008 North George Street), and Rutter's Dairy (2100 North George Street). PADEP files regarding these properties were reviewed and information was obtained for wells located at the Lehr's Exxon, Cars Plus and Rutter's Dairy properties through the file review. Access permission was granted and a reconnaissance visit was made to measure the groundwater levels in the shallow wells located at the North York Car Wash/T Mobile Store. Locations of these properties are shown on **Figure 2.1-1**. Well locations are approximate, based on the PAGWIS database. Summaries of the file reviews and off-Site reconnaissance are provided in memorandums included in **Appendix C**.

### 2.1.4 Stream Flow Measurements in Codorus Creek and Tributaries

Stream flow measurements were performed on Codorus Creek and its tributaries upstream and downstream of fYNOP to determine if Codorus Creek significantly gains or loses water through the creek bottom or creek banks. The groundwater extraction system at fYNOP was in operation during the time of the measurements. As shown on **Figure 2.1-2**, stream flow was measured upstream and downstream in Codorus Creek at locations COD-SW-23, COD-SW-6/SW-7 and COD-SW-8/SW-9, and in Mill Creek (COD-SW-20), Johnsons Run (COD-SW-10) and the unnamed western tributary (COD-SW-11) near their discharge points to Codorus Creek. Treatment plant discharge flow also was obtained from the York City Sewer Authority (YCSA). Flow measurements were collected on September 26, 2013 and November 21, 2013 when stream flows were lower due to seasonal fluctuations. In both cases, rainfall had not occurred for at least three days prior to collection of the measurements to avoid surface runoff. Field conditions at the time of measuring contributed to an unquantified amount of error in the results. For example, a gravel bar formed part of the channel near location COD-SW-6/SW-7 and transported an unknown amount of stream water, and vegetation in the creek at the downstream location (COD-SW-8/SW-9) wrapped around the measuring device in the stream current making collection of the measurements difficult in some instances. Additional flow measurements were planned for the spring of 2014, but could not be performed because water levels and flow rates were too high to safely enter Codorus Creek.

A summary of flow measurements is shown in **Table 2.1-1** and the calculation spreadsheets are included in **Appendix D**.

A seepage run survey was conducted on two tributaries to Codorus Creek. Stream flows were measured along the courses of Johnsons Run and the unnamed western tributary to Codorus Creek located immediately north of the YCSA on September 2, 2014. The purpose of these measurements was to look for gaining or losing conditions along these stream courses. The groundwater extraction system in the WPL was off for 26 days, allowing the aquifer sufficient time to recover from pumping. Flow monitoring locations and results are shown on **Figure 2.1-3** and results are listed in **Table 2.1-1**.

### 2.1.5 Sampling for Remaining Dye Tracer South of the Site

Addendum #3 of the FSP outlined plans for groundwater sampling to detect and trace the flow path of remaining fluorescent dye to the south, particularly D&C Red #28, that had been injected into on-Site well MW-64D on June 7, 2000 by Langan and Crawford & Associates, Inc. (Crawford 2000, in Langan 2002). During the dye tracing test in 2000, monitoring locations for the dye were limited to several down-gradient surface water locations and storm or sewer outlets. When monitoring for the dye ceased on September 15, 2000, the dye remained undetected at the monitoring locations except at two sewer outlets, which may have been background detections. Because background samples had not been collected at those locations, and this dye is commonly found in municipal wastewater, the detections were not considered as positive detections. The red dye was still visible in MW-64D in 2015.

Dye receptors were deployed for approximately one week in monitoring wells intersecting fractures or solution features up-gradient and down-gradient of MW-64D in the suspected groundwater migration pathway. At the time of the charcoal receptor collection a groundwater grab sample was collected using single-use disposable bailers. Groundwater samples and receptors were submitted to Crawford Hydrology Laboratory of Western Kentucky University, Bowling Green, Kentucky, for laboratory analysis. Laboratory results are included in **Appendix E.1**. The analysis of the charcoal receptors provides a qualitative result regarding the presence or absence of the dye, whereas the analysis of the groundwater sample provides a quantitative result regarding the concentration of the fluorescent dye, if detected. This work was delayed until October 2013 due to access issues, and therefore the results were not used for the original purpose of locating the additional characterization wells south of the Site.

### 2.1.6 Repair of Wells MW-50S&D and MW-51S&D (WPL)

Wells MW-50S&D and MW-51S&D had exhibited unusual responses to recharge events. These wells are located in the WPL in low-lying areas of the paved parking lot west of the north end of Building 4 (Bldg4), shown on **Figure 2.1-4**. While it was possible that the unusual responses were caused by the configuration of the karst network, it was suspected that surface runoff could be affecting the water elevations in these wells. On July 21, 2014, Eichelbergers, Inc. removed the old drive-over manhole covers and replaced them with new water-tight manholes. The new manhole covers were installed slightly elevated with their concrete aprons gently sloping toward the parking lot pavement to deflect precipitation runoff. Observations made during subsequent water level monitoring and sampling events indicate that the new manholes are effective at eliminating infiltration by surface runoff, and numerous observations indicate the unusual responses have ceased. Compression caps were removed and left off of wells MW-50S and MW-51D for several hours in order for the groundwater levels/hydrostatic pressure to equilibrate in the wells prior to collecting water level measurements due to their very low water yields.

## 2.2 Phase 2 Drilling Tasks

The following subsections describe ten drilling tasks that were planned for the Part 2 investigation. All drilling tasks were designed to address components of the data gaps described in Section 1. At the beginning of each subsection describing the drilling task, a description is provided explaining how each task addressed the identified data gaps. In implementing the Part 2 investigations, 45 monitoring wells were installed, with a total linear footage of 5,492 feet. Twenty-five new wells were located on the fYNOP property, and 20 wells were installed off of the property. Six of these 45 wells were constructed with Waterloo™ multi-level sampling systems. The Waterloo™ multi-level sampling systems had 2 to 5 sampling ports in each well for a total of 24 separate ports in the six wells. The locations of newly installed wells are shown on **Figure 2.2-1**. A summary of Site-wide well construction data is included as **Table 2.2-1**. New wells installed during this Part 2 investigation are listed on page 3 of this table.

### 2.2.1 Source Area Investigation

An investigation was conducted in an effort to identify the locations of the sources of elevated concentrations of CVOCs in the groundwater near the Bldg58 and WBldg2 Corridor areas at the Site (**Figures 2.2-1 and 2.2-2**). Unlike most near source groundwater plume areas beneath the Site, the exact mode, mechanism, and age of releases within these two areas is unknown. A detailed summary of this investigation can be found in "Summary Report – Source Area Investigation of the Former W Building 2 Corridor and Building 58 Areas for PART 2 of the Supplemental Groundwater Remedial Investigation, Groundwater Sciences Corporation, April 2013" (GSC, 2013d), provided in **Appendix F**.

Ten shallow monitoring wells designated as MW-126 through MW-135 were installed in the Bldg58 and WBldg2 Corridor areas (**Figure 2.2-2**) using air rotary drilling techniques. Locations for the wells were chosen based on historical groundwater and soil sample analytical results and reported or suspected past operations at the Site. These 10 shallow wells were located around known high concentrations in the groundwater in an attempt to better define the direction from where the CVOC source(s) originated.

Groundwater from the shallow monitoring wells was sampled and the results of chemical analyses were used to select locations for membrane interface probes (MIPs) to screen for potential CVOC sources and help guide the placement of the vertical extent wells. MIP is a semi-quantitative field screening device used to detect total volatile organic compounds in unconsolidated material, providing vertical profiling information on the distribution of total CVOCs. The MIP investigation was completed by Vironex, Inc. of Bowie, Maryland.

MIP locations were chosen based on 1) results of the groundwater sampling analyses from the 10 shallow monitoring wells, 2) proximity to suspected source areas based on data from previous investigations, 3) interpretations of bedrock surface topography, updated based on the shallow monitoring well installations and, 4) a ground penetrating radar (GPR) survey at the Bldg58 area. Field data was reviewed after each MIP was completed to enable the results from earlier MIP screening to be used to guide the selection of later MIP screening locations without demobilization of equipment or interruption of testing.

MIP screening was conducted to the depth of hydraulically driven direct-push drilling refusal (assumed to be bedrock), ranging from approximately 21 to 37 feet bgs in the Bldg58 area and 16 to 66 feet bgs in the WBldg2 Corridor area. Confirmatory samples of soil and groundwater were collected from one boring in the Bldg58 area and from four borings in the WBldg2 Corridor and submitted to TestAmerica for volatile organic compounds (VOC) laboratory analyses using SW-846 Method 8260B. The soil and groundwater sampling and analyses were done to verify and further assess the screening-level microvolt responses of the MIP detectors and to assess the concentrations of individual chemicals in locations with relatively higher MIP responses.

### 2.2.2 Vertical Extent in Suspected Source/DNAPL Areas

The vertical extent of elevated concentrations of chlorinated solvents in the groundwater was investigated in six areas of the Site, including:

1. SW-WPL,
2. TCA Tank/Bldg2 Degreaser area,
3. Bldg58 area,
4. NBldg4 area,
5. WBldg2 Corridor, and
6. Southeast corner of the Site in the SPBA.

These six "vertical extent" areas are shown in blue text boxes on **Figure 2.2-1**.

The goal of the vertical extent investigation was to further delineate the potential vertical migration of the chlorinated solvents in these six areas; determine the existence of deep karst features, which will help determine the depth of circulation and active flow paths of groundwater beneath the Site;

and to describe geologic lithologies (rock types), bedding planes and discontinuities (joints and fractures) at depth. The construction of these wells and subsequent testing using these wells contributed to answering critical questions regarding the nature and extent of contamination, potential for migration of Site groundwater under and west of Codorus Creek, hydraulic characteristics of the aquifer and WPL extraction system effectiveness at depth, and fate and transport of Site COCs.

The vertical extent drilling was completed in two rounds which included drilling, construction, development, surveying of monitoring wells and installation of dedicated sampling pumps or multiport samplers in each of the new deep wells. As summarized below and described more fully in Addendum #8 and Section 4.2.4.4 of the FSP, grouted telescoping casing and HQ coring methods were used to reduce the potential for cross-contamination of DNAPLs being dragging down to deeper depths during drilling. Drilling and well construction proceeded as quickly as possible to avoid or minimize open communication between water-bearing zones.

#### 2.2.2.1 **Round 1 Vertical Extent Drilling**

The six vertical extent wells, MW-136A through MW-141A, were installed during a six-month period from July 2012 to January 2013 to explore the vertical extent of contamination in the six suspected source areas by drilling approximately 50 feet beyond the deepest well in each area, and casing off this zone to eliminate contaminants from above. Changes and additions to the FSP described in Addendums #1 (GSC, 2012d) and #5 (GSC, 2012e) include the modified drilling methods that were necessary to address the stacked solution openings penetrated by the borings. These methods include continuous casing advancement (CCA) using the Stradex system, and installation of telescoping casing with depth to seal off potential cross contamination from water bearing zones above, described in further detail in **Appendix G**. Drilling proceeded from one study area to the next while groundwater samples from the first wells were analyzed by a laboratory. All drilling tasks were performed by Eichelbergers, Inc., under the supervision of a GSC geologist. A detailed narrative of Round 1 vertical extent well drilling is included in **Appendix G**.

The hydraulic connection in the carbonate aquifer and the impact of the current groundwater extraction system in the WPL were tested prior to deepening the new vertical extent wells. Extraction wells in the SW-WPL and CPA were shut down from April 26 to May 15, 2013 while automatic recorders monitored the groundwater levels to determine the influence of pumping on wells in the levee area and in the SW-WPL, especially in MW-136A before it was deepened.

#### 2.2.2.2 **Round 2 Vertical Extent Drilling – Multiport Sampler Installation**

During the first round of the vertical extent drilling, numerous stacked solution openings were encountered in bedrock within the upper approximately 200 feet of the karst aquifer, making the installation of conventional monitoring wells difficult, time-consuming and costly. A decision was made to modify the approach for the follow-up phase of the vertical extent investigation, and utilize a multiport sampling system. These modifications are discussed in detail in Addendum #8 to the FSP (GSC, 2013c). Wells MW-136A, MW-137A, MW-139A and MW-140A were subsequently deepened using the HQ coring method that produces a 3.77-inch diameter borehole since this borehole diameter could accommodate installation of the Waterloo Multilevel Groundwater Monitoring System supplied by Solinst Canada, Ltd.

By implementing coring methods, the potential risk of ground subsidence was significantly lessened. Coring was also advantageous for identifying water bearing zones and produced less investigation-derived waste materials for disposal. The wells were drilled an additional 150 feet beyond the Round 1 completed depth. Descriptions for each well can be found in corresponding well logs found in **Appendix H**. Photographs of the rock core are included in **Appendix I**.

Geophysical logging and heat pulse flow monitoring was completed in the boreholes prior to installation of the Waterloo system, as detailed in the geophysical report from Advanced Geological Services (AGS), and included in **Appendix J.1** through **J.3**. A combination of observations from the drill cores, drilling conditions, and geophysical logging was used to select discrete sampling/monitoring intervals most likely to represent water bearing zones spaced throughout the open interval of each well bore. The discrete monitoring points are separated from each other using water-tight expandable packers positioned at appropriate intervals within the borehole. A typical Waterloo system installation with packers and details regarding these installations are included in **Appendix K.1, K.2 and K.3**. A detailed narrative of the Waterloo installation is included in **Appendix G**.

#### 2.2.2.3 Multiport Groundwater Sampling to Mitigate Cross-Contamination by Drilling

After installation of multiport samplers, the ports were sampled. Although measures were taken to prevent cross-contamination from occurring as described in Section 2.2.2, there was still concern that the lower portions of some of the boreholes may have been contaminated by the upper water bearing zones during the drilling process. Therefore, sample ports were developed, purged and sampled frequently over the first few months after completion to reduce and test for VOCs introduced during the drilling process. Water yield from the ports was minimal, generally at about 0.25 gallons per minute or less, and therefore well development and purging were performed simultaneously. Well development, purging and sampling were accomplished using the dedicated Solinst Double Valve Pumps integral to the Waterloo system (see **Appendix K.3**). The ports were sampled three times in 2013 and twice in 2014. A summary of the results of these multiple rounds of groundwater monitoring is provided on **Table 2.2-2**.

Graphs of time vs. chemistry results from sample ports are included in **Appendix L.1**. These graphs can be used to demonstrate the drilling effects on the water chemistry by assuming that initial and early changes result from removing or depleting the impacts of drilling. For instance, in many cases, there is a rapid change in concentrations from the initial samples compared to the subsequent samples, as illustrated on the time vs. concentration graph provided as **Figure 2.2-3**, or a more gradual but consistent change in concentrations, as illustrated on the time vs. concentration graph provided as **Figure 2.2-4**.

### 2.2.3 Potential for Off-Site Migration West of NPBA

Site-related COCs in the NPBA may have migrated off-Site prior to startup of the extraction system, or could begin to migrate off-Site if the NPBA groundwater extraction system was turned off, as planned. Groundwater extraction at the NPBA began in December 1990 to prevent off-Site contaminant migration to the north. Corroborating the concern regarding off-site migration to the north, pumping of the extraction wells east of MW-18 coincided with a rise in CVOC concentrations detected in several monitoring wells, including MW-18D and MW-18S. Therefore, it was postulated that groundwater extraction from wells CW-5 and CW-6 has pulled CVOCs from a source located west of MW-18S&D. TCE and PCE concentrations are higher in the deeper well at MW-18, with the highest TCE concentration detected at 1,800 micrograms per liter (µg/L) in well MW-18D. This observation led to the concern that groundwater could flow off-Site to the west of MW-18, resulting in the need for further delineation of the lateral extent of CVOCs in the area.

As shown on **Figure 2.2-1**, two nested well pairs, MW-142 S&D and MW-143 S&D, were installed along the northern property boundary south of wells MW-18S&D to characterize the groundwater flow direction and migration of CVOCs in that area of the site. Well logs for these locations can be found in **Appendix H**. Well development was performed at least 24 hours after well installation to remove drilling debris, mud, fine silt and sediment from the well. The wells were developed by surging and pumping the well screens using an electric submersible pump while checking for stabilization of temperature, pH, conductivity, dissolved oxygen and turbidity.

Details and results of this investigation were included in the report "Results of NPBA Extraction System and Bldg3 Footer Drain Monitored Shutdown Tests for Part 2 of the Supplemental Groundwater Remedial Investigation" (GSC, 2014b), which is attached as **Appendix M.1**.

### 2.2.4 Levee Area and Wetlands West of the WPL

To evaluate the potential of deep groundwater migrating from the WPL westward past Codorus Creek, two borings with well installations (MW-145A and MW-147A) were completed adjacent to the Levee Area along the east side of the creek and one boring (MW-148A) was advanced adjacent to the levee on the west side of the creek. The boring located west of the creek was completed with the installation of a Waterloo system. The locations of these wells are shown on **Figure 2.2-1**.

Two shallow wells, MW-144 and MW-146 were installed to a total depth of 25 feet bgs in the residuum within the Levee Area east of Codorus Creek to investigate the role of the creek as a discharge boundary. Shallow groundwater from these wells was sampled and analyzed for CVOCs to more fully characterize the vertical extent of CVOCs within the Levee Area and to quantify the concentration of CVOCs in groundwater discharging to the creek.

Two additional shallow residuum wells, MW-155 and MW-156, were installed in the area between the WPL and the levee, in the area north and south of a small wetlands area. The purpose of the wells was to determine groundwater gradients beneath the wetlands area and to characterize the shallow vertical extent of CVOCs in the area.

Using the results from the electrical imaging (EI) and thermal survey of the creek performed as part of the Part 1 SRI, two deep wells, MW-145A and MW-147A, were located east of Codorus Creek within the Levee Area. The purpose of these deep wells was to investigate the existence of deep conduit features in the carbonate bedrock isolated from Codorus Creek, and the potential for migration of groundwater in deep bedrock zones toward the west. MW-145A was located between the MW-99 and MW-100 well clusters and MW-147A was located south of the MW-100 well cluster where deep conduits were suspected. MW-145A and MW-147A were drilled to a total depth of 250 feet.

AGS of Malvern, Pennsylvania was contracted by GSC to perform a geophysical survey using EI on the west side of Codorus Creek at the locations shown on **Figure 2.2-5** in an attempt to locate and install wells that potentially intersect transmissive zones, such as solution features, in the bedrock. A 2,600-foot long transect was completed using two EI survey lines running North-South parallel to the creek, and separated by the wastewater treatment plant discharge. Results were complicated by interferences caused by cultural features. The complete report is included as **Appendix J.4**.

Drilling location MW-148A, located north of the York City Wastewater Treatment Plant outfall was selected based on the presence of an identified aerial photo-derived fracture trace, and reference to the survey data provided by AGS. MW-148A was advanced in December of 2012 using first air rotary methods for the top of the borehole and then PQ coring methods to the total depth of 221 feet. A three-level Waterloo system was then installed in MW-148A which was then developed/purged using the dedicated Solinst Double Valve Pumps. The purged water was monitored for stabilization of temperature, pH, conductivity, dissolved oxygen, and turbidity as described in Subsection 4.2.4.7.1 of the FSP and sampled for COCs. A well log for this location can be found in **Appendix H**.

While the intention was to drill one or two additional wells on the west side of the creek, access and underground utilities limited viable locations, and no available locations coincided with survey data or fracture trace locations that would improve the potential of intersecting the karst network. The option of angle drilling from the east side of the creek was considered but it was concluded that multilevel well MW-148A combined with mapping the stratigraphy and results of the groundwater gradient established from existing wells located west of the creek provided sufficient data to assess the groundwater gradient and presence of VOCs west of Codorus and that additional wells were not needed west of Codorus Creek to complete the data gap regarding westward migration.

### 2.2.5 South of Site Well Installation and VI Screening

The following subsections describe the rationale and installation of wells located in the SPA, south of the SPBA. A set of deeper wells was installed south of Rt. 30 to delineate the extent of COCs in the SPA, and shallow wells were installed along the perimeter of the SPBA and in the residential neighborhood off-Site south of the SPBA as part of the VI assessment. Well logs for wells installed south of the Site can be found in **Appendix H**.

#### 2.2.5.1 **Wells South of Rt. 30**

These wells were installed primarily to address the data gap identified in the Part 1 SRI regarding the horizontal extent of the Site related COCs, believed to have migrated from the SPBA southward across Rt. 30. In addition, the hydraulic characteristics of the karst aquifer, related to the extent of carbonate rock and the frequency of solution features south of the Site, were examined. Addendum #2 to the FSP described the plan to sample existing off-Site wells located south of Rt. 30 and use that data to help select the locations of proposed additional wells (Addendum #9).

The monitoring well installation locations south of the Site were selected using the new VOC chemistry data and data from the Part 1 SRI including: groundwater potentiometric contours and gradients, historic groundwater VOC chemistry, bedrock surface elevation contours, and fracture trace analysis as reported in Addendum #9 (GSC, 2013e). As described in Addendum #9, electrical imaging could not be used as planned to locate the wells due to property access limitations and underground utilities that would interfere with the results. Two single wells (MW-150 and MW-151) and one well couplet (MW-152S & D) were located south of Rt. 30. These wells are shown on **Figure 2.2-1**.

**Figure 2.2-6**, modified from Addendum #9, shows the locations of the wells with respect to the features and data used to position the wells:

1. MW-150 is located on a fracture trace coincident with a deeper depth to bedrock identified by existing well MW-10D. It was positioned along the suspected path of Site-related COCs identified by MW-110 along Old Arsenal Road, north of Rt. 30.
2. MW-151 is located southeast of the intersection of Eden Road and Rt. 30 on a northeast-southwest trending fracture trace. Based on known groundwater chemistry and water table gradient, this location appeared to be in the potential pathway of the migrating COCs from the fYNOP Site.
3. MW-152S&D was positioned to intersect fracture traces, in a spot that is proximal to the estimated southern limit of the migrating COCs from the fYNOP Site.

#### 2.2.5.2 Wells Installed for VI Screening

The scope of work for shallow well installation along the perimeter of the SPBA and in the residential area on Canterbury Lane and Old Arsenal Road located south of the Site was described in Addendum #15 to the FSP (GSC, 2014e). The plan, as approved by the USEPA, was to install shallow monitoring wells screening the top of the saturated zone (i.e., the water table aquifer), and use the laboratory analytical results from the shallow groundwater to assess the potential for vapor intrusion into the residences in the neighborhood south of the Site.

Fifteen borings were drilled and a monitoring well was installed in each boring. Five of the monitoring wells were installed in the SPBA and 10 monitoring wells were installed in the residential area south of the SPBA. Soils were sampled, and gradation analyses performed by a soils laboratory. Water levels in wells were measured, and two rounds of groundwater samples were collected and analyzed for VOCs. The results of groundwater sampling were evaluated using the USEPA's Vapor Intrusion Screening Level (VISL) Calculator (June 2015) to calculate the cumulative cancer risk (CR) and hazard index (HI) associated with maximum concentrations of all COCs constituting a VI concern. **Appendix N** contains the results of this investigation.

### 2.2.6 Stratigraphic Borings

Stratigraphic borings included in the FSP as an optional task were not completed because sufficient stratigraphic information was obtained through other tasks. Wells drilled for the vertical extent investigation and the well drilled north of the sewer plant (MW-148A), as well as the decision to core the vertical extent borings to facilitate the installation of the Waterloo systems provided sufficient stratigraphic information, and the installation of stratigraphic borings was no longer required to adequately characterize the subsurface lithology and structure of the site. Optical televiewer logging of a number of previously installed open rock borings (discussed in the next subsection) also provided sufficient structural information. This structural information helped to characterize the geology and the deep karst beneath the Site that impacts DNAPL penetration in the aquifer and the migration of dissolved CVOCs in groundwater.

### 2.2.7 Down-hole Geophysical Logging

Geophysical logging of selected open-rock wells was completed using a suite of tools, including an optical televiewer, three-arm caliper, heat-pulse flow meter, and a Century Geophysical multitool which records natural gamma rays, normal resistivity, lateral resistivity, single point resistance, fluid resistivity, and temperature. These logs were used to identify water bearing zones and flow conduits, and to determine the strike and dip of fractures and bedding planes in a borehole. Specifically, the three-arm caliper was used to measure the borehole diameter; the optical televiewer, temperature and all of the resistivity measurements were used to detect water-bearing zones; the gamma ray data were used to detect changes in bedrock lithology; and the heat pulse flow meter was used to detect vertical flow within a borehole between 0.03 and 1.0 gallons per minute (gpm). Reports describing the methods and results of the borehole geophysical investigations were provided by AGS of Malvern, Pennsylvania, and are included in **Appendix J**. **Figure 2.2-7** summarizes the predominant bedrock strike and dip measurements for wells logged.

### 2.2.8 Groundwater Quality Profiling and Velocity Testing of Karst Features

Wells MW-137A, MW-145A and MW-147A (see **Figure 2.2-1**) intersected bedrock solution features and were selected for water quality profiling and groundwater velocity testing, which are two separate, but related, tests. Water quality profiling was conducted to determine the presence of active interconnected solution channels in the carbonate bedrock. Point-dilution tracer testing was performed to measure the horizontal groundwater flow velocity through the boreholes at those intervals containing solution channels that were identified by a geological scientist during well drilling or identified during the water quality profiling. KCF of Mechanicsburg, Pennsylvania conducted the testing in August and September 2012, assisted by Eichelbergers, Inc. of

Mechanicsburg, Pennsylvania and GSC. FSP Sections 4.2.4.6 and 4.2.6.8, and Addendum #2 to the FSP describe the procedures for conducting these tests (GSC, 2012b and KCF, 2012, respectively).

Data gaps addressed by this testing are the potential for a deep karst network hydraulically separate from the shallow karst and Codorus Creek, as well as the general hydraulic characteristics of the karst aquifer.

KCF performed the water quality profiling in the screened or open intervals of the wells to collect data including water level (pressure), temperature, pH, conductivity, dissolved oxygen, and turbidity. If water was entering, exiting, or moving through the well bore, there would likely be a change in at least some of the parameters monitored.

Borehole point-dilution tracer testing was subsequently applied to an identified solution channel feature to measure water level, conductivity, and temperature while a tracer of deionized water was injected through a polyvinyl chloride (PVC) tremie pipe into the well at the testing interval. Changes in temperature and conductivity were monitored as the ambient groundwater flowed back into the well borehole and flushed the deionized water out. The rate of changes of temperature and conductivity were used to estimate the average linear velocity of groundwater through the bedrock solution zone.

In addition to water quality profiling and point-dilution testing, KCF utilized a downhole AquaVision colloidal borescope instrument in an attempt to measure groundwater flow direction and velocity in the deep karstic groundwater flow conduits. The colloidal borescope is a video particle tracking system that operates by tracking and measuring the velocities of natural colloidal particles which are suspended in the groundwater. The particles flow past a downhole video camera and are digitized and tracked by a computer for speed and direction. KCF performed the testing in wells MW-137A and MW-147A; however, the data obtained by the colloidal borescope was not usable because of excessive swirling of the particles which prevented accurate tracking. Technical memorandums describing the study and its associated issues are included in **Appendix O.1**.

#### 2.2.8.1 **TCA Tank/Building 2 Degreaser Area – MW-137A**

Testing of well MW-137A was done on September 17, 2012, after the first phase of drilling and prior to deepening the well to its final depth of 452 feet bgs. MW-137A is located in the CPA, near extraction well CW-8 in the TCA Tank Area. This well intersected one of the very few karst solution channels found by the vertical extent drilling, and certainly the largest. Testing of this solution feature is important because it represents one of the few solution channels found on Site below 200 feet bgs. Nearby groundwater extraction well CW-8 was shut down during the testing, but the other extraction wells in the WPL (CW-9, CW-13, CW-15A and CW-17) remained in operation.

The borehole at the time of testing was open-rock from 270 feet to 298.5 feet bgs. Testing was performed inside a 2-inch diameter monitoring well screened from 283 feet to 298 feet bgs. Water quality profiling was conducted throughout the 15-foot screened interval. Point-dilution testing was then performed in the large solution feature identified from 285 feet to 296 feet bgs with deionized water being injected at a depth of 292 feet bgs. No other solution features were identified or tested in well MW-137A. Temperature and conductivity values obtained during the test are graphed on **Figure 2.2-8**, and included in **Appendix O.2**. These data were used to calculate the average linear velocity (v) of the groundwater, using the equation:

v = (average bulk velocity across well bore) / (porosity) * (adjustment factor),

where average bulk velocity across well bore = [-(well segment volume) / (well cross-sectional area) * (natural logarithm of the change in tracer concentration over time)]; (Freeze and Cherry, 1979; p. 428-430). It should be noted that this equation was developed for porous media aquifers, and therefore the results calculated for the fYNOP site should be considered approximate to the order of magnitude when applied to a karst aquifer.

KCF calculated the velocity of groundwater in the solution feature in well MW-137A as 2.07 feet per minute, using a porosity value of 0.25 and an adjustment factor of 1.0. Calculations and the rationale for selecting values used in the equation are provided in **Appendix O.3 through O.5**. The porosity value of 0.25 was selected because drilling data indicated that the solution features being tested were at least partially filled with silt, clay, sand and rock debris (note that a porosity of 1 would describe a solution feature that is water-filled and completely devoid of solid materials). An "adjustment factor" of 1 was used because sand or gravel packing material did not exist in the wells to restrict or divert the groundwater flow in the test intervals. Velocities exceeding approximately 1 foot per minute typically indicate turbulent flow that would occur through interconnected karst solution features (Green et al, 2006 and Ford and Williams, 2007).

#### 2.2.8.2 **Levee Area Well MW-145A**

MW-145A was drilled on the levee on the eastern side of Codorus Creek, located with the goal of intersecting a deep karst solution channel, based on the geophysical (EI) profile performed during the Part 1 SRI (GSC, 2011, p.13). For the purpose of this investigation, solutions channels that occur at a depth below ground surface of greater than 200 feet were considered deep. Finding and testing deep solution features this close to Codorus Creek was an important step toward understanding the potential for migration under and west of Codorus Creek and the potential for a deep karst network hydraulically separate from the shallow karst.

Six borehole intervals were selected for testing in well MW-145A based on the geological well log indicating the zones of water-filled solution cavities. The only tested zone that was partially filled with sediment was the interval of 105.0 to 120.1 feet bgs where 5.7 feet of the 8.2-foot solution feature contained sediment. Below 200 feet bgs in this boring, no solution features were encountered, although an open fracture was intersected at 206 feet bgs. Each solution feature was isolated from the others and water quality profiling was performed in that zone, followed immediately by the point-dilution testing. The solution features were isolated during each discrete test by beginning the test at the bottom of the borehole, with drill rods used to seal off the groundwater flow above the interval being tested. As testing progressed upward in the borehole, the drill rods were raised to expose the next highest solution feature in the borehole, and the bottom of the borehole was filled with sand and sealed with bentonite. Deionized water was injected at each of the six testing intervals and changes in temperature and conductivity were monitored as the ambient groundwater flowed back into the well. These data were graphed (**Appendix O.6**) and were used to calculate the velocity at each solution feature, as listed below and in **Appendix O.7** and **O.8**:

| Test Interval (feet bgs) | Groundwater Velocity (feet/minute) |
|---|---|
| 105.0-120.1 | 0.037 |
| 160.8-164.0 | 0.028 |
| 182.0-186.0 | 0.004 |
| 190.5-194.0 | 0.043 |
| 194.7-198.7 | 0.101 |
| 199.7-201.6 | 0.031 |

Groundwater velocity values of less than 0.1 feet per minute typically indicate that flow is occurring through interconnected small fractures and pore spaces, but not through karst solution features. (Ford and Williams, 2007). Therefore based on this groundwater velocity data, the solution features penetrated by this borehole appear to not be well connected to an open network of solution features, suggesting they may be plugged with sediment.

#### 2.2.8.3 **Levee Area Well MW-147A**

In well MW-147A, a single solution feature was identified between 207 and 215 feet bgs by the geological scientist during advance of the wellbore. As with MW-145A, testing of this deep solution feature this close Codorus Creek provided an opportunity to gather information on the potential for a deep karst network. Calculations and results of water quality profiling and point-dilution testing are graphed (**Appendix O.9 through O.11**) and indicated a rapid groundwater flow velocity of 1.28 feet per minute. Velocities greater than 1 foot per minute suggest that flow occurs through well-connected karstic solution channels (Green et al, 2006).

### 2.2.9 2013 Comprehensive Groundwater Sampling and Monitoring

After the completion of the drilling phase, all of the newly installed wells along with certain wells present prior to the Part 2 SRI drilling were sampled as part of the 2013 Comprehensive Sampling Event. The goals of this sampling event were to: 1) gather a "snapshot" of VOCs for new wells installed during the Part 2 SRI and certain wells designated as Key Wells in the 2011 sampling event; 2) further characterize the horizontal and vertical extent of the CVOC plume; 3) continue to monitor and characterize the extent of other "minor" contaminant compounds; and 4) to sample for MNA parameters. A complete list of wells and the selection criteria for sampling is included in Addendum #10 (GSC, 2013f).

Two rounds of groundwater elevation measurements were completed in 2013 by Leidos, Inc. (Leidos) and GSC to obtain a "snapshot" of the potentiometric surface beneath the Site. The measurements were collected on August 28, 2013 and November 22, 2013. These data are listed in **Table 2.2-3**, along with previous rounds, which can be used for comparison. A map showing groundwater elevation contours from November 22, 2013 is provided as **Figure 2.2-9**.

Prior to sampling on September 3 through 20, 2013, field monitoring parameters such as pH, temperature, conductivity, turbidity, oxidation-reduction potential, and dissolved oxygen were recorded for each well. Groundwater samples were submitted to TestAmerica Laboratories, and Microbial Insights of Knoxville, Tennessee for analysis. Groundwater from all wells was sampled for VOCs. Groundwater from selected wells was sampled for 1,4-dioxane, cyanide, and total and hexavalent chrome. Water from 30 wells was analyzed for MNA parameters. Analytical results are included in **Tables 2.2-4A through 2.2-4D** and **Table 2.2-2** which also list site-wide historical chemistry results. Laboratory reports are included in **Appendix U** and groundwater purging data from sampling events is provided in **Appendix P**.

## 2.3 Phase 3 Testing and Monitoring

Stream studies, weir installation, stormwater monitoring, and hydrodynamic testing of the groundwater extraction system were conducted after the installation of wells. These tests were designed to answer specific questions regarding the nature of flow in the carbonate aquifer, including karst solution channel interconnections, surface water/groundwater interconnections, and influence of the groundwater collection and extraction system on impacted areas of the plume and the creek. Many of the investigations were extended or modified from the original plan in response to results collected during the testing. **Figure 2.3-1** is a time line illustrating the Phase 3 steps during the study period, which stretched from 2013 through October 2015.

In preparation for the testing and monitoring, a Davis Instruments Wireless Vantage Pro2 weather station was installed on Site to record precipitation, temperature, barometric pressure, wind speed and direction. In addition, 26 wells and observation points were instrumented with In-Situ Troll 500 continuous temperature and water level recorders to assess groundwater conditions and aquifer responses to variations in seasonal precipitation over the course of the 12- to 18-month observation period. Nine wells were instrumented with In-Situ Multiparameter 9500 instruments to continuously record temperature, water level, turbidity, oxidation-reduction potential, pH, dissolved oxygen and conductivity for nearly four months. A map showing the weather station and recorder locations is provided as **Figure 2.3-2**. Weather station data and continuous recorder data are included in **Appendix Q.1 through Q.3**.

### 2.3.1 NPBA Extraction System Monitored Shut Down

Monitored shutdown testing of the NPBA groundwater extraction system was performed to evaluate the need for continued operation of the extraction system located in the NPBA. A data gap identified in the Part 1 SRI was whether this portion of the interim remedy could be safely deactivated.

Section 4.3.4 of the FSP describes the rationale for evaluating the deactivation of the NPBA groundwater extraction system (GSC, 2012b). Addendum #6 to the FSP (GSC, 2013a) provided a detailed plan and procedure for the monitored shutdown. NPBA extraction system shutdown testing was performed by monitoring water levels to determine the groundwater gradients under non-pumping conditions and to determine changes in groundwater chemistry as a result of deactivation of the extraction wells. Monitoring locations are shown on **Figure 2.3-3**.

In the two weeks prior to shutdown, manual groundwater elevations were measured and groundwater samples were collected for COCs to monitor conditions while the extraction system was operating.

Deactivation of all nine groundwater extraction wells, CW-1, CW-1A, CW-2, CW-3, CW-4, CW-5, CW-6, CW-7 and CW-7A, occurred on June 19, 2013 (see time line on **Figure 2.3-1**). Based on hydrographs of the continuously recorded groundwater elevation data, nearly 100 percent recovery from the pumping effects of the groundwater extraction occurred approximately ten days after pumping ceased. Manual groundwater elevation measurements were collected again on August 8 and 28, 2013 when the extraction system had been deactivated for about seven weeks and ten weeks, respectively. The groundwater elevation contour map of August 8, 2013 is shown on **Figure 2.3-4** and the data from August 28, 2013 is shown in cross section on **Figure 2.3-5**. Groundwater samples were obtained again in September 2013 as part of the 2013 comprehensive groundwater sampling program at the end of the testing period.

A more detailed description of the field activities was provided in the report titled "Results of NPBA Extraction System and Bldg3 Footer Drain Monitored Shutdown Tests for Part 2 of the Supplemental Groundwater Remedial Investigation" provided in **Appendix M.1** of this report and in the 2014 Annual Progress Report provided in **Appendix M.2**.

### 2.3.2 Bldg3 Footer Drain Monitored Shutdown

The Bldg3 Lift Station was designed to receive drainage from the footer drain located beneath Bldg3 and from a shallow interceptor trench (Toe Drain) located at the toe of the hillslope east of Bldg3. Collectively, this system is known as the Bldg3 Footer Drain System and was installed to ensure that groundwater does not rise sufficiently high to impact the equipment and press pits at the south end of Bldg3 or the subfloor paint sludge pit in the basement along the west central portion of Bldg3. Recent results of samples collected from the Lift Station had shown COCs at very low concentrations or non-detect in groundwater. A data gap identified in the Part 1 SRI was whether this interim remedy could be safely deactivated. Section 4.3.5 of the FSP and Addendum #7 to the FSP describe the rationale and plan for evaluating the deactivation of the Bldg3 Footer Drain System (GSC, 2012b and 2013b).

Pumping of the Lift Station was shut down on June 19, 2013 (see time line **Figure 2.3-1**). Continuous water level monitoring was performed in the Lift Station, wells MW-112 and MW-128, and in Footer Drain Cleanout 1 (FD1) prior to and during the test. These monitoring locations are shown on **Figure 2.3-6**. Manual water level measurements were also collected at these locations and at Footer Drain Cleanout 3 (FD3) and wells MW-111 and CW-19 on a daily basis for the first five days of shutdown, then weekly for eight weeks during the test. A staff gauge was installed in spring S-3 and observations for visible water seepages were made along the hill slope east of Bldg3, and in surface water drainage features located east, north and west of Bldg3. A more detailed description of the field activities was provided in the report titled "Results of NPBA Extraction System and Bldg3 Footer Drain Monitored Shutdown Tests for Part 2 of the Supplemental Groundwater Remedial Investigation" provided in **Appendix M.1**.

Pumping of the Lift Station has remained deactivated, and monitoring continues to occur on a monthly basis. The ongoing monitoring includes the collection of water level data by the automatic water level recorder in the Lift Station, monthly manual water level monitoring in the footer drain cleanout and well CW-19 located in the basement of Bldg3, and Site visits to look for surface water seepage areas proximate to Bldg3. A letter report summarizing the results of 2014 monitoring ("First Year Progress Report of the Building 3 Footer Drain System Shutdown Monitoring") was prepared by GSC and provided to USEPA and PADEP on May 11, 2015. The letter report is included in **Appendix M.3.**

### 2.3.3 Karst Loss Investigation

KCF was contracted to implement a study to quantify karst-loss and to determine attenuation coefficients for estimating karst loss volumes for future storms. KCF conducted the study from September 17, 2013 through November 26, 2013, illustrated on **Figure 2.3-1**. The investigation was conducted by collecting rainfall data and monitoring storm water runoff at four discharge outfalls or inlets. HACH flow monitoring equipment, including a Sigma 910 Area Velocity Flow Meter and an area-velocity sensor, were installed in each of the storm water pipe monitoring locations, and recorded data to calculate continuous storm water flow measurements.

Three monitored rainfall events (September 21, October 7 and October 10-11, 2013) were selected for storm flow modeling using Bentley PondPack software, version 10.1, 2013, and storm flow hydrographs were developed using Technical Release 55 "Urban Hydrology for Small Watersheds", published by U.S.D.A. – Soil Conservation Service. Monitored drainage basin areas of the Site were determined and the modeling was used to calculate the volume of runoff that would occur under conditions that did not include karst loss.

The modeled runoff volume was compared to the actual measured runoff. Karst loss was estimated to equal the theoretically larger modeled runoff volume minus the actual measured runoff volume (karst loss = modeled runoff volume – measured runoff volume). While this approach should produce accurate estimates of karst loss volumes, the study results were diminished by discrepancies between reported rainfall measurements, the measured runoff, and the modeled data output. The report (KCF, 2014), included in **Appendix R,** indicated that there was an inability to reconcile Site data with modeled flow volumes because, in many instances, the measured runoff exceeded the volume predicted by the modeling. Despite the flawed model results, the general conclusion of the study suggests that the percentage of karst loss decreases with increasing precipitation intensity (more intense rainfall produces more runoff and less percent karst loss).

### 2.3.4 Impact of Karst Loss on the Aquifer and Extraction System

Automatic water level and water quality recorder data were used to examine the impact of infiltrating surface water runoff from large precipitation events (karst loss) on the aquifer and the effectiveness of the interim groundwater extraction system in the WPL.

Insitu® Level Troll 500 Transducers (level trolls) and Level Troll 9500 Multi-Parameter Transducers (multi-parameter recorders) were deployed into selected wells in the WPL, West of the WPL, Bldg2 Area, Bldg58 and the Codorus Creek Levee. These recorders were used to observe the interconnection between wells, and to test the impact of karst loss and the connection of the surface with the aquifer by collecting water levels, and other parameters during precipitation events.

From September 2013 to January 2014, GSC deployed nine Level Troll 9500 Multi-Parameter recorders into wells MW-96D, MW-97, MW-99S, MW-99D, MW-100D, MW-113, MW-145A, MW-147A and CW-20, seen on **Figure 2.3-7**. These multi-parameter recorders collected depth to water, temperature, barometric pressure, turbidity, ORP, pH, DO, percent DO saturated, and conductivity, which are included in **Appendix Q.3** and **Q.6**. These wells were selected due to the presence of voids, making them good candidates for monitoring the water quality and change in water levels in the solution channels in the aquifer to precipitation events. Selected depths are included in the table below:

| Well | Open/Screened (ft/bgs) | Screened (ft/bgs) | Voids (ft/bgs) | Recorder Depth (ft/bgs) |
|---|---|---|---|---|
| MW-96D | 75.5-90 | 77.5-87.5 | 77-90 | 85 |
| MW-97 | 68-Undetermined | 70-80 | 62-Bottom Undetermined | 75 |
| MW-99S | 60.5-74.3 | 64.3-74.3 | 67-74.3 | 70 |
| MW-99D | 131-142 | 132-142 | 131-131.5,133-137 & 141-144 | 135 |
| MW-100D | 97.5-114 | 104-114 | 103-121 | 110 |
| MW-113 | 129-Undetermined | 131-151 | 137-152 & 154-Bottom Undetermined | 80 |
| MW-145A | 200-250 | NA | Fractured throughout | 200 |
| MW-147A | 200-250 | NA | 207-215 | 210 |
| CW-20 | 205-215 | 205-215 | 213-214 & 216-217 | NA |

From January 2013 through October 2015, GSC placed Level Troll 500s, which monitor depth to water, temperature, and pressure, in multiple wells across the site, seen on **Figure 2.3-2**. Many wells on the levee had existing recorders which also collected data during this time. All recorders were set to collect data in fifteen minute increments and were downloaded once or twice a week during the testing periods to ensure proper function and calibration. This array of recorders was used to evaluate the impact of karst loss on the extraction system. The complete data set is included in **Appendix Q.2**.

### 2.3.5 Selection of Codorus Creek Sampling Locations

The thermal/water quality survey conducted in August of 2007 indicated that groundwater was discharging to Codorus Creek from discrete locations along the bank and bed of the creek. On August 22, 2013, selected springs/groundwater discharges that were identified in 2007 were located using GPS and a meter with thermal probes. **Figure 2.3-8** shows the locations of low temperature anomalies identified in the 2007 survey. "Areas of Interest" were selected (shown as red circles) where clusters of anomalies were identified, and the 2013 field efforts were focused. An effort was also made to locate additional seepage areas along the banks of the creek.

Guided by the results measured in the field, twelve locations were selected and sampled, including the YCSA outfall (see location COD-SW-12), also shown on **Figure 2.3-8.** Water samples were collected at locations that indicated a temperature difference compared with the surrounding surface water to investigate and confirm the potential of groundwater discharge from the Site. The samples were collected by placing a Van Dorn sampler or a clean plastic container directly into the water flow where the temperature anomaly was detected. Upstream samples COD-SW-6 and COD-SW-7, and downstream samples COD-SW-8 and COD-SW-9 were sampled twice on September 22, 2013: once in the morning and once in the afternoon to detect any changes in chemistry as related to daily temperature fluctuations. Samples were submitted to TestAmerica Pittsburgh for analysis of VOCs, alkalinity, Priority Pollutant metals, chloride, nitrate and sulfate.

Results were initially presented in Addendum #11 to the FSP and used to design subsequent tracer and stream sampling studies (GSC, 2013g). **Tables 2.3-1A through 2.3-1C** present the results of the laboratory analyses. Laboratory reports are included in **Appendix U.**

Two locations were discovered that were apparent groundwater-fed springs into Codorus Creek. In both cases, these discharges were below the water level of the creek on the day of sampling. Samples collected at these locations are designated COD-SW-17 and COD-SW-15, and are considered spring samples, resulting from groundwater discharges. The temperature of the water in these areas was approximately 20°F lower than the ambient temperature of the creek on a date when surface water temperatures would normally be well above groundwater temperatures, indicating direct influence of groundwater discharge to the creek (**Figure 2.3-8**). Total alkalinity in these samples was two times higher than other samples from the creek, suggestive of surface water mixing with groundwater discharging from a carbonate aquifer. Total alkalinity values for each sampled station are included on **Figure 2.3-8** with stream alkalinity posted as 110,000 to 120,000 µg/L and spring samples 220,000 and 244,000 µg/L.

Based on the results of this initial sampling, nine surface water and spring monitoring stations were constructed to collect additional samples from Codorus Creek and its tributaries. The outfall from the YCSA (SW-12) also was added as a monitoring location. As the studies progressed, six additional monitoring stations were established.

### 2.3.6 Tracer Testing of Extraction System Capture of Deep Karst in SW-WPL

A qualitative dye tracing test was performed as part of the hydrodynamic testing and monitoring of the groundwater extraction system in the SW-WPL. Addenda #11 and #13 to the FSP describe details and considerations used for the design of the test (GSC, 2013g and 2014a). The objective of this test was to determine whether intermediate to deep karstic groundwater in the SW-WPL area is captured by the groundwater extraction system. **Figure 2.3-1** delineates the timing of this test with respect to other field investigations and the operation of the extraction wells.

CW-20, which was not operating as a groundwater extraction well at the time of the tracer testing, exhibited a deep karst solution feature in the depth interval of 213 to 216 feet bgs and was therefore selected as the dye injection well. **Figure 2.3-9** shows the locations of the dye injection well (CW-20) and the operating extraction wells (CW-8, CW-9, CW-13, CW-15A and CW-17) and monitoring wells (MW-8, MW-93S&D and MW-107) that were monitored during this test in addition to the combined treatment system effluent. Twenty-five pounds of fluorescent dye sulphorohodamine B (SRB) were injected into the karst solution feature in well CW-20 at a depth of 213 feet bgs on November 11, 2013 while the groundwater extraction system was in operation. The dye was dissolved in 32.5 gallons of potable water and injected as a liquid at a rate of 2.5 gpm. After dye injection was complete, 100 gallons of potable water were injected at a rate of about 2.5

gpm to flush the dye into the aquifer. The water level in the injection well was monitored during injection and water flushing to ensure that a dye/water mound was not created during injection because mounding would potentially cause the dye to travel contrary to gradients established by the pumping.

Groundwater and surface water samples were collected using protocols recommended by Crawford Hydrology Laboratory to monitor for the presence of SRB prior to the dye injection (background samples) and periodically for two weeks after injection. Samples were collected daily for seven days after dye injection, then every two or three days until the two week period had ended. Results are included in **Appendix O.2**.

### 2.3.7 Extraction System Shutdown and Restart Testing

The groundwater extraction system was shut down for nearly five months on two occasions: from November 25, 2013 to April 7, 2014 and from August 11, 2014 to January 27, 2015 (see **Figure 2.3-1**) as described in Addenda #11, #13 and #14 to the FSP, and in a December 30, 2013 letter to Ms. Pamela Trowbridge (PADEP) and Mr. Griff Miller (USEPA) (GSC, 2013g, 2014a and 2014c). The objectives of the system shutdown/restart testing were to:

1. monitor groundwater flow paths under non-pumping conditions by conducting additional tracer testing when the system was turned off;
2. assess impact of uncontrolled groundwater chemical flux to Codorus Creek by monitoring changes in groundwater and surface water chemistry as a result of shutting down the extraction system; and
3. observing the performance of the extraction system by subsequently turning it back on.

The first shutdown test was conducted in the winter and spring when groundwater levels and creek flow are typically higher, and called the Wet Season Extraction System Shutdown Test. Two collection wells, (CW-9) and previously inactive SW-WPL extraction well (CW-20), were active between the two shutdown tests. The second shutdown test was conducted during the typically drier months of the year, with corresponding lower groundwater levels and creek flows, and called the Dry Season Extraction System Shutdown Test.

During the first shutdown test, a variety of fluorescent dyes were injected into wells MW-147A, MW-100D and MW-99D along the Codorus Creek levee and into wells CW-20 and CW-17 in the WPL. The first extraction system restart consisted of pumping only from previously inactive well CW-20 in April 2014, followed by the addition of extraction well CW-9 on July 23, 2014. Both of these wells were then shut down on August 11, 2014. During the second shutdown test, dye was again injected into well CW-17. Groundwater and surface water were monitored for VOCs, alkalinity, the anions sulfate, nitrate, chloride, and the cations calcium, potassium, magnesium, sodium (hereafter described as "common ions") during both of the extraction system shutdown and startup cycles. Investigation methods and rationale are described in the following subsections. Dye laboratory results are included in **Appendix E.2**, and photographs of field activities are included in **Appendix E.3**. A summary of all Phase 3 dye injection tests is provided in **Table 2.3-2** below.

**Table 2.3-2: Summary of Phase 3 Dye Injections**

| Date of Injection | Type of Dye | Injection Well | Targeted Injection Depth (ft bgs) | Mass of Dye Injected (dry weight in lbs.) | Volume of Dye Injected (gallons) |
|---|---|---|---|---|---|
| 11/11/2013 | SRB | CW-20 | 213-216 | 25 | 32.5 |
| 12/17/2013 | Fluorescein | MW-99D | 132-142 | 15 | 15 |
| 12/17/2013 | Eosine | MW-100D | 103-121 | 30 | 30 |
| 12/17/2013 | RWT | MW-147A | 210-215 | 16 | 2 |
| 1/31/2014 | Green 8 | CW-20 | 213-216 | 48 | 50 |
| 3/7/2014 | SRB | CW-17 | 32-64 | 26 | 32.5 |
| 9/12/2014 | SRB | CW-17 | 32-64 | 34 | 42.5 |

#### 2.3.7.1 Levee Area Dye Tracer Testing

In preparation for tracer testing, dye tracer matrix interference and background samples were collected from Codorus Creek to assess the feasibility of conducting dye tracer testing west of the Site at the WPL and levee areas. Laboratory results indicated that common tracer dyes fluorescein, eosine, D&C Red #28, Rhodamine WT (RWT) and SRB would be feasible to use for dye tracing at the Site. This data was used to select tracers for the injection testing.

Tracer testing in wells MW-147A, MW-100D and MW-99D, located on the east side of the Codorus Creek levee was to investigate whether the deep karstic groundwater flowing beneath the

Site discharges to Codorus Creek under natural (non-pumping) conditions. This test was designed to examine the data gap that Site groundwater may be passing under Codorus Creek, and that there may be a deep conduit system that is not connected to the shallow system.

Three different non-toxic commercially available dyes were injected as tracers into karst solution features in wells MW-147A, MW-100D and MW-99D on December 17, 2013, 22 days after shutdown of the extraction system when groundwater levels had returned to natural (non-pumping) gradients. The dyes used in the tracer testing were supplied by Crawford Hydrology Laboratory were RWT, eosine, and fluorescein. **Figure 2.3-10** illustrates the locations of tracer injections and monitoring stations.

Red fluorescent dye RWT injected into well MW-147A by pouring the dye solution into a PVC pipe extending to 195 feet bgs to deliver the tracer to the single karst solution feature located in the well (see **Table 2.3-2** on previous page). The dye conveyance piping was not extended to the depth of the karst feature because of a blockage in the well. This solution feature, at a depth of 207 to 215 feet bgs, was the deepest one encountered at the levee area and was chosen for dye injection because it represents a deep karstic pathway adjacent to Codorus Creek. After dye injection was complete, 50 gallons of potable water were injected through the PVC pipe using a clean centrifugal pump to flush the dye into the aquifer. The water level in the injection well was monitored during injection and water flushing to verify that a dye/water mound was not created during injection that would potentially cause the dye to travel contrary to natural gradients.

In a similar manner, the red fluorescent dye eosine was injected into well MW-100D at a depth of 110 feet bgs to deliver the tracer dye to a solution feature located in the well between 103 and 121 feet bgs. This solution feature represents a moderately deep karstic pathway adjacent to Codorus Creek. After dye injection was complete, 100 gallons of potable water was used to flush the dye into the aquifer.

Green fluorescent tracer dye fluorescein was injected into well MW-99D to a depth of 135 feet bgs into a solution feature located in the well between 132 and 142 feet bgs. This solution feature represents a moderately deep karstic pathway adjacent to Codorus Creek. After dye injection was complete, 50 gallons of potable water were injected through the PVC pipe using the centrifugal pump to flush the dye into the aquifer.

Automatic water samplers were set up to collect samples from spring location SW-15, on the west side of the creek, and spring location SW-17, on the east side of the creek, at a frequency of every four hours for two days. In addition to the water samples collected at SW-15 and SW-17, charcoal dye receptors were placed in the spring discharges, collected and replaced daily for a period of three days, as a secondary detection method.

Monitoring for dyes was conducted at surface water locations and wells shown on **Figure 2.3-10**. Samples were collected daily for the first three days after dye injection and then twice per week for the next three weeks. Monitoring for dyes then continued on a weekly basis through March 4, 2014.

Dyes were monitored using laboratory-supplied charcoal receptors that were left in the creek to adsorb dyes and by collecting discreet water grab samples into laboratory-supplied borosilicate vials. The charcoal receptors were anchored to concrete blocks placed in the flow of surface water. Within the monitoring wells, charcoal receptors were suspended on fishing line or nylon bailer twine in the wells at depths of known solution features. Dye laboratory results are included in **Appendix E.2**

#### 2.3.7.2 **CW-20 Area Dye Tracer Testing**

The shutdown of the groundwater extraction system was extended past the planned re-start date of January 15, 2014 in part, to conduct a second dye tracer test by injecting dye into well CW-20 while the extraction system was turned off. This second dye tracer test at CW-20 was performed to determine potential routes and travel times of groundwater from the deep karst solution features in the SW-WPL area under non-pumping conditions.

Fluorescent dye D&C Green 8, also known as Pyranine dye, was injected on January 31, 2014 into well CW-20 at 213 feet bgs, and flushed with 55 gallons of potable water using a new clean sump pump in a manner similar to the previous dye injections. The location of the injection is illustrated on **Figure 2.3-10**. Dyes were monitored at the previously monitored surface water locations and from wells MW-93S&D, MW-147A, MW-100S,I&D and MW-145A using charcoal receptors. Dye laboratory results are included in **Appendix E.2**

### 2.3.7.3 **CW-17 Dye Tracer Testing**

SRB dye was injected into the large cavern in well CW-17 during two separate events. These dye tracing tests were performed to investigate the potential existence of a conduit system extending from the north-central portion of the WPL to Codorus Creek. Well CW-17 is an extraction well located in the WPL that controls the groundwater migration from two source areas located in the WBldg2 Corridor and the area of NBldg4. This well penetrates a cavern open from 32 to 64 feet bgs. Sonar measurements collected by R. E. Wright Environmental prior to pump installation indicate the cavern is over 20 feet wide. Identification of a dye tracer flow path from this area to the creek under non-pumping conditions would help determine the flow path of COCs from these source area locations under natural conditions, thus providing a location for a future monitoring point or treatment location in the creek.

The first injection occurred on March 7, 2014 when 26 pounds of SRB dissolved in 32.5 gallons of water were injected to a depth of 47 feet bgs into the cavern in CW-17. The dye was injected at a rate of 2.7 gpm through a ¾-inch PVC pipe using a new submersible sump pump. Seventy-five gallons of potable water were subsequently pumped through the pipe to flush the dye out into the cavern.

SRB was re-injected into the solution cavern in well CW-17 during the Dry Season extraction system shutdown period because the suspected discrete channel to Codorus Creek had not been discovered during the monitoring period for the first injection test. It was suspected that higher Spring season flows in the creek during the first injection may have made the dye undetectable. On September 12, 2014, 34 pounds of SRB dissolved in 42.5 gallons of water were injected into the solution cavern followed by 55 gallons of potable water. By increasing the volume of dye and performing the injection under drier conditions, it was anticipated that dilution effects would be minimized for the second dye tracer test at CW-17.

The established surface water locations and 24 wells located west of CW-17 were monitored for dye during the second tracer test at well CW-17. Dye receptors were deployed and collected every three to four days for a period of three weeks, then weekly for seven more weeks. Subsequent monitoring of the surface water stations for dyes continued weekly until January 13, 2015. Dye receptor stations for the second dye tracer testing at CW-17 were monitored for four months. Dye laboratory results are included in **Appendix E.2**

### 2.3.7.4 Creek and Groundwater Monitoring During Extraction System Shutdown and Restart

In addition to conducting tracer testing during the extraction system shutdown periods described above, groundwater and surface water samples were collected and analyzed for water quality parameters and Site-related COCs. This work was done concurrently with the dye tracer monitoring at the same monitoring stations. A primary objective for conducting the groundwater extraction system shutdown and startup tests was to monitor changes in COC concentrations in the groundwater and surface water during complete shutdown and during different groundwater extraction scenarios. Water levels in the wells were also monitored to better understand the aquifer's response to precipitation events under pumping and non-pumping conditions, and the aquifer response to pumping under the various scenarios tested. Results from this task were used to address data gaps, including the potential for migration of Site COCs beneath Codorus Creek, hydraulic characteristics of the karst aquifer, and specifically the impact of extraction well shut down on Codorus Creek surface water chemistry.

#### 2.3.7.4.1 Initial Extraction System Shutdown Monitoring

The work plan for this shutdown monitoring was described in Addendum #11 to the FSP (GSC, 2013g). Sampling locations monitored during the extraction system shutdown and startup testing are shown on **Figure 2.3-10**. The sampled surface water locations were COD-SW-6, COD-SW-7, COD-SW-8, COD-SW-9, COD-SW-10, COD-SW-11, COD-SW-12, COD-SW-15 (spring), COD-SW-17 (spring), COD-SW-20 and COD-SW-26. As testing progressed, the following sampling locations were added to better define the locations of discharges of COCs to the creek: COD-SW-13, COD-SW-16, COD-SW-27, COD-SW-28 and COD-SW-29.

Many of these sample locations were selected because they were potentially in close proximity to submerged groundwater discharges based on variations in surface water temperatures (groundwater was cooler than creek water during the time the survey was conducted to locate the stream monitoring stations, see Subsection 2.3.5). This was done to maximize the potential to detect dye tracers transported by groundwater to the creek. During that process, three distinct spring discharges were located (COD-SW-15, -17 and -26). The depth of submergence of the springs varies based on the stage of the creek An average creek stage of 339.5 feet above mean sea level (amsl) at the Site was estimated by using the annual average flow rate of 275 cubic feet per second reported at the USGS Gage No. 01575500 (see **Figure 2.3-11**), by determining dates when this flow rate occurred at the Gage, and then by using the water level data from the transducer at Codorus 2 on those same dates to determine the average creek stage at the Codorus 2. The average creek stage at each spring location was extrapolated using an average creek slope of 0.0004 and the distance to the spring from Codorus 2. The springs are sometimes completely submerged by the creek, while at other times, the discharges are above creek stage:

- COD-SW-15 – this spring is usually about 0.5 feet above an average creek stage of 339.8 feet amsl at COD-SW-15 and is only submerged below the creek stage after precipitation events raise the creek level to above approximately 340.3 feet amsl.
- COD-SW-17 – this spring is usually about 1 foot below an average creek stage of 340 feet amsl at COD-SW-17, making the discharge difficult to observe visually. Its discharge is visible as “bubbling” only when the creek stage drops to about 339.5 feet amsl. In drier conditions after a storm event, this spring has appeared to shift locations where it discharges to the creek, sometimes by about 0.5 feet upstream or downstream and possibly in vertical elevation when silt and debris clog the spring outlet.
- COD-SW-26 – this spring emerges from the bottom of the creek bed near the western bank and is submerged under flowing creek water except under dry conditions with creek stage of less than about 340 feet amsl at COD-SW-26, when the depression in the creek bottom becomes exposed.

#### 2.3.7.4.2 Groundwater Extraction Testing in the SW-WPL

As a result of confirming the hydraulic connection between the SW-WPL area and the submerged spring discharging to Codorus Creek at COD-SW-17, there was interest in testing the influence on the creek water quality by pumping only from the SW-WPL. Extraction well CW-20 had been constructed and tested in 2006, but never operated. A pump was installed and piping and power changes were made to accommodate operation of this well. CW-20 was activated on April 7, 2014, and pumped at a rate of 97 gpm. Extraction well CW-9 was turned on July 23, 2014 at a rate of 27 gpm so that both wells were operating. Surface water and groundwater samples from Codorus Creek and adjacent wells were analyzed for VOCs, alkalinity, sulfate, chloride, nitrates, total sodium, calcium, potassium and magnesium. Results are listed in **Tables 2.2-4a, 2.2-4d, 2.3-1a** and **2.3-1c**. Laboratory analytical reports are included in **Appendix U**. A groundwater contour map (**Figure 2.3-12**) with only CW-20 pumping was constructed using May 5, 2014 water levels. It is discussed in Section 2.3.9.

#### 2.3.7.4.3 Dry Season Extraction System Shutdown Monitoring

The second groundwater extraction system shutdown, referred to as the 2014 Dry Season Shutdown Test, occurred from August 11, 2014 to January 27, 2015. Illustrated on the timeline on **Figure 2.3-1,** all the extraction wells, including CW-20 and CW-9, were shut off during the testing period. The rationale for conducting the 2014 Dry Season Shutdown Test and the detailed monitoring plans are described in Addendum #14 to the FSP (GSC, 2014c), which was approved by USEPA on October 30, 2014. Groundwater and surface water chemistry results collected prior to and after the first extraction system shutdown and after startup of wells CW-20 and CW-9 provided the basis for comparison as changes were imposed on the groundwater flow system in the SW-WPL area. The 2014 Dry Season Shutdown Test was designed to determine the level of impact that complete system shutdown would have on groundwater and surface water quality when dilution effects in the creek from surface water runoff are at a minimum.

Surface water stations were sampled every two weeks and wells were sampled every four weeks during the test. The groundwater extraction system was restarted on January 27, 2015 with the operation of wells CW-9, CW-13, CW-15A, CW-17 and CW-20. After the restart, monitoring of surface water and groundwater chemistry continued for four months at a frequency of every four weeks (monthly), through the week of May 18, 2015, with sample collection and analysis for the same parameters as described above. Laboratory reports are included in **Appendix U**.

### 2.3.8 2014 Comprehensive Groundwater and Surface Water Monitoring

A total of 162 discrete locations/depth intervals were included in the 2014 Comprehensive Sampling event that occurred under non-pumping conditions during the Dry Season Extraction System Shutdown test described above. As with the 2013 Comprehensive Sampling event, the objective was to gather a snapshot of VOC concentrations from selected wells and surface water locations to further characterize the horizontal and vertical extent of the VOC plume and other "minor" compounds, and to sample for MNA parameters. The sampling event occurred in October 2014 after the groundwater extraction system had been off for two months, allowing for the groundwater elevations to return to natural static conditions. This is in contrast to the 2013 Comprehensive Sampling event which was conducted under pumping conditions. Refer to FSP (GSC, 2012b) Section 4.2.4.7 for groundwater sampling protocols, to the Quality Assurance Project Plan (QAPP) (GSC, 2012c) for quality control procedures, and to Addendum #14 to the FSP (GSC, 2014c) for the detailed work plan of the 2014 Comprehensive Sampling event.

Prior to sample collection, water level measurements were collected on October 7, 2014 by Leidos and GSC from 209 wells, 25 Waterloo multilevel sampling ports, two stream locations, and from the inactive, water-filled quarry owned by Standard Concrete Products located south of the Site. Water level data is included in **Table 2.2-3** and shallow- to intermediate-depth groundwater elevation contours are shown on **Figure 2.3-13**. Field monitoring parameters are included in **Appendix P**.

One location (MW-64S) could not be sampled because the water level in the well had receded below the screened interval of the well. In three proposed locations, water could not be obtained from Waterloo sampling ports (MW139A 305.5 – 306 feet, MW-139A 454.5 – 455 feet, MW-140A 285 – 285.5 feet). All remaining 158 locations were sampled for VOCs; 52 locations were sampled for alkalinity, common ions; and selected wells were sampled for 1,4-dioxane, cyanide, and total and hexavalent chromium. Laboratory results including historical data, are summarized in Tables 2.3-4a through 2.3-4d. Thirty wells were analyzed for natural attenuation parameters, discussed in the following subsection.

Sampling locations are shown on **Figure 2.3-14**. A list of the locations sampled and their selection criteria are included in Addendum #14 (GSC, 2014c).

#### 2.3.8.1 MNA Sampling and Analysis

The MNA sampling was performed following the Addendum #10 to the FSP (GSC, 2013f) at 30 well locations across the Site to assess the degree of reductive dechlorination within various portions of the aquifer and the groundwater plume. Areas at the Site where MNA samples were collected and well locations/open intervals in the wells that were sampled are presented on **Figure 2.3-15**. Additional information on the MNA sampling and work scope changes are provided below:

1. NPBA – Seven wells were sampled within the fractured quartzitic sandstone aquifer beneath the NPBA.
2. SPBA and SPA – Five wells were sampled within the carbonate aquifer that represent the groundwater plume conditions at and downgradient of the source at the SPBA.
3. CPA, WPL and Codorus Creek Levee within the WPA – 18 carbonate aquifer wells were sampled within the WPA that represent source/plume conditions in the CPA and WPL and downgradient plume conditions along the flood control levee on the east of Codorus Creek. The 18 WPA wells include:
    a. CPA wells MW-49D, MW-137A (conduit well), MW-139A, CW-8 (conduit well) and CW-15A. Wells MW-49D and MW-139A were not originally proposed for sampling in the FSP, but were included in the second round of sampling in October 2014 to obtain supplemental MNA data from within the deep carbonate aquifer beneath the karst solution features.
    b. WPL wells MW-7, MW-51S, MW-51D, MW-136A and CW-13. Two separate zones were sampled deep within the carbonate aquifer at well MW-136A (356 to 356.5 feet bgs and 434 to 443.5 bgs). An MNA sample from the MW-136A Waterloo port at the open interval from 356 to 356.5 feet bgs was not collected during the second sampling round in October 2014 because of a concern that a sufficient volume of water for the MNA analyses could not be generated due to the low yield of the sampling port.
    c. Codorus Creek Levee wells MW-98S, MW-98I, MW-99S, MW-99D, MW-100S, MW-100D, MW-146 and MW-147A.

The MNA groundwater samples from September 2013 and October 2014 were analyzed for the following parameters:

- VOCs.
- Transformation indicators/inorganics (electron acceptors – nitrate, ferric iron [$Fe^{+3}$], etc.).

- Microbial Analyses – *dehalococcoides spp*, (ethene degraders) including three specific strains that are TCE and VC degraders, and *dehalobacter spp* (ethane degraders).
- MNA field screening parameters – dissolved oxygen (DO), oxidation-reduction potential, pH, specific conductance, temperature and turbidity.

The October 2014 samples were also analyzed for dissolved gases to assess microbial respiration by-products (carbon dioxide and methane) and dechlorination end-products (ethene and ethane). The September 2013 samples were accidentally omitted for analysis of dissolved gases.

A summary of the analysis results for the MNA samples is provided on **Table 2.3-3**.

The MNA analytical results and screening for anaerobic biodegradation processes following the USEPA's *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* dated September 1998 are included in Section 3.3.1. All laboratory reports are included in **Appendix U**.

### 2.3.9 Groundwater Level Monitoring During Phase 3 Testing

In addition to the monitoring performed on October 7, 2014 described in Section 2.3.7, site-wide groundwater elevation measurements were also completed on January 16, 2014 and May 5, 2014. Water elevation contours for these dates are shown on **Figures 2.3-16 and 2.3-12**, respectively. The groundwater extraction system was off for the winter/spring shut down during water level measurements conducted on January 16, 2014. Only extraction well CW-20 was operating during the May 5, 2014 water level round. Because the solution feature in CW-20 is highly transmissive, a deflection of groundwater contours cannot be observed on **Figure 2.3-12** when CW-20 was operating. On each of the groundwater elevation contour maps, the contours were constructed by using elevation data from the shallowest wells among a cluster of wells in a particular area of the Site, as shown in blue text on the maps.

### 2.3.10 2015 Comprehensive Groundwater and Surface Water Monitoring

A total of 99 discrete locations/depth intervals were sampled as part of the 2015 Comprehensive Sampling event that occurred after the restart of the interim groundwater extraction system on January 27, 2015. As with the 2013 and 2014 Comprehensive Sampling events, the objective was to gather a snapshot of VOC concentrations from selected wells and surface water locations to further characterize the horizontal and vertical extent of the VOC plume and other "minor" compounds. The sampling event occurred in late September and early October 2015 after the groundwater extraction system had been operating for eight months which allowed for the groundwater elevations to return to stable pumping conditions. Refer to FSP (GSC, 2012b) Section 4.2.4.7 for groundwater sampling protocols and to the Quality Assurance Project Plan (QAPP) (GSC, 2012c) for quality control procedures. Sampling locations are shown on **Figure 2.3-17** and are listed in **Table 2.3-4**. Associated groundwater elevation data for measurements collected on September 3, 2015 are included in **Table 2.2-3.** A groundwater elevation contour map (**Figure 2.3-18)** shows the piezometric surface depression surrounding well CW-13, and extending around CW-9, CW-17 and CW-20 as a result groundwater extraction in the WPL.

## 2.4 Laboratory Data Quality Assessment

A comprehensive quality assurance/quality control (QA/QC) program was followed during Part 2 of the SRI at fYNOP. A total of 212 sample delivery groups (SDGs) were generated for 1,580 groundwater, surface water, and treatment system (effluent) samples that were collected from June 1, 2012 through October 7, 2015. **Table 2.4-1** lists these environmental samples, including the lot number, laboratory sample identification number (assigned by the analytical laboratory), sample type (source description), sample identification number (assigned in the field), sample location, date and time of collection, and the type of data validation (complete validation or general review) performed on the analytical laboratory results. **Table 2.4-1** also indicates whether a duplicate sample was collected.

**Table 2.4-2** lists the 315 QC blank samples that were collected during Part 2 of the SRI. These QC samples consist of equipment rinse blanks, field blanks, and trip blanks. The column on Table 2.4-2 listed as "Validation Type" identifies whether the sample received a full validation or a general review.

Nearly all of the 1,580 environmental samples, all of the 315 associated QC blank samples and all duplicate samples were analyzed for VOCs using approved methods specified in the QAPP (GSC, 2012c and 2014d) and in Addendum #15 of the FSP for Part 2 of the SRI (GSC, 2014e). Some samples were also analyzed for inorganic and indicator parameters, metals, and dissolved gases.

**Table 2.4-3** summarizes the 36 analytical methods that were used during Part 2 of the SRI, and shows the total number of analyses performed for each method.

GSC systematically reviewed 21 SDGs randomly selected from the 212 SDGs generated during the project (10 percent of all data packages) for compliance with QC criteria in accordance with Section B.2.8 of the QAPP. The GSC Data Validator conducted a complete data validation on these 21 SDGs using SAIC Technical Procedure TP-DM-300-7 (Rev. 3, June 2009) and based on the following categories:

1. Review and verification of the laboratory case narrative;
2. Verification of sample reanalysis and secondary dilutions;
3. Holding time limits;
4. Surrogate (System Monitoring Compound) percent recoveries (%R) for organic methods;
5. Internal Standard (IS) area counts and retention times for organic methods;
6. Blank contamination (in method, field, equipment rinse and trip blanks);
7. Relative Response Factors (RRFs) in initial calibration and continuing calibrations, Percent Relative Standard Deviation (%RSD) in initial calibrations, and Percent Difference (%D) in continuing calibrations;
8. Matrix Spike and Matrix Spike Duplicate (MS/MSD) Percent Recovery (%R) and Relative Percent Difference (RPD);
9. Laboratory Control Sample and Laboratory Control Sample Duplicate (LCS/LCSD) %R and RPD.

All 212 SDGs generated during the project were screened for holding time exceedances, surrogate recoveries, and method blank detections of VOCs as part of the general review of data packages. The laboratory case narratives were also reviewed for all SDGs.

For the 21 data packages subjected to complete validation per TP-DM-300-7, the contents of the data packages and QA/QC results were compared to the requirements contained in the requested analytical methods. GSC evaluated QC data reported by the laboratory against required precision and accuracy limits established in Table A-4 of the QAPP. The validation reports generated for the 21 data packages receiving complete validation are included in **Appendix U**. All groundwater and surface water VOC chemistry data tables (e.g., Table 2.2-4a) include qualifiers added by the data validator.

Consistent with the data quality requirements as defined in the data quality objectives (DQOs) on Table A-4 of the QAPP, project data and associated QC data were evaluated on these categories and qualified according to the outcome of the review. During the review, laboratory-applied data qualifiers such as “E” (estimated concentration outside the calibration limits) and “B” (analyte detected in the associated method blank) were evaluated, defined and explained. During verification, individual sample results were qualified, as necessary, to designate usability of the data toward meeting project objectives. The qualifiers used are defined as follows:

U - The analyte was analyzed for, but was not detected above the reported sample quantitation limit. These results are qualitatively acceptable.

J - The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample. Although estimated, these results are qualitatively acceptable.

UJ - The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample. Although estimated, these results are qualitatively acceptable.

R - The analyte result was rejected due to serious deficiencies in the ability to analyze the sample and/or meet QC criteria. The presence or absence of the analyte cannot be verified.

Data qualifiers were applied based on deviations from the measurement performance criteria identified in TP-DM-300-7 and Table A-4 of the QAPP.

A secondary stage of validation occurred following completion of the initial validation for a discrete sampling event. Individual equipment rinse blanks, trip blanks, and field blanks (**Table 2.4-2**) were associated with the corresponding environmental samples (**Table 2.4-1**). These field QC blanks were evaluated using the same criteria as method blanks, and the associated environmental samples were qualified accordingly.

In addition to the validation procedures described above, graphs showing historical chemistry changes over time were visually scanned for comparability with historic data for each well, spring or surface water sampling location. Where laboratory results appeared to be out of line with historical or expected results for a particular sampling location, an inquiry was made to TestAmerica-Pittsburgh laboratory for further investigation into the laboratory analysis and reporting methods. This additional laboratory QA/QC investigation resulted in the discovery of six samples from 2014 and 2015 where the sample dilution factors reported by the laboratory were incorrect on the original lab reports, resulting in incorrect chemical concentrations being reported. Also discovered by the laboratory were two instances where additional sample dilutions were not reported in the original laboratory reports. The laboratory instituted an internal corrective action plan, corrected the analytical reports and reissued revised reports. A letter explaining the errors and a corrective action report from the laboratory is included in **Appendix V**.

The following sections address the laboratory chemical analysis program implemented for Part 2 of the SRI. The project DQOs are summarized in the following sections and include a review of precision, accuracy, bias, representativeness, comparability, completeness, and sensitivity.

### 2.4.1 Precision

Precision was evaluated using the analysis of two types of QC samples: LCS/LCSDs and field duplicate sample analyses. A third type of QC sample, the MS/MSD, was also evaluated but data was not qualified based solely on MS/MSD results.

The first type of QC sample used to assess data precision was the LCS/LCSD. The %R for 258 reported analytes was outside LCS/LCSD control limits. The results for 146 samples were ultimately qualified based on LCS/LCSD %R acceptance criteria. Twenty results were qualified as estimated ("J") and 234 results were qualified as not detected and estimated ("UJ"). Four results, all for carbon disulfide, were rejected ("R"). The most common analytes requiring qualification were trans-1,3-dichloropropene (48 results), acetone (36 results), cis-1,3-dichloropropene (17 results) and 1,1,2,2-tetrachloroethane (19 results). For the six principal VOCs at the site, only five results, all for 1,1-dichloroethane, were qualified based on LCS/LCSD criteria.

The second type of QC sample used to evaluate precision for VOCs was the field duplicate. Duplicate sample pairs were collected at 65 locations to ascertain the contribution of variability (i.e., precision) associated with environmental media and sampling precision techniques. The QAPP specifies the collection of one field duplicate sample per 20 environmental samples being analyzed for VOCs. As shown on **Table 2.4-3**, there were 1556 analyses for VOCs by SW-846 Methods 8260B and 8260C. Meeting the 5% specification required collecting at least 77 duplicate samples from the total number of VOCs samples (5% of 1556 samples). Collection of the 65 duplicate samples represents 4% of the total; however, the 5% duplicate requirement was met when several categories of samples were subtracted from the total: screening samples collected from newly installed wells, surface water locations that were not reproducible, and from GWTS effluent samples (60 duplicates were collected out of 1152 samples). Field duplicate RPDs were calculated for each of the six principal VOCs at the site and are shown on **Table 2.4-4** for all 65 field duplicates. According to Table A-4 of the QAPP, the maximum acceptable RPD for duplicates is 30% or, for results less than five times the reporting limit, the maximum acceptable RPD is three times the reporting limit. RPDs exceeding the acceptance criteria are highlighted in red. As shown on **Table 2.4-4**, most RPDs are less than 30%. The RPD cannot be calculated for samples where one of the results was non-detect.

Data was not qualified based solely on the results of field duplicates, since the USEPA Contract Laboratory Program (CLP) National Functional Guidelines for Organic Data Review (EPA 540R/R-99/008) does not include control limits for field duplicate RPD values.

MS/MSD results above the UCL or below the LCL affected 78 analytes. However, as noted above, data for this project was not qualified based solely on MS/MSD results.

Based on an evaluation of LCS/LCSD and field duplicate RPDs, the overall precision of samples collected for the project appears to be acceptable. As a result, the laboratory DQO for precision was met.

## 2.4.2 Accuracy

Analytical accuracy was measured through the use of LCSs, surrogates, internal standards, initial and continuing instrument calibrations, serial dilutions, method blanks, and field QC blanks (trip blanks, field blanks, and equipment rinse blanks).

The first type of QC sample used to assess data accuracy was the LCS and/or LCSD sample. As noted in Section 2.4.1, the LCS and/or LCSD percent recoveries were acceptable with the exception of four results that were rejected for carbon disulfide, 20 results that were qualified as estimated ("J"), and 234 results that were qualified as not detected and estimated ("UJ").

The second QC measure used to assess the accuracy of the data was the surrogate %R for VOCs. Sample results were qualified as estimated ("J/UJ") if the associated surrogates were below the LCL. Detected organic sample results were qualified as estimated ("J") if the associated surrogate recovery was greater than the UCL. Non-detected organic sample results were qualified as rejected ("R") if the associated surrogate recovery was less than 10 percent. None of the environmental and QC blank samples that received complete validation required qualification for surrogate recovery.

Internal standards were added to calibration standards, environmental samples, and QC blanks in accordance with SW846 Methods 8260B and 8260C for VOCs. Data was qualified based on area counts and retention times being outside the control limits only in the data packages that received complete validation.

Initial calibration of each analytical instrument was completed in accordance with SW-846 method requirements for all analyses. Data was qualified based on RRFs and %RSDs being outside the control limits only in the data packages that received complete validation.

Continuing calibration verification (CCV) of each instrument was completed in accordance with SW-846 method requirements. Data was qualified for CCV criteria only in the data packages that received complete validation. Organic sample results were qualified as estimated ("J/UJ") if the associated CCV was less than the LCL. Detected organic sample results were qualified as estimated ("J") and non-detected sample results were qualified "UJ" if the associated CCV was above the UCL.

Method blanks were analyzed with each batch (SDG) of samples in accordance with the analytical methods listed in the QAPP (GSC, 2014d). Five VOCs were detected in method blanks and the results for 164 samples were evaluated due to method blank contamination by one or more VOCs. The most common VOC detected in method blanks was methylene chloride (MC), a common laboratory contaminant. MC results in 51 samples were qualified as non-detect ("U") due to method blank contamination.

During activities conducted as part of the groundwater monitoring program at fYNOP, field QC blanks were collected to assess the potential effects of various components of field activities on the analytical results. Field QC samples were obtained to determine the degree of cross-contamination, verify successful decontamination procedures, or determine the effects of media heterogeneity on results. Equipment rinse blanks and field blanks provide a way of measuring the degree of cross-contamination, decontamination efficiency, and other potential error that can be introduced from sources other than the sample. Field sample results associated with contaminants found in field QC blanks are considered non-detect ("U") if the concentrations are less than ten times the level found in the associated blank for common laboratory contaminants such as acetone and MC, and less than five times the level found in the associated blank for other contaminants.

A total of 50 equipment rinse blanks and 49 field blanks were collected. The QAPP specifies the collection of one equipment rinse blank and one field blank per 20 environmental samples being analyzed for VOCs. As was the case with the duplicate samples, this 5% specification was not based on the total number of samples collected because some of the 1,580 environmental samples were not analyzed for VOCs. The 5% specification required 77 field blanks and 77 equipment rinse blanks (5% of 1556 unique groundwater and surface water samples, as discussed in Section 2.4.1) and was met when excluding the surface water samples and any samples that were collected with dedicated well sampling equipment. Collection of the field blanks for surface water sampling did not meet the 5% specification due to the frequency of surface water sampling. For example, when surface water samples were not collected using a pump, there was no equipment from which to collect a rinse blank sample. Since field blanks were typically collected in conjunction with equipment rinse blanks to identify potential contaminants in the deionized water source, the number of field blanks was also less than the goal of one per 20 samples.

Several VOCs were detected in field blanks sourced from deionized water theoretically organic-free, at concentrations that were not high enough to bias analytical results. For the associated samples that had detections less than ten times the field blank (for common laboratory contaminants) and less than five times the field blank (for the remaining contaminants), the results were qualified as non-detect ("U") for field blank contamination.

Several VOCs were detected in equipment rinse blanks but the concentrations were not high enough to bias the analytical results. The associated sample detections less than five times the blank results were qualified as non-detect ("U") for rinse blank contamination.

Supporting QC information cited above was qualitatively evaluated with respect to the analytical accuracy DQO. Only five data points for carbon disulfide were rejected due to unacceptable accuracy. Based on the evaluation of the LCSs, surrogates, internal standards, initial and continuing instrument calibrations, serial dilutions, method blank, and field QC blank results, the laboratory accuracy has been determined to be acceptable for all other analyses. The analytical DQO for accuracy has been met except as noted.

Based on an evaluation of the compounds and elements detected in the field QC blanks, overall field accuracy is acceptable, except where noted. As a result, the field DQO for accuracy has been fulfilled.

### 2.4.3 Bias

Bias is the systematic or persistent distortion of a measurement process causing errors in one direction. Data conditions that imply a potential for high bias in the sample result include:

1. Detection of a target compound in an associated method blank, trip blank, field blank, or equipment rinse blank,
2. A surrogate recovery greater than the acceptable range for a specific compound's analytical analogue,
3. A CCV sample recovery greater than the acceptable range for a specific compound, and
4. A LCS/LCSD or MS/MSD recovery great than the acceptable range for a specific compound.

Similarly, data conditions that imply a potential for low bias in the sample result include:

1. Analysis of the sample outside the holding time (i.e., 14 days for preserved VOCs),
2. A CCV sample recovery less than the acceptable range for a specific compound, and
3. A LCS/LCSD or MS/MSD recovery less than the acceptable range for a specific compound.

For this project, high analytical bias was evaluated by reviewing blank detections, low analytical bias was evaluated by reviewing holding times, and both high and low analytical biases were evaluated by analysis of LCS/LCSD and MS/MSD samples, and CCV sample recoveries in data packages receiving complete validation. The laboratory performed a LCS/LCSD or MS/MSD for each SDG, as appropriate. MS/MSD results that were not from samples collected during Part 2 of the SRI (i.e., that were from samples of other clients in the laboratory's analytical train) were not evaluated. Acceptance criteria for LCS/LCSD and MS/MSD measurements are expressed as a percent recovery and are specified in Table A-4 of the QAPP.

**Table 2.4-5** summarizes the number of analytes and the number of samples that were qualified for various reasons under the data validation criteria in TP-DM-300-7 and Table A-4 of the QAPP. VOC results for 86 analytes in 74 samples were qualified "J" (estimated) due to method blank detections with the potential for high bias. Similarly, VOC results for 79 analytes in 70 samples were qualified "U" (not detected) due to method blank detections with the potential for high bias. VOC detections in 128 samples were qualified "U" (non-detect) due to trip blank contamination and VOC detections in 7 samples were qualified "U" due to field blank contamination; these qualifications are also due to the potential for high bias.

Holding time exceedances with the potential for low bias resulted in the qualification of 709 VOC analytes in 33 samples. The qualified samples were flagged as estimated ("J") or estimated undetected ("UJ"), but none of the VOC data was rejected for holding time exceedances because samples were analyzed within two times the holding-time limit (e.g., if the holding time was 14 days for VOCs, then the sample was analyzed within 28 days or the results were rejected). For the 10% of SDGs that received full validation, LCS/LCSD and MS/MSD results outside the QC limits for VOCs resulted in the qualification of 334 analytes in 178 samples. These qualifications for laboratory control sample and matrix spike results were due to the potential for either high or low bias, depending on whether the results were greater than (high bias) or less than (low bias) the QC limits.

Based on a review of the results in **Table 2.4-5**, the data conditions implying a potential for low or high bias in a sample have been addressed by validation and resulting qualification of the analytical data using the following flags: "U", "J", "UJ" and "R" (Rejected). Note: Both "UJ" and "R" are validation qualifiers whereas "U" and "J" can be either laboratory qualifiers or validation qualifiers. **Table 2.4-6** shows the 113 records that were rejected and considered unusable. All other data is acceptable as qualified.

### 2.4.4 Representativeness

Representativeness was satisfied by verifying that the QAPP (GSC, 2014d) was properly followed, that proper sampling techniques were used, that proper analytical procedures were followed, and that analytical holding times of the samples were not exceeded. When holding times were greater than two times the method required holding time the sample results were rejected ("R") for non-detects and were qualified as estimated ("J") for detects. No sample results were rejected due to missed holding times. Based on an evaluation of sample precision and accuracy, the samples collected during Part 2 of the SRI are considered to be representative of the environmental conditions at the time of sampling.

### 2.4.5 Comparability

Comparability expresses the confidence with which one data set can be compared to another data set measuring the same property. Comparability is achieved through the use of established and approved sample collection techniques and analytical methods, consistency in the basis of analysis (wet weight vs. dry weight, volume vs. mass, etc.), consistency in reporting units, and analysis of standard reference materials.

Data comparability is achieved by using standard units of measure. The use of EPA-approved methods to collect and analyze samples, along with instruments calibrated against Standard Analytical Reference Materials (SARM), which are National Institute for Standards and Technology (NIST)-traceable standards, also aids comparability.

The visual comparability scan performed by GSC described in Section 2.4 above resulted in TestAmerica-Pittsburgh laboratory performing correlation and comparability analyses on 190 laboratory reports (over 2,100 analytical runs) for samples collected from the fYNOP Site in 2014 and 2015. This analysis checked correlation between multiple sample analytical runs for a particular sample (the laboratory indicated that methods typically reference 20% as an allowable RPD between replicates) and reviewed the results relative to the historical range of analyses for that sampling point. The laboratory issued revised reports for the six samples for which dilution errors had occurred and for two samples where the results from additional sample dilutions had not been reported on the original laboratory reports. Analytical results from one sample did not compare favorably with historical results and the laboratory could not definitively determine that a dilution-reporting error was the cause. Therefore, analytical results for one sample were rejected, “R”, as unusable due to comparability issues as listed in Table 2.4-6.

Based on the precision and accuracy assessment presented above and the use of EPA-approved methods, the data collected during Part 2 of the SRI, (except for one sample noted above) are considered to be comparable to data collected using similar EPA-approved methods.

### 2.4.6 Completeness

Completeness measures the quantity of valid data generated from the laboratory analysis and sampling processes. For data to be valid, all acceptance criteria must be fulfilled, including accuracy and precision, analytical methods must be followed, and each data point must be validated satisfactorily. Results from Part 2 of the SRI that have been qualified for completeness reasons have limited impact on the data quality. The DQOs (Table A-4 of the QAPP) were set at 90 percent for analytical laboratory completeness. Based on the evaluation of the laboratory QC results, the data exceeded 90 percent completeness and were deemed useful for assessing results and developing recommendations.

Results that have been flagged or qualified “U”, “UJ”, or “J” for various reasons encountered minor analytical problems, and have a limited impact on the data quality.

### 2.4.7 Sensitivity

Sensitivity requirements were specified as minimum required reporting levels for VOCs, SVOCs, metals, and miscellaneous parameters as listed in Tables A-6 through A-10 of the QAPP. A statistical summary of non-detect reporting limit data exceedances due to serial dilution by the analytical laboratory is provided in **Table 2.4-7** for seven target VOCs at the Site. For example, the table shows that for TCE, there were 290 non-detects out of 1,556 total analyses, and serial dilutions were performed on three of those non-detect samples such that the laboratory reporting limit exceeded the applicable regulatory standard for TCE. Similarly for VC, where the reporting limits were most affected by serial dilution, Table 2.4-7 indicates that laboratory reporting limits for 491 of the 1,417 non-detect results for VC are greater than the USEPA's Regional Screening Level. Otherwise, the reporting limit criteria were met, with the exception of those samples that required serial dilution due to matrix interferences or elevated concentrations of target compounds. Therefore, the analytical DQO for sensitivity was met.

# 3 RESULTS OF INVESTIGATIONS

This section is organized with respect to the five data gaps that were identified in Section 1, as opposed to Section 2 that followed the four phases of work as described in the FSP. For investigations that addressed two or more data gaps, the additional data gap is discussed along with the primary analysis, but referenced or expanded upon in subsequent subsections. For instance, the deep wells that were drilled to determine the vertical extent of chlorinated organic compounds also were used to establish the stratigraphy, vertical and lateral extent of the karst aquifer, and the distribution of solution channels in the karst aquifer. Since these latter items exert control on the vertical extent of the chlorinated compounds, they were described in the section on vertical extent, and referenced or in some cases, discussed in more detail in subsequent sections.

## 3.1 Nature And Extent

There were four nature and extent data gaps summarized in Section 1. Each is addressed in this subsection.

### 3.1.1 Vertical Extent of Chlorinated Solvents in Source/DNAPL Areas

**Figure 2.2-1** shows the six known or suspected source areas for which additional vertical characterization was necessary. The results of groundwater sampling following the initial vertical extent drilling are summarized in **Table 3.1-1** below. The chemistry posted in this table is from the last sample collected prior to deciding whether to deepen the boring and install a multi-level sampler. The table includes concentration data for PCE, TCE, and their degradation products c12DCE and VC. These VOCs are most prevalent at the Site and were used as an indication of the vertical extent of chlorinated solvents.

| Table 3.1-1: Summary of Initial Vertical Extent Drilling Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Well** | **PCE (ug/L)** | **TCE (ug/L)** | **C12DCE (ug/L)** | **VC (ug/L)** | **Depth (ft/bgs)** | **Yield (gpm)** | **Vertical Hydraulic Gradient** |
| SW-WPL – MW-136A | 13,000 | 6,100 | 1000u | 1000u | 270-320 | 1 | ↑ |
| TCA Tank Area – MW-137A | 13J | 510 | 1000 | 15J | 280-298 | 600 | ↑ |
| Bldg58 Area – MW-138A | 0.42J | 52 | 37 | 1u | 260-320 | 0.14 | ↑ |
| NBldg4 Area – MW-139A | 110 | 440 | 860 | 11J | 270-320 | 0.8 | ↑ |
| WBldg2 Corridor – MW-140A | 300 | 1,100 | 900 | 50u | 195-305 | 0.25 | ↑ |
| SPBA – MW-141A | 6.2 | 4.6 | 0.48J | 1u | 200-300 | 0.1 | ↑ |

*u – undetected at laboratory reporting limit. Larger u values (>1) due to laboratory dilutions.*

*J – estimated value; above method detection limit and below reporting limit.*

With one exception, the yields of these open interval depths are 1 gpm or less, determined by measuring the recovery of the water levels in the borehole after drawing down the well during sampling. The exception is MW-137A, located near the TCA Tank area in the CPA that intersected one of the deepest solution cavities encountered on the Site at a depth of 280 to 298 feet bgs. The yield of this zone was estimated to be approximately 600 gpm, based on blown yield testing during drilling advancement.

Vertical groundwater elevation gradients were also examined to determine whether groundwater containing dissolved COCs would tend to migrate vertically upward or downward under natural (non-pumping) conditions. Extraction wells in the TCA Tank Area (CW-8) and in the WPL (CW-9, CW-13, CW-15A, CW-17) were shut down on April 26, 2013 and allowed to recover to static conditions for 19 days to monitor vertical gradients under non-pumping conditions near wells MW-136A, MW-137A, MW-139A and MW-140A on May 15, 2013. Water elevation measurements were collected from wells near MW-141A on December 7, 2012 and from wells near MW-138A on April 25, 2013 to determine vertical gradients since those locations were not believed to be impacted by operation of the extraction wells in the TCA Tank area and WPL. A summary of wells used for the gradient determination, their lateral distances from the vertical extent source area wells, their screened or open intervals, groundwater elevations, and the direction of the vertical gradient is listed on **Table 3.1-2** below.

| Table 3.1-2: Vertical Gradient Data | | | | | |
|---|---|---|---|---|---|
| Vertical Extent Source Area Well (in bold) and Nearby Wells | Screened or Open Interval Monitored (ft bgs) | Lateral Distance from Source Area Well (ft) | Date | Groundwater Elevation (ft amsl) | Direction of Vertical Gradient |
| MW-37S | 11-33 | 60 | 5/15/2013 | 343.24 | ↑ |
| MW-37D | 125-141 | 60 | 5/15/2013 | 343.54 | |
| CW-20 | 205-215 | 62 | 5/15/2013 | 343.87 | |
| **MW-136A** | 270-320 | | 5/15/2013 | 343.89 | |
| CW-16 | 30.5-50.5 | 62 | 5/15/2013 | 344.82 | ↑ |
| MW-32S | 138-148 | 65 | 5/15/2013 | 345.83 | |
| MW-32D | 210-220 | 65 | 5/15/2013 | 345.90 | |
| **MW-137A** | 270-298.5 | | 5/15/2013 | 346.01 | |
| MW-80 | 20.5-40.5 | 24 | 4/25/2013 | 345.35 | ↑ |
| MW-87 | 75-95 | 30 | 4/25/2013 | 345.26 | |
| MW-113 | 131-151 | 27 | 4/25/2013 | 345.26 | |
| **MW-138A** | 260-320 | | 4/25/2013 | 347.08 | |
| MW-49S | 135-155 | 65 | 5/15/2013 | 347.19 | ↑ |
| MW-49D | 202-212 | 65 | 5/15/2013 | 347.11 | |
| **MW-139A** | 270-320 | | 5/15/2013 | 348.10 | |
| MW-81S | 28-43 | 148 | 5/15/2013 | 346.54 | ↑ |
| MW-81D | 52-66 | 148 | 5/15/2013 | 346.94 | |
| MW-114 | 90-143.7 | 50 | 5/15/2013 | 347.02 | |
| **MW-140A** | 195-305 | | 5/15/2013 | 347.15 | |
| MW-64D | 70-75 | 10 | 12/7/2012 | 356.62 | ↑ |
| **MW-141A** | 200-300 | | 12/7/2012 | 367.99 | |

Results from two of the six wells, MW-138A and MW-141A, indicated no deeper investigation was required, as a result of reductions in COC concentrations, upward vertical gradients that would inhibit downward aqueous-phase migration, and very low yields, indicating relatively low transmissivity in this portion of the bedrock carbonate aquifer.

The remaining four wells were advanced approximately 150 feet deeper by coring. Multiport samplers were installed in these wells at likely water bearing zones, determined by the examination of the rock core and geophysical logging of the borehole. This investigation provided information on the stratigraphy and structural geology of the Site, the vertical gradient in the karst aquifer, and the distribution (vertical extent) of chlorinated solvents in the aquifer. The data was compiled, along with all available data from existing wells, and presented on cross sections that are discussed in the following subsections.

##### 3.1.1.1 **Stratigraphy and Structural Geology**

Drilling for vertical extent wells penetrated to depths of 298 to 470 feet in six critical areas of the Site and produced 562 feet of rock core. Changes in rock types (stratigraphy), the location and depth of the contiguous contacts and faults between the different rock types, and the orientation of bedding planes were identified based on results of rock core logging and geophysical borehole logging. As a result, the boundaries of the carbonate basin were refined, and the nature of the geologic contacts beneath the Site was further characterized. The boundaries of the carbonate basin are important because the formation of solution channels is limited to the extent of the carbonate bedrock aquifer.

Cross section A-A’ (**Figure 3.1-1**) runs west to east from Codorus Creek through the SW-WPL, the TCA Tank Area, and the Bldg58 Area, terminating at MW-2 near the eastern property boundary. The bore holes for MW-137A and MW-140A (700 feet north of section A-A’) penetrated the limestone and dolostone of the Vintage Formation into the underlying quartzite of the Antietam Formation. This boundary between these formations forms the lower extent of the carbonate aquifer. Near the bottom of the Vintage, white marble was encountered, which has been recognized in the literature as a lithologic unit that occurs near the bottom of the Vintage Formation (Stose and Jonas, 1939, p.48). The conformable contact dips 25 to 35° to the west. The bottom of the carbonate was not penetrated by drilling at MW-136A in the SW-WPL to a depth of 467 feet. Extending the dip to beneath the SW-WPL, it is estimated that the bottom of the carbonate is approximately 600 feet bgs at this location.

Cross section B-B’ (**Figure 3.1-2**) extends west to east, passing through the northern end of the WPL. This section roughly parallels section A-A’ at a location 800 feet to the north, running from MW-148A on the west side of Codorus Creek, eastward through the northeast corner of the WPL, extraction well CW-17, and suspected DNAPL source areas at the NBldg4 Area. The section terminates near the NETT, where drums of waste were stored in the 1970s. The depth of the carbonate aquifer along this section ranges from about 200 feet beneath Codorus Creek, to over 400 feet deep at MW-139A, near the NBldg4 Area. In this area, the marble is not present, but the

Vintage becomes more phyllitic with depth, and contains interbeds of quartzite. The quartzite interbeds at the contact between the Vintage and the Antietam are consistent with the published description of the lower Vintage in this area (Stose and Jonas, 1939, pp.47-50). The carbonate Vintage Formation is underlain by phyllite rock of the Harpers Formation. As shown on **Figure 3.1-2,** the contact between the Vintage Formation and the Harper consists of a fault, which surfaces to the north of the Site (see geologic map **Figure 1.3-1**) and dips approximately 20 to 30° to the south.

The fault contact between the Vintage and Harpers formations, which forms the northern limit of the carbonate aquifer under the Site is better illustrated on cross sections C-C' (**Figure 3.1-3**) and section D-D' (**Figure 3.1-4**). Cross section C-C', which runs from south to north, along the eastern levee of Codorus Creek and shows the northern limit of the carbonate aquifer formed by the fault contact between the Harpers and Vintage Formations. The northern portion of this section illustrates the southward dipping fault and location of the phyllite. Section D-D', which runs south to north through the middle of the CPA, starting at the southern Site property line along Rt. 30, crossing A-A' at the TCA Tank Area, running through the WBldg2 Corridor, extending northward beyond the northern Site property line. The northern portion of this section is underlain by the non-carbonate Chickies Quartzite and Harpers Phyllite, which underlie the topographic ridge north of the Site. The fault contact between the Chickies/Harpers and the Vintage is shown, dipping approximately 20° to the south. Wells MW-137A and MW-140A both penetrated the Vintage at depths of 420 and 310 feet, respectively, establishing the depth of the conformable contact between the Vintage and the Antietam formation, which defines the bottom of the carbonate aquifer. Marble was encountered at the base of the Vintage in these two borings.

#### 3.1.1.2 Distribution of Solution Channels and Water Bearing Zones within the Carbonate Aquifer

Karst solution features within the carbonate aquifer intersected by wells and borings are illustrated on the cross sections introduced above by yellow rectangles behind the black lines representing each borehole. For the purpose of characterization on the sections, whether solution features were filled with water, clay or gravel was not differentiated. Most solution features when drilled, appeared to be partially filled with clay or gravel, although determination was difficult with the drilling techniques used because drilling water returns often ceased upon penetration. These sections indicate in general the voids are more frequently encountered within the top 200 feet bgs.

**Table 3.1-3** shows the ratio of feet of voids per feet of bedrock for the new vertical extent wells MW-136A, MW-137A, MW-138A, MW-139A, MW-140A and MW-141A (see well logs in **Appendix H**). **Table 3.1-3** specifies the "Depth Range" as the feet below the top of rock instead of depth bgs to provide consistency for comparison purposes with the void ratio data reported in the Part 1 SRI report. The data in the table illustrates that most of the voids in these wells occur in the top 150 feet of rock (the top 170 to 200 feet bgs) with a void ratio of 15% to 19%. These ratios are similar to the 16% value reported in the Part 1 SRI report (subsection 3.3.2.2.1) using 87 wells penetrating carbonate rock. Below this depth of 150 feet below the top of rock (or below 170 to 200 feet bgs), there is a sharp decline in frequency. Solution features continue to occur 300 feet below top of rock. The deepest solution feature encountered was at a depth of 374 feet bgs, penetrated by MW-136A in the SW-WPL.

**Table 3.1-3: Ratio of Feet of Voids per Feet of Bedrock Drilled in the Carbonate Formation Beneath the Site**

| Depth Range (feet below top of rock) | 0-50' | 50'-100' | 100'-150' | 150'-200' | 200'-250' | 250'-300' | 300'+ |
|---|---|---|---|---|---|---|---|
| Total feet drilled into rock | 300 | 300 | 300 | 300 | 290 | 210.0 | 291.0 |
| Total feet of voids | 45 | 57 | 53 | 17 | 0.0 | 11.0 | 2.5 |
| feet voids/feet rock | 0.15 | 0.19 | 0.18 | 0.06 | 0 | 0.05 | 0.01 |

On cross section A-A' (**Figure 3.1-1**), the concentrated zone of solution channels under Former Bldg2 and the Bldg58 Area is limited to approximately 150 feet bgs. Under the SW-WPL and the Levee, concentrated stacked caverns reach to approximately 200 feet bgs. Voids that occur below 200 feet bgs are:

1. The large void in MW-137A near the TCA Tank Area was encountered at a depth of approximately 284 feet bgs. The apparent thickness of this void intersected by the MW-137A borehole was 11 feet. The short-term yield during air rotary drilling through this void was about 600 gpm.
2. A 2.2-foot thick, cobble-filled void in MW-136A in the SW-WPL was observed in the rock core at a depth of 356 feet bgs, with a smaller 0.2-foot gravel-filled solution feature observed at 372 feet bgs, and a 0.1 foot gravel-filled void observed at 374 feet bgs in the same boring. These solution features are the deepest discovered during investigations at fYNOP.

On cross section B-B' (**Figure 3.1-2**), solution channels under former Bldg4 extend to a depth of 175 feet bgs; beneath the WPL, they are limited to approximately 100 feet bgs, and at the levee, 150 feet bgs.

Below 200 to 250 feet bgs in the carbonate aquifer, hydraulic conductivity is much reduced. As demonstrated by **Table 3.1-1**, the yield or recovery rates of the six open boreholes exposed to the aquifer from 200 to 320 feet bgs, ranged from 0.1 to 1 gpm. The obvious exception to that is in MW-137A that penetrated a deep solution feature from 282 to 293 feet bgs.

Four of these boreholes were deepened by coring an additional 150 feet:

1. Borehole geophysical logging did not indicate vertical flow in the MW-137A borehole below the large solution channel. A potential fracture zone from 284 feet to 287 feet bgs was identified by the geophysical logging, but the zone was characterized as a "very tight microfracture". Rock cores collected from 298.5 feet to 452 feet bgs indicated no occurrence of voids or open fractures.
2. No apparent vertical flow, and no significant fractures or fracture zones were encountered in the MW-139A borehole as a result of borehole geophysical logging or rock coring.
3. Borehole logging in MW-140A indicated vertical upward flow from an apparent water-bearing zone at 323 feet bgs, but below that there was no indication that vertical flow was occurring. No voids or solution features were observed in the rock cores.
4. MW-136A geophysical testing was less complete, and did not include the more definitive tests, however pumping rates of Waterloo ports resulted in drawdown at pumping rates of

0.02 to 0.03 gpm, and suggests the yields of the most likely zones of fracturing are relatively low, even in the deep solution features mentioned above.

#### 3.1.1.3 **Natural Vertical Gradients**

One of the goals of shutting down the groundwater extraction system was to examine the vertical hydraulic gradients in the aquifer beneath the WPA in order to examine the potential for migration of dissolved COCs, transported with the groundwater. Establishing the natural vertical gradient is necessary to accomplish the goal of determining the vertical extent of COCs, which is the goal of this data gap investigation.

As DNAPL, PCE and TCE can migrate vertically downward through the saturated aquifer, even against a vertical upward gradient; that is not true of PCE and TCE in the dissolved state. Likewise, the degradation products of TCE and PCE, cis12DCE and VC, form only after the parent compounds have dissolved in groundwater, and only occur in an aqueous state. Therefore the degradation products cannot be transported as a DNAPL.

Water levels measured on October 7, 2014 in accessible observation points across the Site were posted and contoured in plan view as discussed in Subsection 2.3.7. The October 2014 water levels were measured approximately one month after the wells extracting groundwater were turned off, and represent natural hydraulic head potentials during a portion of the year when aquifer recharge from precipitation is typically limited due to runoff and evapotranspiration by trees and other vegetation.

The October 2014 water levels were posted on cross sections and contoured. They are shown on the previously introduced cross sections A-A' through D-D' (**Figures 3.1-1 through 3.1-4**).

Pertinent findings regarding apparent lateral and vertical gradients depicted on cross section A-A' (**Figure 3.1-1**) include:

1. There is a lateral gradient from east to west toward Codorus Creek, relatively steep in the east near the quartzite, and dissipating westward in the carbonate aquifer.

2. For the top 200 feet of the aquifer, there is a slight vertically upward gradient in the carbonate portion of the aquifer west of Former Bldg2, shown by the near vertical piezometric contour lines.
3. There is an upward vertical gradient from a depth of approximately 200 feet, illustrated by the 344-foot contour which becomes horizontal beneath the TCA Tank Area (MW-137A) and westward beneath the WPL. This 344-foot contour is based on water levels measured in open intervals in the shallow sample ports above the Waterloo sampling ports and transducers, and the upward gradient is in comparison to shallower wells in the immediate vicinity. There is a calculated head potential from the deepest Waterloo port in MW-136A of 345 feet amsl. Water levels measured in the Waterloo sampling ports between the deepest port at 435 feet bgs and the open borehole from 270 to 348 in MW-136A tend to be similar, and a few feet lower than Port 1 (the deepest port) and Port 5, the open borehole. There is concern regarding the accuracy of the calibration of these ports, and for that reason the corrected values were not contoured. The lower head potentials of approximately 342 feet amsl measured in these middle ports may result from a fracture or solution channel connection with the upper portion of the aquifer, and in all cases still result in a net upward gradient with respect to Codorus Creek, which has an average elevation of 338 to 339 feet amsl.

An upward gradient is apparent beneath Codorus Creek as shown in the western portion of cross section A-A'.

Pertinent findings regarding apparent lateral and vertical gradients depicted on **Figure 3.1-2**, cross section B-B', include:

1. There is a lateral gradient from east to west toward Codorus Creek, steeper in the east near the quartzite, and dissipating westward in the carbonate aquifer.
2. For the top 150 feet of the carbonate aquifer east of Codorus Creek, there is nearly no vertical gradient, shown by the vertical piezometric contour lines.
3. An upward vertical gradient is apparent in the deepest part of the carbonate aquifer, shown by the curved piezometric contours below an elevation of 150 feet amsl. Higher head pressures above 350 feet amsl in the deepest ports in MW-139A appear to be related to the

underlying Harpers Phyllite and the fault contact being recharged by the higher elevations to the north.

4. A clearly upward gradient is illustrated by the U-shaped contours beneath Codorus Creek, indicating groundwater discharging to the creek from the east and the west.

Cross section C-C’ (**Figure 3.1-3**) runs south to north along the eastern levee of Codorus Creek. Pertinent findings regarding apparent lateral and vertical gradients depicted on this cross section include:

1. Piezometric levels indicate two feet of upward vertical head difference in the 250 feet of aquifer below the creek.

Pertinent findings regarding apparent lateral and vertical gradients depicted on cross section D-D’ (**Figure 3.1-4**) include:

1. This section essentially runs parallel to the horizontal contours, and thus indicates little gradient across the section.
2. While minimal vertical gradient is measured in MW-140A as it penetrates the carbonate aquifer, the Antietam and the Harpers, the higher piezometric pressures that were detected in section B-B’ are represented by the 346- through 349-foot piezometric contours.

#### 3.1.1.4 Vertical Extent of Groundwater Chemistry

The vertical extent of CVOCs is discussed below, using the four previously introduced cross sections, on which chemistry data and contours have been posted. The discussion includes specific data for PCE, TCE and cis12DCE which are the most wide-spread CVOCs at the Site and are detected at the highest concentrations. VC, a degradation product of these compounds, is distributed sporadically throughout the site, and its occurrence is discussed in other portions of this report. Trichloroethane (TCA), 1,1-dichloroethane, and 1,1-dichloroethene, are also detected in the groundwater, but not as pervasively or at as high concentrations. These CVOCs are detected only in wells that also contain PCE, TCE and/or cis12DCE. Therefore, PCE, TCE, and cis12DCE (the most common intermediate degradation product of PCE and TCE) are indicators of the vertical extent of CVOCs. For TCE and PCE, the vertical extent is defined as the estimated location of the 5 µg/L contour line, which is the PADEP MSC for groundwater (used aquifer with <2,500 mg/L

TDS). For cis12DCE, the MSC is 70 µg/L, and the limit of the plume will be described as 70 µg/L. However, cis12DCE concentration contours down to 5 µg/L are shown because the distribution is important with respect to characterizing the degradation processes that occur within the aquifer.

Five of the areas targeted with vertical extent drilling are discussed in the following subsections. The fifth area targeted is the SPBA, which is discussed later in subsection 3.1.3. The TCE, PCE and cis12DCE isoconcentration contours on these cross sections, like all other isoconcentration contours in this report use the concentrations from the October 2014 Comprehensive sampling event. This event was completed while the groundwater extraction system was not operating, and therefore the distribution of these COCs represents conditions absent of the interim remedy. In cases where a sampling point was not sampled during the 2014 event, guidance was taken from previous data, and time vs. concentration (trend) graphs were considered. TCE, PCE and cis12DCE were selected for the data analysis of the vertical extent of COCs because they are most pervasively detected in the groundwater beneath the Site and represent the worst-case scenarios for vertical extent.

The chemistry contouring of the vertical profiles discussed in this section benefitted from horizontal contouring of the chemistry at three levels within the aquifer (310 feet amsl, 210 feet amsl, and 110 feet amsl), providing three dimensional contouring, and providing a method to effectively consider data points that fell off of the cross sections. The horizontal contouring is introduced and discussed later in this report.

Regarding the construction of isoconcentration contours in a karst aquifer, it is acknowledged that contouring in the highly karstified portion of the aquifer is more subject to misrepresentation of actual conditions than in a porous media. Contour lines represent concentrations expected in the groundwater within the interconnected fractures and solution channels in the saturated zone.

#### 3.1.1.4.1 SW-WPL Area: MW-136A

As illustrated on cross section A-A’ (**Figure 3.1-5**), vertical profile multiport well MW-136A in the SW-WPL penetrates the carbonate aquifer to a depth of 460 feet bgs, to an elevation of -110 feet mean sea level datum (msld). Based on ten separate sampled intervals within this vertical profile, and numerous wells surrounding the immediate vicinity, a deep vertical plume of TCE is shown.

The two darkest shaded contour intervals illustrate concentrations exceeding 1,000 µg/L of TCE to a depth of at least 434 feet bgs. **Figure 3.1-6** shows posted concentrations and contours for PCE and **Figure 3.1-7** shows concentrations and contours for cis12DCE. The distribution and concentrations of TCE, PCE and cis12DCE are similar, however cis12DCE extends deeper into the aquifer, as shown on **Figure 3.1-7** where 2,700 µg/L of cis12DCE was detected in the deepest sampling port in MW-136A at a depth of 460 feet bgs.

Graduated pie diagrams are posted on the cross section to provide a reference to the ratio of the mixture of chlorinated solvents and degradation products. These diagrams help illustrate similarities and differences that suggest common sources, locations that may be connected by conduits of fractures, or changes resulting from degradation. An examination of the pie diagrams indicates a general increase in the ratio of cis12DCE with depth in the borehole, evidence that natural attenuation and degradation of TCE and PCE is occurring, particularly below the karstified portion of the aquifer. This same condition is also illustrated on **Figure 3.1-7,** with higher concentrations of cis12DCE (> 500 µg/L) occurring below 200 feet bgs.

The vertical extent of contamination in the SW-WPL area is primarily related to two mechanisms: the depth of penetration of DNAPL TCE/PCE against a vertically upward hydraulic gradient and the transformation of these substances to cis12DCE as described above. This is examined more completely in Section 3.3.2. The deepest vertical extent of COCs in the SW-WPL is extrapolated to be 515 feet bgs (-160 feet msld) based on the 70 µg/L cis12DCE concentration contours.

#### 3.1.1.4.2 TCA Tank Area: MW-137A

The TCA Tank Area is also illustrated on section A-A’, **Figure 3.1-5** in an east-west profile and on section D-D’, **Figure 3.1-8** in a north-south profile. Vertical profile multiport well MW-137A penetrates 420 feet of carbonate aquifer, into the underlying quartzite. The deepest sampling port has an elevation of approximately -80 feet msld. Based on 15 separate sampled intervals within the vertical profile, a broad plume of TCE, apparently originating to the east in the Bldg58 Area, is illustrated. Separation is shown between sources to the north (**Figure 3.1-8**) based on three dimensional contouring. Below the very large void intersected in MW-137A at approximately 295 feet, TCE concentrations diminish rapidly. The similar pie diagrams for CW-8 and the MW-137A –

295.5-296 sample port suggest that the deep conduit and the conduit intercepted by CW-8 are connected and have a common source.

**Figures 3.1-6 and 3.1-9** show posted concentrations and contours for PCE. PCE concentrations are generally lower than TCE, and form a slender vertical plume. The pie diagrams show high ratio of cis12DCE below the karstified portion of the aquifer. **Figures 3.1-7 and 3.1-10** indicate generally higher concentrations of cis12DCE than parent products TCE and PCE occurring below 200 feet bgs. The deepest vertical extent of COCs in the TCA Tank Area is interpreted to be 425 feet bgs (-65 feet msld) based on the 70 µg/L cis12DCE concentration contours.

### 3.1.1.4.3 Bldg58 Area: MW-138A

Five hundred feet east of the TCA Tank Area, and shown on section A-A', is the Bldg58 suspected Source/DNAPL Area. Vertical profile well MW-138A penetrated 320 feet of carbonate aquifer. Unlike in the two previously discussed DNAPL source areas, MW-138A is constructed as an open rock hole, exposing 60 feet of the deeper aquifer between 260 and 320 feet bgs. This well is very slow to recover when pumped, having a recovery rate of 0.14 gpm, indicating very low hydraulic conductivity in this portion of the aquifer. **Figure 3.1-11** shows steadily decreasing concentrations of TCE over four sampling events. This trend may indicate that COCs were initially mobilized by the drilling method, in spite of the sealed casing installed prior to advancing the borehole, but as groundwater purging occurred during each successive sampling event, concentrations returned to representative ambient conditions.

On **Figure 3.1-5**, TCE concentration contours were drawn using six separate sampled intervals from individual wells in the immediate vicinity, plus three dimensional contouring using a number of adjacent shallow wells. TCE concentrations exceed 500 µg/L to an estimated depth of 230 feet bgs (130 feet amsl). The TCE plume is not as deep in this suspected source area, as in the two previously described areas, and may indicate a smaller DNAPL release or less favorable vertical DNAPL transport conditions.

**Figure 3.1-6** illustrates concentrations of PCE are less than 50 µg/L in these same wells indicating that this COC has limited vertical extent in the Bldg58 source area. The cis12DCE concentration contours shown on **Figure 3.1-7** indicate concentrations similar to TCE. The 70 µg/L contour extends to a depth of 220 feet bgs (150 feet amsl).

### 3.1.1.4.4 NBldg4 Area: MW-139A

As illustrated on cross section B-B' **Figure 3.1-12**, MW-139A in the NBldg4 Area penetrates the carbonate aquifer to a depth of 323 feet bgs, to an elevation of approximately 40 feet amsl. Based on eleven separate sampled intervals within and surrounding this vertical profile and the three dimensional contouring, a somewhat broad vertical plume of TCE is shown, reaching to a depth of nearly 300 feet bgs (60 feet amsl). The shaded contours illustrate TCE concentrations in groundwater exceeding 1,000 µg/L to a depth of approximately 240 feet bgs (120 feet amsl). The contours illustrate that this plume has been drawn towards extraction wells CW-14 and CW-17, also shown on section B-B'. **Figure 3.1-13** shows posted concentrations and contours for PCE. PCE concentrations are lower than TCE, but similarly distributed. **Figure 3.1-14** shows generally higher concentrations of cis12DCE in the NBldg4 area compared to TCE. Unlike the previously discussed areas, very high cis12DCE concentrations (>500 µg/L) occur in the shallow karstified portion of the aquifer above 200 feet bgs. The 70 cis12DCE µg/L contour extends to a depth of approximately 340 feet bgs (70 feet amsl) in the NBlg4 Area. Below 300 feet bgs concentrations of degradation product cis12DCE make up nearly all of the chlorinated fraction, as illustrated by the pie diagrams.

### 3.1.1.4.5 WBldg 2 Corridor: MW-140A

The location of MW-140A in the WBldg2 Corridor is approximately 170 feet southeast of MW-139A and the NBldg4 Area. As illustrated on cross section D-D' **Figure 3.1-8**, MW-140A in the WBldg2 Corridor Area penetrates the carbonate aquifer to a depth of 298 feet bgs, to an elevation of approximately 60 feet amsl. As illustrated by the TCE isoconcentration contours, the interpreted presence of TCE dissolved in groundwater extends to a depth of about 200 feet bgs, less than the other source areas investigated. A significant dissolved presence of PCE was not identified in the groundwater in this area (**Figure 3.1-9**). Cis12DCE was detected at a concentration of 110 µg/L in the deepest sampling port in MW-140A, along with 35 µg/L of VC (**Figure 3.1-10**), and is in striking contrast to the TCE and PCE concentrations. The vertical extent of COCs in the WBlg2 Corridor is extrapolated to be 425 feet bgs (-40 feet msld).

#### 3.1.1.4.6 Levee Area

Although the Levee area is not a source area, two deeper wells were drilled in this area during the Part 2 investigation, and a depth of the CVOC plume migrating from the Site was analyzed by modifying the cross section from the Part 1 report. **Figure 3.1-15** illustrates the presence of TCE dissolved in groundwater in cross section C-C' along the Codorus Creek levee, parallel to the creek. The reader is reminded that these results reflect non-pumping conditions. Shutdown of the extraction system increased the concentrations in many of the wells in the Levee area, which is discussed later in this report. In this area, the TCE groundwater plume with dissolved concentrations greater than 5 µg/L extends to a depth of approximately 250 feet bgs. PCE concentrations (**Figure 3.1-16**) detected in groundwater in this area are generally less than 50 µg/L except in wells MW-145A (71 µg/L) and MW-146 (52 µg/L). The vertical extent of COCs in the levee area is defined by the 5 µg/L PCE contour line, interpreted to follow the fault contact between the carbonate and the phyllite. Cis12DCE isoconcentration contours, shown on **Figure 3.1-17** did not exceed 70 µg/l at the Levee Area, the PADEP MSC for this compound.

### 3.1.2 Lateral Extent of Chlorinated Solvents in the NPBA

Pre- and post-shutdown groundwater chemistry data presented in the monitored shutdown test report that was accepted by the PADEP and EPA in April 2014 determined that concentrations of COCs in off-Site former residential wells were below RUA MSCs. The concern in the NPBA is the potential for elevated concentrations of COCs in groundwater to migrate off-Site to the west of shallow and deep well pair MW-18S and MW-18D. The investigation indicated the source of the elevated concentrations of COCs is located to the west of MW-18S&D, although the exact source location has not been pinpointed (GSC, 2014b). The elevated groundwater concentrations appear to be limited in extent to the area of MW-18S&D and possibly to the west of the well pair, which would be northeast of MW-142S&D. As shown on the time vs. concentration graphs in **Appendix L.2**, concentrations of COCs in wells MW-18S&D have generally declined over the last 4 to 6 years.

Post-shutdown groundwater elevation data and potentiometric contours from August 2013 established the existence of a natural (non-pumping) lateral groundwater gradient to the southwest in the area of MW-18S&D as shown by the groundwater flow path arrow on **Figure 3.1-18**. Given the relative close proximity of MW-18S&D to the northeast-southwest trending property line and the apparent lateral gradient under non-pumping conditions being nearly parallel to the property line, there is a potential for the groundwater contaminant plume to flow along a pathway that crosses the property line to the west. However, if COCs would extend off-Site to the west of MW-18S&D because of the apparent natural groundwater gradient or due to dispersion of COCs in the groundwater, the COC plume is expected to migrate down-gradient and back on-Site within approximately 1,000 feet, where the property line changes to a northwest-southeast orientation.

The results for the first year of NPBA post-shutdown monitoring were reported in the "2014 Annual Monitoring Progress Report for the NPBA Extraction System Shutdown" (GSC, 2015a). The monitoring program included the collection of water levels and groundwater samples. Evaluation of the groundwater elevations and VOC analytical data for the first year of post-shutdown monitoring indicated stable (unchanged) conditions. The October 2014 post-shutdown groundwater elevations and potentiometric contours were nearly identical to the August 2013 post-shutdown elevations and contours (**Figure 3.1-18**), and showed a consistent gradient to the southwest with a groundwater flow path that would theoretically cross the property line to the west then return to the Site approximately 100 feet west of MW-143S.

Monitoring in 2015 was coincident with the Comprehensive Sampling event in October, and results are displayed on **Figure 3.1-19**. The hydraulic gradient is nearly identical to the 2013 and 2014 results. Groundwater chemistry in down-gradient wells MW-142S&D, MW-143S&D, MW-82, MW-102S&D and MW-103S&D two years after shutdown (October 2015) showed no significant concentration changes (**Figure 3.1-19 and Appendix L.2**).

### 3.1.3 SPBA and Off-Site SPA

This section will be updated and revised in a separate report as a result of additional work that has been conducted in these areas. USEPA commented on the August 2016 version of this report, requesting a more complete description and illustration of the hydrogeologic conceptual site model. The text and figures in this subsection are unchanged from the August 2016 report, and do not reflect responses to USEPA comments. See Section 1.5 for a more complete description of this action.

Three separate field investigations were completed in the SPBA and the off-Site SPA as part of the Part 2 SRI:

1. The first investigation consisted of the installation of vertical extent boring MW-141A in the extreme southeast corner of the Harley-Davidson property. The location of this well is shown on **Figure 2.2-1**. This deep well was installed to evaluate the vertical extent of high concentrations of TCE, PCE and degradation products in the groundwater in well pair MW-64 S&D. Results of MW-141 demonstrated a considerably reduced concentration of these COCs in the aquifer about 50 to 100 feet below the previously deepest well in the area, MW-64D.
2. The second investigation involved the installation of borings in three locations south of Rt. 30, (**Figure 2.2-6**) to characterize the migration and establish the horizontal and vertical extent of Site-related COCs in the SPA.
3. The third investigation was conducted on-Site, along the southern property line and off-Site, within the residential area immediately to the south (**Figure 3.1-20)**. The purpose of this investigation was to determine whether VI is a potentially complete pathway for COCs from the Site to enter neighboring residences. The results of this investigation were submitted to USEPA and PADEP on July 1, 2015, and are included in this report as **Appendix N**.

The following subsections summarize the results of the third investigation, and then combine that information with the results of the first and second investigations to more completely describe the geology, hydrogeology, nature and extent, and the migration pathway of COCs from the SPBA.

#### 3.1.3.1 **SPBA/Canterbury Lane VI Investigation**

Historical accounts indicate that liquid waste containing VOCs was used to control weeds and reduce dust along the SPBA perimeter road. Previous investigations identify TCE and PCE as COCs in the SPBA. In 2005, results of a VI assessment of the SPBA, and the off-Site area to the south, concluded that the VI pathway due to volatilization from shallow groundwater is not complete (Langan, 2005). Thereafter, USEPA issued its Documentation of Environmental Indicator Determination finding that the VI pathway in the residential area off-Site in the vicinity of the SPBA was not significant (USEPA, 2005). In 2014, the USEPA reviewed the 2005 VI assessment and concluded that the methodology and modeling approach that it previously approved for the

2005 VI assessment are no longer considered by USEPA to be reliable methods to estimate the potential for VI into neighboring residences. In August 2014, USEPA therefore requested more information to determine whether VI is a potentially complete pathway for COCs from the Site to enter neighboring residences.

A work plan, identified as Addendum #15, was reviewed by USEPA, and after addressing comments, approved. The plan specified the use of USEPA's VISL calculator (Version 3.3.1, May 2014) pursuant to USEPA's current VI screening policy, to screen VOC concentrations in shallow groundwater in the wells and NSSG sample results. However, prior to completion of the report provided in **Appendix N**, USEPA released a new version of the VISL calculator (June 2015), and the new version was used.

As shown on **Figure 3.1-21**, 15 stratigraphic borings were completed and a monitoring well was installed in each of the stratigraphic borings. Five of the monitoring wells were installed in the SPBA. Ten monitoring wells were installed in the residential area south of the SPBA. Soils were sampled, and textures analyzed by a soils laboratory. Water levels in wells were measured, and two rounds of groundwater samples were collected and analyzed for VOCs.

Based on the results of geologists' descriptions and gradation analyses of soil samples, the underlying soils in the vadose zone are, for the most part, fine-textured and are classified as falling within the loam, silt loam, silty clay loam and clay loam portions of the USDA trilinear diagram, although a few samples are classified as sandy loam and sandy clay loam. **Figure 3.1-22**, taken from Appendix N, presents a contour map of groundwater elevations measured in the shallowest wells at each monitoring location in the study area. As such, it is an approximation of the water table contours. Although these contours describe an apparent overall lateral groundwater gradient sloping generally southward from the SPBA towards the off-Site residential area, the pattern of the contours is irregular. This is due to several factors, but is mostly attributable to the fact that the principal groundwater gradient and associated flow direction is vertically downward.

To illustrate this condition, cross sections F-F' and G-G' have been drawn along the cross section lines shown on **Figure 3.1-23**, also from Appendix N. Cross section F-F' extends east-west along the southern property boundary and includes wells that characterize the likely source of the southern plume, and cross section F-F' has been drawn from southwest to northeast across the study area to examine vertical relationships in the neighborhood.

As shown on **Figure 3.1-23**, cross section F-F' illustrates a strong downward vertical groundwater gradient from the saturated residuum into the underlying limestone in the SPBA source area. Cross section G-G' on this same figure shows this downward gradient extends into and beneath the residential area to the south, and a corresponding downward flow path of groundwater from the on-Site source area in the SPBA through the residuum into the underlying carbonate aquifer, with limited lateral migration southward. The downward vertical head between the residuum and the bedrock persists throughout the residential neighborhood to the southern limits of the Study Area, marked by Old Arsenal Road.

Two rounds of groundwater sampling in the newer wells and the adjacent pre-existing wells were analyzed for VOCs. Analytical results are posted on **Figure 3.1-24,** and additional wells associated with a gasoline release at the Rutters Gas Station and Convenience Store are shown on **Figure 3.1-25**. As expected from the results of the MIP and soil vapor investigations conducted by Langan, (Langan, 2005) and from the results of groundwater chemistry from pre-existing wells MW-64 S&D, concentrations of TCE and PCE in the SPBA (i.e., within the boundary of the Harley-Davidson property) are elevated. Groundwater concentrations in the newer shallow wells in the Canterbury Lane neighborhood show substantially lower TCE and PCE concentrations, and no other significant concentrations of other VOCs with respect to vapor intrusion potential. The highest concentrations of these compounds in shallow off-Site groundwater occur in MW-167, with concentrations of 2.6 µg/L of TCE and 8.6 µg/L of PCE.

The results of groundwater sampling were evaluated using the USEPA's VISL Calculator (June 2015) to calculate the cumulative target cancer risk (TCR) and HI associated with maximum concentrations of all COCs constituting a VI concern. As expected, MW-161 and MW-162, the eastern-most wells on the Site property, and MW-165, further to the west, in the suspected on-Site source area exceed screening criteria. However, no groundwater chemistry results in off-Site wells within the study area exceed the screening criteria as calculated by the VISL calculator. The comparisons of the VISL results indicate that neither the TCR nor the target HI have been exceeded in groundwater sampled in the Canterbury Lane neighborhood.

As a result of these findings, USEPA "has determined that VI is not expected to be a significant exposure pathway for the off-site residential area downgradient of the SPBA at this time. The Human Exposures EI has been revised to reflect that current human exposures are under control at the facility" (email dated August 10, 2015 from Griff Miller [USEPA] to Steve Snyder [GSC]).

However, as a result of the review of the groundwater HHRA submitted to USEPA and PADEP after the review of the August 2016 version of this report (NewFields, 2016), USEPA raised concern about residential vapor intrusion exposure potential in residential properties located within 100 feet of groundwater with COCs exceeding VISL screening levels occurring on Site. The USEPA review letter is included in Appendix W. As a result, additional efforts were conducted which will be addressed and recorded in the future report previously mentioned in Section 1.5.

#### 3.1.3.2 **SPA Investigation**

The VI investigation described above determined that the pathway of the Site-related COCs was vertically downward through the overlying layers of residuum into the underlying carbonate aquifer. Groundwater then migrates through the bedrock aquifer generally southward, across US Rt. 30. For clarity, this area is designated as the SPA. The lateral extent of the Site-related COCs in the SPA was identified as a data gap.

##### 3.1.3.2.1 Hydrogeology and Groundwater Chemistry

Monitoring wells MW-150, MW-151 and MW-152S&D, shown on **Figure 3.1-25,** were located to target locations of regionally mapped fracture traces, which characteristically are indications of areas within a carbonate aquifer that are more prone to solution activity, and have been historically used at other sites to locate high capacity wells and to penetrate karst solution features. This was done in order to maximize the potential to intercept karst conduits that may serve as preferential flow paths for groundwater within the SPA. A four-foot thick zone of solutioned limestone was penetrated between 24 and 30 feet bgs in the MW-152 boring. The upper two-foot void was open (water-filled), while two lower solution channels were clay-filled. No other solutioned zones or karst features were encountered in the 472 feet of drilling in these three wells.

**Figure 3.1-25** also displays the groundwater surface contours in the SPBA and SPA. Because of the timing of the shallow groundwater investigation in the Canterbury Road neighborhood, this map shows a composite of groundwater levels and groundwater chemistry. The groundwater surface contours were adjusted to account for water level changes that occurred between the Site-wide round of water levels collected in October 2014, and the round of water levels collected in April of 2015. The groundwater contours show a general southward lateral gradient from the SPBA toward and across Rt. 30 in the carbonate aquifer. South of Rt. 30, the groundwater lateral gradient shifts westward toward Codorus Creek.

The lateral extent of the TCE and PCE plumes in the SPA are shown on **Figures 3.1-25 and 3.1-26**, respectively, and on **Plates 1 and 2**. Cis12DCE did not extend to the SPA. The 5 µg/L TCE contour extends approximately 400 feet south of Rt. 30. The PCE distribution is somewhat less consistent than TCE. The contouring was drawn to illustrate two disconnected closed contours off-Site and south of the SPBA. One area is located under Old Arsenal Road and Rt. 30, centered on MW-110, which is screened in the carbonate bedrock, with adjacent wells MW-174 and MW-175, which are screened in the residuum, showing much lower concentrations. The second closed PCE contour is 300 to 700 feet south of Rt. 30. Analyses of groundwater samples from wells installed further down gradient to the west indicated no detections of VOCs. VOC analysis of groundwater samples from RW-5, the former water supply well for the car dealer southwest of the southwestern corner of the Site, indicates low concentrations (2 µg/L) of TCE.

#### 3.1.3.2.2 Results of Residual Dye Injected at MW-64D

Samples were collected in the SPBA and off-Site to the south for residual D&C Red #28 dye from 15 wells on October 17 or 31, 2013 (see Section 2.1.5). The sampling locations are shown on **Figure 3.1-27** and include wells MW-64D&S; up-gradient wells MW-22 and MW-92; on-Site down-gradient wells MW-43D&S; and off-Site down-gradient wells GM-1D, Ru-MW-5, Ru-MW-6, MW-110, Cole F, MW-4 (Cole), MW-8 (Cole B), MW-2 (Cole Flush), and MW-12 (Cole Steel).

Analytical dye results are summarized on **Table 3.1-4** and laboratory reports from Crawford Hydrology Laboratory are included in **Appendix E.1**. Results are posted on **Figure 3.1-27.** With obvious up-gradient locations MW-22 and MW-43S&D having dye results of 0.03 to 0.04, a positive dye detection was interpreted to be ten times greater than background, which is consistent with laboratory recommendations. The pink shaded area shown on **Figure 3.1-27** highlights the pathway of the tracer migration in a southwesterly direction for a length of approximately 2,600 feet from the injection point, and 1,300 feet south of Rt. 30. To date, water in MW-64D is still visibly tinted pink, 15 years after injection of the dye, and provides a continuing source of tracer from the southeast corner of the Site.

This data corroborates the groundwater flow data indicated by the groundwater elevation contours and the lateral extent of COCs detected southwest of the Site.

### 3.1.4 Potential for Migration of Site Groundwater Under and West of Codorus Creek

In a non-karstified aquifer, a stream the size of Codorus Creek in a setting similar to the fYNOP Site would serve as a natural discharge boundary for Site groundwater flow, and a barrier to further westward migration, absent artificial pumping centers that could alter the natural lateral and vertical gradients. In a karst aquifer, there is a potential that Site groundwater could migrate in open solution channels at depth in the aquifer that would not result in complete discharge to the creek of groundwater originating on the Site. The presence of this potential pathway was examined through multiple lines of evidence, as listed below and described in this subsection.

1. Water levels from wells on the west side of Codorus Creek were examined.
2. The occurrence and orientation of a layer of shale and its impact on groundwater flow was considered.
3. Tracer dyes were injected into open karst conduits at various depths along the eastern levee of Codorus Creek. Groundwater wells, springs, and stations established in Codorus Creek and its tributaries were monitored. The pathways and interconnections of the karst solution channels were assessed.
4. A well was located on the west side of Codorus Creek to address the potential that the Kinzers Shale is not persistent in one area northwest of the Site.

#### 3.1.4.1 Water Levels West of Codorus Creek

The lateral gradient in groundwater west of Codorus Creek was determined by measuring water levels in monitoring and water supply wells that were identified during the field reconnaissance of wells located west of Codorus Creek and by reviewing data in the PADEP files (see **Appendix C** for file review memorandums and **Figure 2.1-1** for well locations). Results of the water level monitoring indicated groundwater elevations in wells on the west side of the creek were higher than shallow groundwater elevations at the Site. Data indicated that the groundwater table on the west side of the creek sloped eastward toward the creek, which would create a groundwater flow gradient towards the creek. This slope of the gradient suggests that shallow groundwater from the Site does not flow westward past Codorus Creek.

#### 3.1.4.2 **Kinzers Shale West of Codorus Creek**

The occurrence of a persistent layer of shale west of Codorus Creek, identified in published geologic studies as the Kinzers Shale (Stose and Jonas, 1939), was confirmed by mapping of the local geology (Subsection 2.1.1). As shown on **Figure 1.3-5** (cross section) and **Figure 2.1-1** (regional geologic map), this band of shale runs along the entire west side of the creek across from the Site, limiting the extent of the carbonate aquifer and eliminating the potential for westward migration of groundwater in karst solution channels. Regional geologic mapping indicates the Kinzers Shale extends southward (upstream), crossing to the east side of Codorus Creek approximately 4,000 feet upstream, essentially eliminating the potential for further southward migration in the karst aquifer in that direction. The published geologic mapping was confirmed by GSC, and some adjustments were made to the geologic contacts. The results of the geologic field mapping are shown on **Figure 2.1-1**.

Geologic field mapping indicates that the persistence of the Kinzers Shale is interrupted northwest of the Site and immediately north of the YCSA wastewater treatment plant. For the purposes of clarity during this investigation, this potential pathway has been referred to as "the Northwest Passage". Vintage Formation carbonate rocks form a small continuous lens of potentially solution-prone aquifer material between the Harpers Formation north of the east-west trending fault, and the Kinzers Shale, which can be seen on **Figure 2.1-1**. The valley of the unnamed tributary which passes under I-83 follows this narrow lens.

Monitoring well MW-148A was installed on the west levee of Codorus Creek immediately east of the Northwest Passage. As discussed in Subsection 2.2.4, geophysics was used to enhance the potential of drilling a well that would intersect a karst conduit. The boring was advanced 214 feet through the carbonate aquifer, where it intersected the fault contact of the Harpers Formation, which established the bottom of the carbonate aquifer and the lower possible limit of solution features.

Drilling of the borehole for well MW-148A intersected no karst solution features, penetrating dense, unweathered limestone and dolostone. Most bedrock core recovery had a Rock Quality Designation (RQD) of 100%, indicating the rock penetrated is very competent with few widely-spaced joints/fractures and a corresponding limited ability to transmit groundwater (low transmissivity).

A two-level Waterloo sampler was installed in the MW-148A boring. Sampling ports and water level transducers were installed at one depth within the carbonate aquifer at a possible fracture zone inferred by inspection of the rock core and at a second depth across the fault contact at the bottom of the carbonate aquifer. As illustrated on **Figure 3.1-2** (cross section-B-B'), there is an upward hydraulic gradient toward Codorus Creek at the MW-148A location and groundwater chemistry results indicate no detections of Site-related COCs.

### 3.1.4.3 **Levee Area Dye Tracer Testing**

The levee area dye tracer testing was initiated 22 days after shutdown of the extraction system, which occurred on November 25, 2013. At the time of the dye tracer testing the effects of extraction system pumping were dissipated, and natural groundwater flow conditions prevailed.

#### 3.1.4.3.1 Selection of Dye Injection Locations

Dyes were injected into three levee wells. Based on the well logging, these wells are inferred to intersect karst features between 211 and 216 feet bgs (MW-147A), between 132 and 142 feet bgs (MW-99D), and between 103 and 121 feet bgs (MW-100D). The apparent karst features encountered in MW-147A are representative of the deepest karstic development identified adjacent to Codorus Creek, and the apparent karst features encountered in MW-99D and MW-100D are representative of intermediate karstic pathways through this area.

Prior to injection, dye monitoring stations were established in wells and the creek to establish background concentrations. Locations of these dye monitoring stations are shown on **Figure 2.3-10**. The monitoring stations were then maintained throughout the monitoring period and were the same locations monitored for chemistry during the groundwater extraction system shutdown tests.

The following tracers were injected:

1. RWT into MW-147A,

2. Fluorescein into MW-99D, and
3. Eosine into MW-100D.

#### 3.1.4.3.2 Dye Quantification and Detection

Concentrations of dyes reported by Crawford Hydrology Laboratory are considered to be semi-quantitative values for samples that were collected using charcoal receptors. Semi-quantitative values are reported because the quantity of dye adsorbed by the charcoal is a function of the concentration of not only the dye but also other factors such as the size of the water body, flow velocity, temperature and duration of exposure, and the presence of interference molecules that may compete with the dye for charcoal adsorption sites. Crawford Hydrology Laboratory's procedures are presented in **Appendix E.4** and provide details regarding dye quantification and quality control/quality assurance.

For these semi-quantitative values, the laboratory reports dye results as (1) non-detected (ND), (2) detected as an initial background concentration (IB), (3) detected as background (B) where the sample does not meet the criteria for a positive detection or the concentration is greater than or equal to the quantitation limit but less than 10 times the concentration of the IB value, or (4) as positive detections. The positive detections are reported as Positive + (10 times the IB or equal to the lowest detection limit), Very Positive ++ (100 times the IB or the lowest detection limit), or Extremely Positive +++ (1,000 times the IB or the lowest detection limit). The laboratory also reports questionable positives if high dye concentration was detected, but an initial background sample had not been collected.

Non-detections and those labeled as B detections were generally interpreted to indicate that dye did not travel to a specific monitoring location and therefore no hydrologic connection (solution feature or diffuse pathway) exists between the dye injection location and the sampling point. However, where reported B detections followed several reported non-detections, such as for Green 8 at spring SW-17, professional judgement was considered in the analysis. In those cases, an interpretation was made that a positive detection did, in fact, occur and that there is a direct hydrologic connection between the injection location and the sampling point. Similarly, professional judgement was used to interpret positive detections of eosine in well MW-146, even though the lab reported the results as questionably positive because an initial background sample had not been collected.

#### 3.1.4.3.3 Histograms of Dye Tracer Detections

Histograms of the dye concentrations were used to assist in identifying trends for analysis of the dye tracer results. The histograms are included in **Appendix E.5**. An example of a typical positive response to a dye trace test, shown on the histograms is included as **Figure 3.1-28**, which is pulled from **Appendix E.5** and includes data from the laboratory results included in **Appendix E.6**. This figure shows fluorescein concentrations in Codorus Creek sample SW-8, which is approximately 1,000 feet downstream of the Site, monitoring the east side of the creek channel. The histogram shows background concentrations of fluorescein dye detected prior to and one day after the injection of dye in MW-99D. After two days, fluorescein concentrations began to increase, peaking in approximately six days. The concentrations dissipated over the next several weeks, but concentrations exceeding the background concentrations persisted through the next three to four months, and beyond the sampling period of this test.

#### 3.1.4.3.4 Dye Transport Pathways in Cross-Section

Dye transport pathways and the associated estimated (ballpark) travel times of the dye were determined from the analytical results of the charcoal dye receptors. Literature (Ford and Williams, 2007, and Green et al, 2006) indicates that there is a gradational transition from laminar flow (through secondary openings such as joints, fractures, faults and bedding plane partings) to turbulent flow (through large karstic solution features) when the groundwater velocity is between 0.1 feet per minute (ft/min) and 1.0 ft/min. Flow velocities lower than 0.1 ft/min are considered to be laminar flow grading downward to matrix flow (through intergranular pore spaces), and velocities greater than 1.0 ft/min are considered to be turbulent flow through open karstic solution features. The estimated dye velocities calculated for each dye injected at the levee area are listed on the figures specified below. Actual travel velocities may be much higher than calculated because of the circuitous pathway that water and dye may travel in the aquifer. Also, it is likely that pathways are made up of a combination of solution features and secondary openings, and that measured travel times are the averages of the velocities through more than one path type.

The red arrows on **Figure 3.1-29** illustrate the straight-line paths of RWT from injection point MW-147A to monitoring stations where RWT was detected in water samples and dye receptors. **Figure 3.1-30** provides a cross sectional view of these pathways from the injection site. RWT was detected in SW-8, the downstream receptor on the east side of the creek within three days (0.53 ft/min), suggesting an efficient conduit connection. This supports the borehole point dilution test measurement in MW-147A of 1.28 ft/min. The tracer traveled northward (downstream) under the eastern bank of Codorus Creek to MW-100I and to MW-145A within seven days (0.02 and 0.075 ft/min, respectively), with these velocities suggesting fracture-controlled flows. Later detections in MW-98I (0.003 ft/min) and SW-13 (0.004 ft/min) indicate slower velocities, and suggest laminar or matrix flow in the aquifer.

The green arrows on **Figure 3.1-31** illustrate the straight-line paths of fluorescein from injection point MW-99D to monitoring stations where the tracer was detected in water samples and dye receptors. **Figure 3.1-32** provides a cross sectional view of these pathways from the injection site. The tracer was detected in five locations in the creek and in wells along the east side of the creek within three days. **Figure 3.1-33** is a photograph of dye seeping into the surface water at the confluence of Codorus Creek and Johnsons Run. The dye appeared at this location within two days of injection (0.076 ft/min). This appearance of fluorescein dye suggests the existence of a strong fracture-controlled upward vertical pathway. The tracer was also detected in MW-100I (0.59 ft/min), which is 840 feet upstream, indicating the vertical head in the karst network exceeds the influence of the Codorus Creek surface water level head distribution on groundwater flow directions.

The blue arrows on **Figure 3.1-34** illustrate the straight-line paths of eosine dye from injection point MW-100D to monitoring stations where the tracer was detected in water samples and dye receptors. **Figure 3.1-35** provides a cross sectional view of these pathways from the injection site. The tracer was detected in ten locations, however, unlike the other two tracers, detection times were on the order of months rather than days, with a maximum velocity of 0.086 ft/min measured to SW-8. This is somewhat surprising, since the open interval into which this tracer was injected is a solution cavity open over a borehole interval of at least 18 feet. Another surprising observation is that the injected dye appears to have been detected in adjacent well MW-147A, which is south (upstream) of MW-100D and approximately 75 feet deeper, suggesting groundwater travels counter to the generally upward gradient in the karst network in the levee area. Eosine also was detected in levee well MW-98I (north of MW-100D, apparent velocity of 0.018 ft/min). These detections to the south and north of MW-100D indicate that there is a north-south component of flow under non-pumping conditions along the levee. Detection of eosine in shallow wells MW-100I, MW-100S and MW-146, submerged spring SW-17, and at the creek sampling stations SW-16, SW-13, SW-28 and SW-8 demonstrates that there is a vertically upward flow gradient under non-pumping conditions. Detection of eosine continued to occur for more than a year after the dye was injected, and was detected in the last sample collected.

The results of the Levee Area dye tracer injection test show that under non-pumping conditions, dyes travel in groundwater parallel to the creek (upstream and downstream) to wells along the eastern side of the creek, traveling vertically upward and downward. There is a general upward hydraulic gradient, and in all cases, the injected dyes discharged to the creek. **Figure 3.1-36** is a cross sectional view of the apparent flow paths for the three dyes compiled on the same view. The actual flow paths are certainly more complicated than this description, and are presumed to take circuitous paths through the numerous solution channels and through fractured portions of the aquifer. Flow appears to be occurring in a well-connected network of solution-enhanced channels, as evidenced by the rapid travel times, and through slower pathways, presumed to be the fractured rock or possibly sediment plugged solution channels.

The observance of eosine dye in shallow overburden well MW-146 provided evidence for upward flow occurring into the overburden from its injection point at 110 feet bgs in MW-100D. Therefore, all the results of dye testing at the levee indicate that there appear to be numerous discrete and possibly convoluted pathways that are oriented in multiple directions, including some that are counter to the general lateral and vertical gradients.

The lack of positive dye detections in SW-15 and SW-26, spring discharges on the west side of Codorus Creek is a notable observation, suggesting that these springs are not directly connected to the intermediate and deep injection points on the levee.

### 3.1.5 On-Site and Off-Site Horizontal Extent of COCs

As a result of the well installation, and the groundwater, surface water and spring sampling completed during the Part 2 SRI, the horizontal extent of Site-related COCs was characterized with the groundwater extraction system turned off. Groundwater isoconcentration maps for three primary COCs are included as **Plates 1** (TCE), **2** (PCE) and **3** (cis12DCE). The contours represent the shallow groundwater chemistry, which, except for the higher elevations to the north and east, is approximately 310 feet amsl, approximately 40 to 50 feet bgs in the CPA and WPA, using the three-dimensional contouring from the cross sections discussed earlier in this section. In the upper elevations, concentrations from wells in the top 100 feet bgs were generally used to construct isoconcentration contours. Where there are well couplets open to different depths, the shallower of the two couplets is used. The plates are presented as oversized drawings for the convenience of readers that may wish to view the groundwater chemistry more carefully.

For TCE and PCE, the horizontal extent is defined as the estimated location of the 5 μg/L contour line, which is the PADEP RUA MSC for groundwater (used aquifer with <2,500 mg/L total dissolved solids). For cis12DCE, the RUA MSC is 70 μg/L, and the limit of the plume will be described as 70 μg/L. However, cis12DCE concentration contours of 50 and 5 μg/L are also shown because the distribution is important with respect to the degradation processes that occur within the aquifer.

As with the vertical extent exercise TCE, PCE and cis12DCE were selected for the analysis of the horizontal extent of COCs because they are most pervasively detected in the groundwater beneath the Site and represent the worst-case scenarios. As was stated in a previous section describing the vertical cross sections, the construction of isoconcentration contours in a karst aquifer, is more subject to errors than in a porous media. Contour lines represent concentrations expected in the groundwater within the interconnected fractures and solution channels in the saturated zone.

In addition to the geologic contacts and October 2014 groundwater elevation contours, these plates include the pie diagrams that illustrate the ratios of chlorinated compounds used throughout this document. The pie diagrams show the predominance of TCE, PCE and cis12DCE, but also indicate the occasional presence of VC and the less prevalent TCA and its degradation compounds 1,1DCE and 1,1DCA.

Common to these maps are the data boxes beside each sample point. For wells, the data boxes indicate the station (well designation), the screened or open interval. **Plates 1 and 2** post the TCE and PCE concentrations for four sampling events: 2008 RI (Round 1); 2013 Comprehensive Round (Subsection 2.2.9); 2014 Comprehensive Round (Subsection 2.3.8); and 2015 Comprehensive Round (Subsection 2.3.10). **Plate 3** posts cis12DCE and VC concentrations for the same sampling events. For the surface water and spring samples, the data boxes indicate the station, and concentrations for the same rounds of sampling. Groundwater chemistry contouring used the 2014 Comprehensive Round data, which were collected under non-pumping conditions. If a well had not been sampled in 2014, guidance was taken from the results of the other chemistry rounds and the trend graphs (**Appendix L.3** and **L.4a and b**) to approximate 2014 values. The 2015 chemistry data was not used for contouring because data analysis for this Part 2 SRI report began prior to obtaining the analytical data for the 2015 Comprehensive Round.

The TCE contours on **Plate 1** illustrate the widespread distribution of relatively low concentrations of TCE across the eastern half of the Site. Higher concentrations are evident at the NETT, Bldg58 area, TCA Tank Area, WBldg 2 Corridor, NBldg4 Area, the former industrial wastewater treatment plant (IWTP), and the northern half of the WPL. TCE concentrations in the shallow groundwater in the SW-WPL do not exceed 50 µg/L, although concentrations at depth are much higher. The shallow portion of the aquifer surrounding the wetlands west of the WPL appear to have TCE concentrations of less than 5 µg/L, but higher concentrations occur along the eastern levee of Codorus Creek.

The PCE contours on **Plate 2** illustrate the distribution of PCE across the Site as much less widespread than TCE in the northeastern quadrant of the Site, but with higher concentrations than TCE along the southern half of the eastern perimeter road. PCE is generally co-located with TCE in the Bldg58 area, WBldg2 Corridor, NBldg4 Area, and the IWTP. Also, PCE concentrations are found near the southwest corner of Bldg4, the SW-WPL and the northwest corner of the WPL.

Because of the limited distribution of VC, TCA, 11DCA (dechlorination product of TCA), and 11DCE concentrations of these CVOCs have not been contoured. VC concentrations are posted on Plate 3 and Tables 2.2-2 and 2.2-3A where concentrations above 1 µg/L are limited to CVOC source areas: NBldg4 Area and downgradient to the west (see MW-114, MW-116, MW-50D, MW-140A-all sampling depths); the TCA Tank Area (see MW-137A (420-420.5' and 434.5-435')); SW-WPL (see MW-136A (356-356.5';372.5-373'; 459.5-460')). VC was also detected west of the Site in shallow well MW-155 at 1.5 µg/L in 2014. The pie diagrams on Plate 3 illustrate the chemical signature and relative ratios of each of the CVOCs detected. Detections of TCA, 11DCA and

11DCE are limited to the NBldg4 Area, the TCA Tank Area and downgradient of those areas including the SW-WPL.

Data from the 2015 Comprehensive sampling event in September and October 2015 (**Tables** 2.2-4a and **2.3-1a**, and **Plates 1, 2, and 3**) indicate that the horizontal distribution of CVOCs remained stable, but there were changes in chemistry in individual wells. For instance, the PCE concentration in well MW-110 located in the SPBA increased by more than 30 percent to 80 µg/L in 2015, and concentrations of TCE, PCE and cis12DCE more than doubled in well MW-94 located east of Bldg2 compared to the previous sampling event in 2008. Wells MW-45, MW-46, MW-47 and MW-81D&S, located in the WBldg2 Corridor, had not been sampled since 2008. CVOCs in these wells showed a comparative decrease in 2015.

Wells MW-45, MW-46, MW-47 located west of former Bldg 4, and MW-81D&S, located in the WBldg2 Corridor, had not been sampled since 2008. They were sampled in preparation for the development of a monitoring program for groundwater when the proposed new building for this area is constructed. CVOCs in these wells showed a decrease in 2015 compared to 2008.

#### 3.1.5.1 **Lateral Extent of Groundwater Chemistry at Different Elevations**

The distribution of TCE, PCE and cis12DCE also are illustrated in plan view for three different elevations beneath the western portion of the Site underlain by carbonate bedrock to delineate the horizontal extent of these COCs with depth. **Figures 3.1-37 through 3.1-39** show isoconcentration contours for TCE at elevations of 310 feet amsl (the shallowest horizon, at 50 to 70 feet bgs), 210 feet amsl (intermediate horizon, 150 to 170 feet bgs), and 110 feet amsl (deepest horizon, 250 to 270 feet bgs). PCE concentration contours for the same elevation slices are shown on **Figures 3.1-40 through 3.1-42**. Cis12DCE concentration contours for the same elevation slices are shown on **Figures 3.1-43 through 3.1-45**. These maps show that the highest and most wide-spread concentrations of TCE and cis12DCE are located within the intermediate zone where numerous karst solution features were encountered (see Subsection 3.1.1.2). The highest concentrations of PCE occur in more discrete locations: in the shallower zone at the NBldg4 area and in the intermediate and deep zones at the SW-WPL. Cis12DCE is generally distributed less extensively than TCE and more extensively than PCE in the horizontal views of the deepest zone, indicating that degradation processes are occurring below the karstified portion of the aquifer, which is generally below 200 ft bgs.

#### 3.1.5.2 **Chemistry Changes After Extraction Well Restart**

Chemistry changes after restart of the groundwater extraction system in January 2015 can be observed in the data boxes on Plates 1, 2, and 3, and are shown graphically on the plots included in Appendices L.4a and L.4b. Historical chemistry data for VOCs are included in Table 2.2-4a.

At the NBldg4 Area, the most notable change in concentrations from non-pumping to pumping conditions occurred in well MW-50S where TCE increased by approximately 1,600 µg/L (to 2,100 µg/L on May 21, 2015), PCE increased by 360 µg/L (to 560 µg/L on May 21, 2015), and cis12DCE increased by 2,380 µg/L (to 3,100 µg/L on May 21, 2015). These increases were likely the result of the operation of wells CW-13 and CW-17 redirecting groundwater flow westward from a source of higher concentrations located east of MW-50S.

In the northwest corner of the WPL, wells MW-74S and MW-95 exhibited notable decreases in CVOCs after restart of the extraction system (see graphs in Appendix L.4a and b). These decreases likely resulted from dilution as groundwater from farther west was being pulled eastward and southeast by operation of extraction wells in the WPL.

Operation of extraction well CW-20, located in the SW-WPL, most likely caused the notable increases in CVOC concentrations detected in proximal wells MW-37D, MW-75D&S, MW-93D (Appendix L.4a and b), and in the three shallowest ports of well MW-136A (Appendix L.1) for the 2015 Comprehensive sampling event. CW-20 appears to pull in and capture elevated concentrations of CVOCs, particularly PCE, from a likely source area to the northwest or west of well CW-20. The most pronounced increases occurred for PCE at MW-37D where its concentration increased from 350 µg/L (2014 Comprehensive Sampling Event) to 1,100 µg/L (2015 Comprehensive Sampling Event); at MW-75D where the increase was from 420 µg/L in 2014 to 15,000 µg/L in 2015; at MW-75S where PCE increased from 6,800 µg/L in 2014 to 16,000 µg/L in 2015; and at MW-93D where PCE increased from 71 µg/L in 2014 to 160 µg/L in 2015. For the shallowest port in MW-136A (270-348'), the most pronounced increase occurred for the compound cis12DCE, where the concentration increased from 67 µg/L in 2014 to 20,000 µg/L in 2015. A more detailed analysis of the concentration changes in well MW-136A is provided in Section 3.3.2.

Concentrations of TCE, PCE and cis12DCE in the levee area wells generally decreased in response to the restart of the extraction system. CVOC concentrations in most of the wells located along the northern part of the levee (MW-98I&S, MW-145A) decreased by 50 percent or more (see chemistry graphs in Appendix L.4b). In the northern part of the levee, an exception to the decreasing trends can be observed in MW-99D where concentrations of TCE appear variable and may show an increase when the extraction system is in operation: however, an alternative explanation for the increases in TCE concentrations is that there could be a two to three month lag time in concentration responses in this well after the extraction wells are shut down or restarted. In the southern part of the levee area adjacent to the Site, cis12DCE decreased by about 50 percent in MW-147A when the extraction system was restarted, but TCE and PCE concentrations were variable after the restart. CVOC concentrations in wells MW-100I and MW-101D&S appeared to be unaffected by the status of the groundwater extraction system over the time period examined.

After restart of the groundwater extraction system, CVOCs in Codorus Creek generally decreased to less than 1.0 µg/L at all in-stream creek monitoring stations except at SW-27 where the TCE concentration was slightly higher at 1.1 µg/L in September 2015. CVOC concentrations of individual parameters in the spring monitoring station SW-17 dropped below 50 µg/L after restart of the extraction system. In springs SW-15 and SW-26, located on the western side of Codorus Creek, CVOC concentrations initially decreased after the extraction system was restarted, but subsequently increased in August and September 2015. A more detailed analysis of chemistry at selected Codorus Creek monitoring stations is provided in Section 3.5.6.

## 3.2 Hydraulic Characteristics of the Karst Aquifer

A number of data gaps were identified relating to the hydraulic characteristics of the karst aquifer after the Part 1 SRI. The vertical extent of the carbonate aquifer, the vertical extent of karst features, and the potential that there is a deeper karst network with limited hydraulic connection to the shallow aquifer resulted in concerns regarding the effectiveness of the relatively shallow groundwater extraction system and the extent to which contaminant migration may be transported by groundwater migration. In addition, the aquifer conditions without the influence of the groundwater extraction system had not been observed. The relationship of tributary streams to the carbonate aquifer had not been determined. A number of tracer tests were conducted to resolve specific questions regarding the karst solution channel network.

### 3.2.1 Vertical Extent of Carbonate Aquifer and Solution Features

The vertical extent of the carbonate aquifer and the potential that there may be a deeper karst network with limited connection to the shallow aquifer were discussed in the previous section, since those answers were integral to the nature and extent of contaminant migration. In addition to the cross sections showing the distribution of voids throughout the aquifer, a digital three-dimensional visualization of the fYNOP Site, first developed during the Part 1 SRI effort, was updated, adding information from the wells drilled as part of the Part 2 SRI investigation. The model differentiated rock type (carbonate or noncarbonated) and solution channel elevation and thickness. Snapshots from the model are included with the digital version of this report in **Appendix S.**

Also contributing to the understanding of the vertical extent of the carbonate aquifer was the determination of the orientation of bedding planes from the geophysical borehole logging. The range of strike and dip orientations at logged boreholes are shown on **Figure 2.2-7**. The measurements confirm the carbonate bedrock underlying the WPA is a syncline (a U-shaped down fold) plunging 10 to 20° to the west. Based on that orientation, the depth to the bottom of the carbonate aquifer and the top of the quartzitic sandstone at the SW-WPL is estimated to be approximately 600' bgs (see section A-A' on **Figure 3.1-1**). At Codorus Creek, the projected depth would be approximately 650' bgs where cross section A-A' crosses the creek. However, the south dipping fault between the Harpers Phyllite and the Vintage carbonate that occurs north of the Site would intersect A-A' at approximately 400 feet bgs if the 17-20° dip angle is projected, as shown on section C-C' (**Figure 3.1-3**). Based on those projected orientations, the deepest portion of the carbonate aquifer under the SW-WPL may not be much deeper than the 468 feet drilled at MW-136A.

### 3.2.2 Influence of Precipitation and Surface Water on the Carbonate Aquifer

GSC reviewed data collected from multi-parameter recorders placed in wells that intersected karst conduit features to determine how the conduits in these wells were influenced by precipitation events, and as a result, determine the degree to which the conduits are connected to the surface, and how water quality parameters are influenced by the interconnection. The well locations are shown on **Figure 2.3-7**. A relatively large precipitation event, totaling about 6.36 inches of rain over 41 hours from October 10, 2013 at 7am to October 12, at 12am, during pumping conditions, was chosen to analyze the multi-parameter data for noticeable changes. Several of the meters showed marked changes in data collected during this event. Graphical results discussed below can be seen in **Appendix Q.4**.

Codorus Creek Levee wells MW-99S, MW-99D, MW-100D, MW-145A and MW-147A showed an immediate response in groundwater elevation to the rainfall event with a sharp rise during and then gradual decline following the event. **Figure 3.2-1** is the graph of MW-145A extracted from **Appendix Q.4** information showing a typical water level response from these wells. MW-145A is open to the aquifer from 200 to 250 feet bgs, and has been classified as representing the deep portion of the karst system along the creek. The water level in this well was compared to the elevation of Codorus Creek at Codorus 2, approximately 440 feet downstream from MW-145A, shown on the top graph. This comparison indicates a consistent 2 to 3 foot upward head differential between 145A and the creek except at the peak of the water level rise, when the Codorus Creek level exceeded the MW-145A level by approximately 2.5 feet. Simultaneously there was a brief decline in conductivity, shown on the middle graph. Groundwater temperature also reacted, with a small but consistent drop occurring when the water level in the well spiked, as shown on the lower graph on **Figure 3.2-1**. Conductivity then rose over the next two days as the creek level dropped below the level in the well, only to drop again when the levels in MW-145A and the creek became nearly equal. After approximately ten days, conductivity stabilized and began to generally decline with the groundwater level. Other wells on the levee had similar reactions to varying degrees.

The initial drop in conductivity may have resulted from Codorus Creek water, which has a lower conductivity than groundwater, being pushed downward into the aquifer when Codorus Creek stage exceeded the piezometric levels in the groundwater. This hypothesis is suggested because the conductivity changes appear to coincide with the times when the Codorus Creek stage exceeds groundwater piezometric levels. Alternately, the change in conductivity could be a result of surface water recharging the aquifer (karst loss), but the dynamics and coincidence of the events suggest the former hypothesis. Regardless of the actual cause of the reactions, the results of this analysis indicate a karst conduit system in the levee area in the aquifer that is well connected to the surface, and impacted by precipitation events.

Wells MW-96D and MW-97 in the WPL showed similar increases in groundwater elevation in response to the rain event as compared to the levee wells, yet the responses were of lesser magnitude and were slightly delayed, occurring just after the rainfall event. These wells showed an initial decrease in conductivity, but no temperature changes were observed. With the exception of conductivity and temperature, other parameters collected by the Multi-Parameter recorders showed no distinguishable variations during the event. Most wells displayed a response in conductivity and in some locations showed a temperature response.

Based on an analysis of this Multi-Parameter data, MW-96D, MW-97, MW-99D, MW-99S, MW-100D, MW-145A, and MW-147A are interpreted to be well connected to open interconnected solution cavities in the karst aquifer due to the water level, conductivity and temperature responses presented during this large precipitation event. MW-99S, MW-145A and MW-147A are believed to be more directly connected to surface infiltration than the other wells because of the marked conductivity and temperature responses as well as significant water level responses.

### 3.2.3 Non-Pumping Hydrostatic Conditions

A number of observations and tests were made while the extraction system was turned off. Since groundwater extraction as an interim remedy had been deployed in the WPL and CPA in November 1990, there have been numerous investigations and well installations completed to supplement the initial characterization of the aquifer. To assist with the evaluation of some of the remedial alternatives being considered, the aquifer was observed under non-pumping or natural conditions. Groundwater levels and gradients, groundwater chemistry, and surface water chemistry were monitored from November 2013 through October 2015, and results are included in this report.

**Figure 3.2-2** depicts water level hydrographs of well MW-136A monitoring ports and nearby wells MW-93D and MW-37D for a two week time period that spans the beginning of the groundwater extraction system shutdown on November 25, 2013. Reference to **Figure 2.3-1** indicates that WPL wells CW-9, CW-13, CW-15A and CW-17 and TCA Tank area well CW-8 were actively extracting groundwater prior to the shutdown. The aquifer response displayed in the hydrographs on this figure indicate that within one week, the SW-WPL portion of the aquifer recovered from the pumping and appears to have reestablished vertical head potentials that respond to natural, non-pumping conditions. The following observations are noted:

1. During pumping, there is a consistent upward gradient, with the deepest ports (Ports 1 and 2) having the highest water levels, and the shallowest well (MW-37D) having the lowest water level.
2. After shutdown, the deepest Ports 1 (459 feet bgs) and 2 (434 feet bgs) show no water level response. These ports are open to the bedrock portion of the aquifer below karst solutioning. The shallow wells (MW-37D and MW-93D, both at 140 feet bgs) and Ports 3 and 4 in MW-136A show water level rises, recovering from the pumping. Ports 3 and 4 intersected the two deepest karst solution features penetrated during the investigation of fYNOP at depths of 356 and 372 feet bgs. The response to the shutdown of the extraction wells indicates an interconnection between the shallow pumping wells and the deepest portion of the karst network.
3. During recovery, a strong and consistent upward gradient remains, with the highest piezometric level in deepest port, the second highest piezometric level in the second deepest port, and continuing into the water level in MW-37D, which screens a void at a depth of 137 feet bgs.
4. Well MW-93D is also shown on **Figure 3.2-2;** it is open to a void at 142 feet, a similar depth as MW-37D. This well is located 100 feet to the northwest, and thus demonstrates a westward gradient in the shallow conduit system under non-pumping conditions.
5. One day after system shutdown, approximately 1.3 inches of rain fell over a period of roughly 24 hours. While water levels were gently rising due to the shutdown, except for the two deepest ports in MW-136A, all potentiometric levels responded to the rainfall, indicating a piezometric connection to the surface. After three days, the additional head caused by the precipitation dissipated.

**Figure 2.3-15** presents groundwater table contours from water levels measured January 16, 2014, a few weeks after the shutdown. All wells in the groundwater extraction system had been deactivated since November 25, 2013, a period of 52 days. Groundwater contours through the WPL are widely spaced and indicate a generally westward lateral gradient toward Codorus Creek. The water level at

CW-13 appears to be a half foot higher than adjacent wells, causing an unusual pattern to the 346-foot contour, and may be a reflection of a karst conduit connection with higher head potential water levels to the east.

Two groundwater mounds noted on the November 2013 groundwater contour map (**Figure 2.2-9**) persist under non-pumping conditions, as they may be related stormwater discharges to the groundwater or a water supply line leak. The south parking lot area has an apparent steeper lateral gradient during the extraction system shut down as compared with potentiometric conditions during pumping, suggesting greater potential for groundwater migration from the MW-127 area (Bldg58 Source Area) in a south- to southwesterly direction.

### 3.2.4 Deep Karst in SW-WPL Connection to Surface Water (Codorus Creek)

Green dye #8 (also called Pyranine) was injected into CW-20 in the SW-WPL on January 31, 2014 while the groundwater extraction system remained off. Within five days, the tracer was detected in MW-147A (0.08 ft/day or $6x10^{-5}$ ft/min), and within 11 days it was detected in SW-17 (0.05 ft/day or $3x6x10^{-5}$ ft/min), confirming a connection between the deep karst features in the SW-WPL with deep karst features along the east side of the creek (MW-147A) and with the shallow karst features along the east side of the creek (SW-17). This information is illustrated by the green arrows on **Figure 3.2-3** and is shown as a histogram on **Figure 3.2-4**. In addition, the tracer was detected in nested wells MW-75S and D, in close proximity to CW-20, indicating upward vertical migration of the dye through the karst network.

The calculated velocities are below the range considered to be conduit flow (1 foot per minute), suggesting that at least a portion of the groundwater pathway is matrix or laminar flow through the diffuse part of the aquifer, either fractured bedrock or unconsolidated materials. The connection between CW-20 and the deep conduit in MW-147A further demonstrates a well-connected karst solution channel network to the creek, since MW-147A was the subject of its own dye tracer injection that showed groundwater in that well discharges to Codorus Creek (**Figure 3.1-30**).

### 3.2.5 Shallow Cavern in Northern WPL Connection to Surface Water

Tracer dye was injected into the large cavern in well CW-17 during two separate events. Monitoring for the first tracer test was conducted for one month after dye injection, as shown on

**Figure 3.2-1**, and was interrupted by the start-up of extraction well CW-20. During that 1-month period, dye was detected only in wells MW-96S and MW-96D and not in Codorus Creek. It was concluded that a second tracer test would be conducted during drier conditions to minimize potential dilution effects and to extend the monitoring period. Approximately six months after the first injection when background samples were collected prior to dye injection for the second test, the tracer was detected in additional wells MW-39D, MW-74S, MW-95, MW-99D, MW-99S and MW-98S (interpreted as a positive detection because prior results had been non-detected).

The results of the second tracer test at well CW-17 are summarized on **Figure 3.2-5**. The tracer was detected in every down-gradient well that was monitored between CW-17 and Codorus Creek, and it was detected in Codorus Creek at sampling station COD-SW-13. It should be noted that COD-SW-13 is not an identified visible spring, but was located because a subsurface groundwater discharge was indicated at this location by a thermal survey of the creek, and corroborated by a water temperature 2°F lower and alkalinity 10 mg/L higher than ambient stream water (see **Figure 2.3-8**.

Flow in Johnsons Run was intermittent during this tracer test. The tracer was not detected in any samples obtained from Johnsons Run during the tracer test, indicating that groundwater from the area of CW-17 was not discharging to Johnsons Run.

Histograms of dye detections are provided in **Appendix E.5**. **Figures 3.2-6 through 3.2-8** are histograms taken from the appendix that show examples of the SRB detections at COD-SW-13, well MW-98S located along the levee, and well MW-74S located about 250 feet southwest of CW-17. The histograms clearly show a marked increase in SRB detections resulting from the second dye tracer test and show that the highest dye concentrations were detected in groundwater samples collected from well (MW-74S) closest to the injection well and occurred at much lower concentrations in the creek due to distance and dilution.

Groundwater velocity calculations based on travel times of the dye are listed on **Figure 3.2-5**. Groundwater velocities from CW-17 to each respective sampling location ranged from 0.01 ft/min at COD-SW-13 to 0.03 ft/min at well MW-74S. These velocity values are relatively low and would not represent turbulent flow through large solution features even though the dye was injected into the 32-foot void existing in well CW-17. Therefore, it is reasonable to conclude that the large void feature in well CW-17 is not continuous to the west, but that, similar to the conduit features in CW-20, it connects to a series of smaller solution features, plugged solution features, or bedrock fractures along its migratory pathway to the creek. The shotgun pattern of the dye direction arrows shown on **Figure 3.2-5** suggests diffuse flow through the fractured portion of the aquifer.

### 3.2.6 Relationship of the Small Tributaries to the Carbonate Aquifer

Stream flow measurements were collected on September 2, 2014 from Johnsons Run which is a tributary to the east side of Codorus Creek, and from an unnamed tributary to the west side of Codorus Creek immediately north of the YCSA. Johnsons Run is fed by a spring or springs located north of the NPBA, and springs and seepage from the sandstone/quartzite bedrock that occurs along the base of the hill in the vicinity of former buildings 14, 15 and 30, which feed a southern tributary to Johnsons Run that originates on Site near the small pond west of the northwest corner of Bldg 3 (**Figure 2.1-2**). The source of the unnamed western tributary to Codorus Creek is a large spring that emerges from the limestone bedrock at the Rutters Brothers Dairy farm (**Figure 2.1-1**) located more than 0.6 miles northwest of Codorus Creek.

As described in Section 2.1.4 and shown on **Figure 2.1-3**, flow measurements collected on September 2, 2014 indicate that both of these tributaries, flowing in the streambeds over the carbonate aquifer, were losing water as they approached Codorus Creek. Johnsons Run was dry at the discharge point to Codorus Creek on September 2, 2014 during groundwater extraction system operation, but had a flow of approximately 2.7 gpm upstream near the geologic contact between the sandstone and the carbonate bedrock (see location John-3 on **Figure 2.1-3**). In the western unnamed tributary, flow decreased from approximately 370 gpm to 311 gpm over a distance of approximately 1,500 feet. It is therefore concluded that both Johnsons Run and the unnamed tributary lose water to the carbonate aquifer. This conclusion is also supported by the undetected SRB dye from the second tracer test at CW-17, suggesting a lack of groundwater discharge to Johnsons Run during the groundwater extraction system shutdown period.

### 3.2.7 Relationship of Codorus Creek to the Carbonate Aquifer

As described in Section 2.1.4, a comparison was made of Codorus Creek upstream and downstream flow volumes measured on September 26, 2013 and November 21, 2013, accounting for inflow to

Codorus Creek from the tributaries and the YCSA discharge, to determine the volume of water that Codorus Creek was gaining from unidentified seeps, springs or groundwater sources or if Codorus Creek was losing flow through the streambed or streambanks. Data shown in **Table 2.1-1** indicates flow loss occurred in Codorus Creek of approximately 8% and 12%, respectively on the two dates, comparing the upstream and downstream locations. These data should be caveated, however, because of error inherent in the measuring technique, as discussed in Section 2.1.4. Discharge from springs at locations SW-15, SW-17 and SW-26 was physically observed, and therefore indicates groundwater discharging to the creek, and an increase in flow. In addition, dye tracer testing indicates that Codorus Creek does receive groundwater flow (see Subsections 3.1.4.3 and 3.2.4;). Therefore, the results from stream flow measurements were considered inconclusive due to the results of the dye tracer testing, and the physical evidence of Codorus Creek receiving groundwater flow at the identified springs and at SW-13 where groundwater flow also occurs.

The analysis of data from the multi-parameter recorders discussed in Subsection 3.2.2 suggests that there may be occasions when creek water could flush into the aquifer presumably through solution channels. While the normal gradient between groundwater and the Codorus Creek is upward, indicating a potential for discharge of groundwater to the creek, the peak stage of the creek during a storm event appears to exceed groundwater levels, which could cause creek water to flow into the aquifer for a short period of time during rises in creek stage.

## 3.3 Fate of Site Chemicals of Concerns

Data gaps regarding the fate of dense nonaqueous phase liquid (DNAPL) COCs, involved the persistence of the diffused mass of contaminants as a continued source, and the potential that natural degradation processes may play a role in a final remedy.

### 3.3.1 Natural Attenuation of Chlorinated Solvents

In September 2013 and October 2014, as part of the comprehensive groundwater sampling program, analyses of samples from selected wells for MNA indicator parameters was performed to enhance the understanding of where on the Site transformation of primary CVOCs to daughter products is occurring by reductive dechlorination. **Table 3.3-1**, from FSP Addendum #14, provides additional information and the rationale for testing of each of the MNA parameters. Understanding the degree to which CVOCs are being metabolized and where in the aquifer it is occurring will also be useful during development and screening of remedial alternatives and remedy selection.

Professional judgement was used to evaluate the efficiency of natural attenuation within the aquifer based on the Site-specific hydrologic and geochemical characteristics, along with the MNA transformation indicator parameters. In addition, the USEPA's *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* dated September 1998 was used as guidance to "screen" the MNA results and provide an interpretation of the degree to which biodegradation via reductive dechlorination is occurring in areas within the Site where the MNA sampling was conducted.

The screening process consisted of awarding "points" for each of the MNA indicator parameters and then totaling the points (score) for each sample. For example, if cis12DCE (a daughter product of TCE) was detected in a sample, 2 points were awarded because its presence demonstrates that biodegradation is occurring in the groundwater. Likewise, if the DO concentration in a sample was less than 0.5 mg/L (a favorable condition for biodegradation of chlorinated solvents), 3 points were awarded. The numerical score for each of the samples was then compared to a range of possible scores to obtain an interpretation of evidence for reductive dechlorination in accordance with the following:

| Total Score | Evidence for Reductive Dechlorination |
|---|---|
| 0 to 5 | Inadequate |
| 6 to 14 | Limited Evidence |
| 15 to 20 | Adequate Evidence |
| >20 | Strong Evidence |

This screening process was performed for six groups of wells: 1) wells with conduits in the CPA, 2) wells within the source area in the CPA, 3) levee area wells, 4) NPBA wells, 5) SPBA wells, and 6) WPL wells. Screening calculations for each grouping of wells are shown on **Table 3.3-2a through 3.3-2f**. The total scores for the MNA samples ranged from -1 to 16, and indicated inadequate to adequate evidence of reductive dechlorination. Samples from the wells in the SPBA (**Table 3.3-2e**) had the lowest total scores (inadequate evidence) compared to the wells in the other areas. Samples indicating adequate evidence of reductive dechlorination were only present in the NPBA (see well MW-9 in **Table 3.3-2d**) and the CPA (see well MW-139A [421.5-433 feet] in **Table 3.3-2b**), although the scores for the wells in these areas varied due mostly to differences in DO concentration.

Pie diagrams shown on chemical cross sections and maps illustrate the ratio of daughter products cis12DCE and VC to parent products PCE and TCE. The cross sections clearly illustrate an increase in the proportion of daughter products deeper in the aquifer. A good example for reference is cross section D-D' (**Figure 3.1-8**). This section runs south to north through three source areas, the TCA Tank area, the Wbldg2 Corridor, and the Former Building 41 IWTP. The high concentrations of TCE are shown by the three separated areas of red contours.

- In all three areas the pie diagrams illustrate higher proportions of PCE, TCE and TCA closer to the ground surface, and increasing proportions of cis12DCE deeper in the aquifer. In the Wbldg2 area cis12DCE predominates at an elevation of approximately 250 feet amsl, or a depth of roughly 100 feet bgs. VC also increases proportionally with depth in this area, as does 11DCE, a product of abiotic degradation of TCA.
- At the TCA Tank area, cis12DCE predominates below 50 feet amsl (approximately 300 feet bgs). This is unusually deep compared to other source areas because of the large solution channel intersected in MW-137A.
- At the IWTP the pie diagrams indicate over 50% of the shallowest sample to be made up of degradation products cis12DCE and VC, and continuing to increase with depth.

This condition of more degradation with depth is also clearly shown by comparing the TCE and PCE contours (**Figures 3.1-8 and 3.1-9** with the cis12DCE contours (**Figure 3.1-10**) on section D-D'. The cis12DCE concentrations generally penetrate deeper and, in the TCA Tank area, higher concentrations are shifted deeper in the aquifer than TCE and PCE.

More distant from the source areas, the condition of more degradation with depth is not as apparent. For example, an examination of the pie diagrams on section C-C' (**Figure 3.1-15**) indicates no apparent change in the proportion of degradation products with depth. The screened intervals in the wells on the levee intersect solution features, with the exception of MW-101S and D and MW-98D. Therefore, it is suggested that the depth in the aquifer is not as much a factor as the absence of solution features that allows the reductive dechlorination of the CVOCs to occur. Since the solution channels provide a more direct route for oxygenated water from the surface to penetrate the aquifer, anaerobic conditions are disturbed and the bacterial population is damaged.

The following is a summary of the overall observations and the lines of evidence for reductive dechlorination of CVOCs based on the analysis results for each area of the Site where MNA sampling was performed:

1. NPBA (sandstone aquifer) – Reductive dechlorination is occurring in the NPBA under reducing (anaerobic) conditions in the shallow and deep bedrock wells, which is evident by the elevated concentrations of daughter product cis12DCE. Anaerobic conditions are apparent in most of the MNA samples that show little or no DO, low nitrate and elevated concentrations of iron and manganese (electron acceptors) compared to published concentrations for groundwater in the Chickies Formation quartzite (Wilshusen, 1979). In addition, the data indicates sulfate reduction and the presence of *dehalococcoides spp* population data and methane concentrations suggest limited methanogenesis.
2. SPBA (carbonate aquifer) – The SPBA wells have elevated concentrations of PCE and TCE. Oxidizing conditions (elevated DO) and the lack of cis12DCE indicates reductive dechlorination is not an active degradation mechanism in the four shallow bedrock wells (open intervals at depths of 77 feet bgs or less). Low CVOC concentration deep bedrock well MW-141A (open interval from 200 to 300 feet bgs) shows evidence of degradation based on the detection of cis12DCE under reducing conditions.
3. WPA (carbonate aquifer) – Reductive dechlorination at and down-gradient of the source areas in the WPA under manganese, iron, and sulfate reducing conditions is evident at varying degrees that is likely due to variable DO from karst recharge conditions. In the deep wells that are screened within the diffuse portion of the carbonate aquifer beneath the WPA (MW-49D, MW-136A and MW-139A), there is adequate evidence of dechlorination under reducing conditions with little to no DO and dehalococcoides population data/methane concentrations that suggest limited methanogenesis at MW-49D and MW-136A.

### 3.3.2 DNAPL Penetration of the Aquifer and Natural Degradation of Dissolved CVOCs in the SW-WPL

Investigations in the SW-WPL have identified carbonate bedrock conditions with open and sediment-filled stacked caverns to a depth of over 200 feet bgs, less frequent solution features to a depth of 373 feet bgs and the near certain existence of separate phase TCE and PCE. Over the years, investigations and interim remedial actions have resulted in the placement of five wells (MW-37S, MW-37D, MW-75S, MW-75D and CW-20) and a 5-level Waterloo sampler installation (MW-136A) in the immediate vicinity of the source area, four additional wells surrounding the source area (MW-93S, MW-93D, MW-107 and MW-156), and five wells directly down-gradient on the east levee of Codorus Creek (MW-100S/I/D, MW-146 and MW-147A). This area has also been the subject of three different dye tracer tests.

The installation of MW-136A was completed in August 2013 for the primary purpose of determining the vertical extent of the CVOCs in the aquifer and CVOCs fate and transport. **Figure 3.3-1** is a portion of cross section A-A’ illustrating the chemistry of the CVOCs in the groundwater. While no DNAPLs were observed in any of these wells, they are suspected to be present due to the high dissolved concentrations that exceed 1% of the solubilities of TCE and PCE. The shading and isoconcentration contour lines on the cross section indicate concentrations exceeding 1,000 µg/L of TCE to a depth of at least 434 feet bgs. At the lowermost sample port in MW-136A at a depth of 460 feet bgs, a TCE concentration of 80 µg/L was detected. An analysis of available data was conducted to evaluate the mechanism for TCE penetrating so deeply into the aquifer. The following scenarios were considered:

1. DNAPL has penetrated into the aquifer to the deepest port.
2. High concentrations of aqueous phase CVOCs have penetrated the aquifer to the deepest port.
3. The drilling and sampling system installation resulted in the downward vertical transport of shallow zone DNAPL or high aqueous phase CVOC concentrations contaminating the deeper ports.

To consider these three scenarios, the nature of the water bearing zone sampled, the hydraulic head potentials, the responses to pumping, the responses to sampling, and the distribution and changes in PCE/TCE series chemistry over time were graphed and evaluated.

**Figures 3.3-2, 3.3-3, 3.3-4, 3.3-5 and 3.3-6** show concentrations of PCE, TCE, cis12DCE, and VC (PCE/TCE series compounds) over time for the five sampling ports for the five sampling rounds that were collected after installation of MW-136A. PCE and TCE are considered parent compounds, while cis12DCE and VC are degradation products of the parents caused by reductive dechlorination of dissolved PCE and TCE in groundwater.

**Figure 3.3-7** displays two graphs. The upper graph on the page shows the concentration of the PCE/TCE series compounds mentioned above, converted or "normalized" to their molar equivalent mass and added to the concentrations of the parents PCE and TCE. Although TCE is a degradation product of PCE, it was also the primary chlorinated solvent used at the Site, so it was not normalized to PCE. The upper graph shows the PCE series concentrations for each of the five ports in MW-136A that represent different depths in the aquifer, and their changes over time. The lower graph displays the percentage of parent compound compared to the normalized total mass.

These graphs also show time lines when groundwater extraction system changes occurred (i.e., pumping and non-pumping conditions). Sampling during different pumping conditions provided an opportunity to evaluate changes in chemistry possibly related to the pumping where dissolved CVOCs would be pulled toward an extraction well in a different direction than under natural (non-pumping) conditions.

Degradation can only occur in the dissolved state (degradation does not occur in the DNAPL). CVOCs in solution migrating with the groundwater must move with the hydraulic gradient, while DNAPL migration may be directed downward, and in some cases, counter to hydraulic gradient. Degradation is not reversible. Therefore, if PCE increases, it is likely a result of influence by a DNAPL source. A more detailed discussion of this subject and the principles used to analyze the chlorinated solvent data is presented in Section 4.1.1 of the Part 1 SRI (GSC, 2011). By considering the nature of the water bearing zone sampled, the vertical gradients and the pumping conditions, observations were made and conclusions derived from this data.

Following is a summary of observations from these graphs, starting with the shallowest zone:

1. MW-136A (270 to 348 feet bgs) – This long interval is an open rock hole through 78 feet of limestone and dolostone, with no apparent water bearing zones, fractures or other

discontinuities. Although this zone is open to a large portion of the aquifer, the yield of the zone is relatively low, indicating low hydraulic conductivity. As illustrated on **Figure 3.3-2**, concentrations of PCE and TCE predominate, initially increasing and then variable. The pie diagram for this port is similar to well MW-75S, which is screened 80 feet higher in the aquifer (**Figure 3.3-1**). **Figure 3.3-7** indicates this shallowest zone has the lowest total normalized mass (upper graph) and the highest percentage of parent compounds (lower graph) compared to other zones until the extraction system was restarted. After the system was restarted, the cis12DCE concentration increased by a factor of nearly 1,000 and the percentage of parent compounds was reduced to only 0.2 percent.

2. MW-136A (356 to 356.5 feet bgs) – This Waterloo port is open to a 2-foot thick solution cavity filled with cobbles. Pie diagrams (**Figure 3.3-1**) are similar to wells CW-20 and MW-75D, which are screened roughly 150 feet higher in the aquifer. Parent and degradation concentrations are highly variable, and percent parent concentrations, are likewise, highly variable. See **Figures 3.3-3 and 3.3-7**. After system restart, concentrations of individual compounds and percent parent returned to pre-shutdown conditions.
3. MW-136A (372.5 to 373 feet bgs) – This port is open to a small solution channel filled with gravel and unweathered fractures. Chemical characteristics are nearly identical to the zone described above from 356 to 356.5 feet bgs, although overall concentrations in this port are consistently higher than the port above it (16 feet higher). See **Figures 3.3-4 and 3.3-7**. After system restart, concentrations of individual compounds and percent parent returned to pre-shutdown conditions.
4. MW-136A (434 to 434.5 feet bgs) – This port is open to two unweathered fractures in competent dolostone identified by examination of the core between packers at depths of approximately 430 feet to 438 feet bgs. The fractures show minimal signs of weathering, and this sample represents the fractured portion of the carbonate aquifer not enlarged by solutioning. Chemistry in this zone showed the greatest change of percent of parent compounds, a decrease from more than 80% to approximately 10%, as illustrated on **Figure 3.3-7**. In addition, the series concentration remained stable over the sample period, with a dramatic reduction in TCE and an equally dramatic increase in cis12DCE (**Figure 3.3-5**). After restart of the groundwater extraction system, the TCE concentration increased and cis12DCE concentrations decreased, approaching pre-shutdown conditions.

5. MW-136A (459.5 to 460 feet bgs) – This port is open to the bottom 24 feet of the boring that intercepted a discrete clay-filled fracture. This zone yields minimal water during sampling. Samples from this zone are consistently the lowest concentrations of TCE and PCE in this multiport sampler (**Figure 3.3-6**), percent parent concentrations are lowest, the next to lowest PCE/TCE series concentrations, and stable concentrations.

As a result of these observations, the following descriptions of the aquifer are inferred:

1. Solution caverns predominate in the section of the aquifer from roughly 150 feet to 200 feet bgs (see **Figure 3.3-1**). DNAPL appears to have entered these solution features, and based on the concentrations of parent compounds, including TCA, is likely to still be present in the aquifer at these depths represented by CW-20 and MW-75S&D. The aquifer zone below the massive stacked caverns, from roughly 200 feet to 350 feet bgs, represents an unweathered section of fractured limestone hydraulically connected to the stacked cavern area through fracture permeability. This is apparent from the response seen in the shallowest port (Port 5 - 270-348 ft. bgs) during pumping of CW-20 (**Figure 3.3-8**). Port 5 does not have a continuous recorder record, but the 4-foot drop in water level after nine days of pumping was manually recorded. In addition, there is a high concentration of PCE and TCE, indicating proximity to undegraded parent compounds from a nearby DNAPL source. However, once the extraction system was restarted, the degradation product cis12DCE appears to have been pulled through this zone from deeper in the aquifer.
2. Intermediate zones between roughly 350 feet bgs and 375 feet bgs are connected to the karst solution channel network indicated by the similarity in chemistry with the water in the stacked caverns represented by CW-20 and MW-75D. The variability in the percent parent compounds indicates changes caused by or enhanced by groundwater flow direction changes as a result of the intermittent pumping that occurred during the period of sampling. This was confirmed by the return to pre-shutdown concentrations and percent parent compounds after system restart.
3. Deeper in the aquifer, open karst solution channels are not present. The initially high concentrations of parent products in the aquifer zone represented by the port at 434 feet bgs are likely a result of contamination that occurred during the drilling process from the zone above at 373 feet bgs. The rapid and consistent decline in the percentage of parent

compounds coupled with the relatively constant PCE/TCE series concentration (**Figure 3.3-7**) may indicate active degradation of parent compounds to cis12DCE or a combination of purging of the aquifer and degradation of the parent compounds, returning to chemical conditions representative of the aquifer. In either case, this portion of the aquifer, isolated from the karst network and sufficiently distant below the DNAPL sources, appears to host natural biodegradation of the parent compounds to cis12DCE. Upon restart of the groundwater extraction system in January 2015, cis12DCE concentrations dropped and TCE concentrations increased, indicating influence of the extraction system in this portion of the aquifer.

4. The deepest portion of the aquifer penetrated by the port at 460 feet bgs has low hydraulic conductivity and the vertical gradient is strongly upward. Groundwater chemistry indicates a highly degraded portion of the plume composed predominately of cis12DCE, with less than 5% parent compounds. This zone appears not to have been contaminated by the drilling operation, possibly because of the absence of clay in the fractures and the higher head potential that would have minimized penetration of contaminated drilling water into the fractures. In addition, the absence of samples from the earlier groundwater sampling events could have allowed the aquifer time to recover from the drilling operation disturbance. Samples could not be initially sampled due to the combination of the depth of the sampler and the low yield of the zone. A procedure was eventually developed that resulted in collection of groundwater samples from this zone.

The results of this investigation indicate that the vertical migration of DNAPL in the SW-WPL is the most-likely mechanism for chlorinated compounds to have penetrated so deeply into the aquifer. DNAPL penetrated through the highly karstified zone of the aquifer (from 150 to 200 feet bgs), the fractured zone and the minimally karstified zones from 200 to 375 feet bgs, and the fractured zones of low permeability from 375 feet bgs to the extent of drilling (460 feet bgs) and potentially some depth beyond. The penetration of TCE and PCE as a DNAPL into the deepest zone of low hydraulic conductivity and subsequent reductive dechlorination of dissolved phase CVOCs is the most likely way that degradation product cis12DCE could have been sourced at these depths, since cis12DCE would not have been transported downward with groundwater due to the consistently upward hydraulic gradient as shown on **Figure 3.2-2**. Transport of dissolved CVOCs downward into the deep portions of the aquifer below 375’, in this case of the SW-WPL, is considered unlikely because of the lack of open karst solution channels and the strong upward gradient. Due to the higher density, DNAPL would have been able to penetrate deep into the aquifer, in spite of the upward hydraulic gradient. Cis12DCE can only be formed after dissolution of TCE or PCE, and therefore cannot migrate counter to the hydraulic gradient.

The reduction in percent parent compounds as depth increases in the lowest portion of the aquifer (**Figure 3.3-7**), as shown by the increasing proportion of cis12DCE in the pie diagrams on **Figure 3.3-1** and the presence of low VC concentrations **(Figure 3.3-6)**, is evidence of active natural biodegradation in the deeper portions of the aquifer that are not exposed to solution-enhanced karst conduits. As discussed in Subsection 3.3.2, there is adequate evidence of dechlorination under reducing conditions at MW-136A with little to no DO and dehalococcoides population data/methane concentrations that suggest limited methanogenesis.

Based on these observations, fate and transport CSM for this DNAPL source area is:

1. DNAPL penetrated to significant depths into the aquifer, through the highly karstified zones generally above 200 feet bgs, the fractured portions of the aquifer represented by sections of unweathered fractured rock between solution-enhanced conduits, and the deeper portions of the aquifer where karst solutioning is diminished.
2. There is inconsistent and potentially intermittent anaerobic biodegradation in karst solution channels due to introduction of oxygen into the aquifer from precipitation events. All monitored levels within the aquifer responded to rainfall events, as can be seen on **Figure 3.2-2**, with larger responses in the shallower portions of the aquifer.
3. Fairly consistent degradation to cis12DCE occurs in the deep portions of the aquifer not exposed to conduit flow.

## 3.4 Source Area Investigations

The investigation of CVOC sources at Bldg58 and the WBldg2 Corridor was conducted to determine if an area could be delineated that contained sufficient mass of COCs that it should be considered for active remediation. Field activities, which involved the installation and sampling of ten shallow wells and 54 MIP borings are summarized in Section 2.2.1. A detailed description of findings from this investigation can be found in “Summary Report – Source Area Investigation of the Former W Building 2 Corridor and Building 58 Areas for PART 2 of the Supplemental Groundwater Remedial Investigation, Groundwater Sciences Corporation, April 2013".

Data acquired during the source area investigations at the WBldg2 Corridor and Bldg58 areas indicate that DNAPL sources were not identified in the shallow subsurface or below the water table. The investigation demonstrated that the methodology would have the ability to identify such a source area, but an area of elevated concentrations in the unsaturated zone either does not exist, or is of limited size. No further investigations are recommended at this time at the Bldg58 area, west of Bldg2, or in the northern portion of the Bldg2 pad. CVOCs in the shallow groundwater in these areas are being captured by the groundwater treatment system and CVOC concentrations detected in soil samples in these areas were below the MSCs.

The MIP sampling did not provide data that enabled a source to be pinpointed at the sump/tank area east of Bldg2 pad. The historic detection of CVOC concentrations in soil samples collected prior to January 2007 (SAIC, 2009) at or above MSCs in this area, and the lack of confirmation during this study indicates that the area of CVOCs at concentrations greater than the MSCs is limited. Thus, no additional investigation is warranted in this area. As long as the building slab remains in place, risks from soil contact in this area are mitigated.

## 3.5 Evaluations of Groundwater Extraction Systems

Monitored shutdown testing was performed to evaluate the need for continued operation of the extraction system located in the NPBA and the Bldg3 Footer Drain System. Two of the data gaps identified in the Part 1 SRI were whether these two interim remedies could be safely deactivated.

In addition, a question was raised regarding the ability of the WPL extraction system wells, which are connected to relatively shallow solution-enhanced water bearing zones, can effectively capture groundwater in the deeper conduit zones, particularly those found in the SW-WPL. Finally, the impact ceasing operation of the WPL extraction system on surface water and groundwater was evaluated in detail via the performance of shutdown tests. Impacts associated with shutdown of these interim measures will be evaluated as part of the groundwater risk assessment and may be used in the analysis of remedial alternatives.

### 3.5.1 NPBA Extraction System Monitored Shutdown

The NPBA pre- and post-shutdown monitoring results are documented in a report titled "Results of NPBA Extraction System and Bldg3 Footer Drain Monitored Shutdown Tests for Part 2 of the Supplemental Groundwater Remedial Investigation" (GSC, 2014b). The shutdown monitoring results indicated that groundwater beneath the NPBA is not migrating off-Site to the north under non-pumping conditions. Rather, COCs present in the groundwater beneath the NPBA are expected to migrate along the natural gradient in a south to southwesterly direction towards the interior of the Site (**Figure 3.1-18**). A comparison of pre- and post-shutdown groundwater laboratory analytical results showed that TCE and PCE concentrations decreased or remained undetected in the majority of the NPBA sampled wells (16 of 23 sampling locations) and that cessation of pumping in the NPBA did not result in an increase in COC concentrations in these wells during the monitoring period.

In April 2014, EPA approved a recommendation to continue the monitored shutdown of the NPBA groundwater extraction system for a period of five years to provide a sufficient amount of data to determine if COC concentrations are rebounding or migrating off-Site. The shutdown plan consisted of annual monitoring and reporting of water levels and chemistry for the NPBA. If after five years of monitoring, no concerns are raised regarding plume migration from the NPBA, consideration shall be given toward decommissioning of the NPBA groundwater extraction system and development of a long-term monitoring plan for this portion of the Site.

In April 2015, the results for the first year of NPBA post-shutdown monitoring were reported in the "2014 Annual Monitoring Progress Report for the NPBA Extraction System Shutdown" (GSC, 2015a). The 2014 and 2015 monitoring included the collection of water levels and samples from locations in and north of the NPBA and to the southwest (down-gradient) of the NPBA. The water levels were measured in January, May and October 2014 and September 2015. Groundwater samples were collected for laboratory analysis of VOCs in October 2014 and 2015, coincident with the comprehensive sampling across the Site. Evaluation of the groundwater elevations and VOC analytical data for the first and second years of post-shutdown monitoring indicated stable (unchanged) conditions based on the following:

1. A comparison of the September 2015 post-shutdown groundwater elevations and potentiometric contours (**Figure 3.1-19**) to the August 2013 post-shutdown elevations and contours (**Figure 3.1-18**) that showed there was essentially no change in the NPBA area.
2. Consistent post-shutdown groundwater analytical data from samples collected in October 2014 and September 2013 (**Figure 3.1-19**) that showed no indications of northward plume migration.

No changes to the plan for the third year of NPBA post-shutdown monitoring in 2016 were recommended based on the first year results. The 2016 monitoring is to consist of collecting water levels and groundwater samples for laboratory analysis of VOCs during the 2016 comprehensive event that is planned for late summer or early fall. Monitoring data will be analyzed and a progress report will be prepared during the first quarter of 2017. The analysis will include the chemistry data from wells MW-82, MW-102 D&S and MW-103 D&S located downgradient from the NPBA. If the data analysis would indicate off-Site migration of elevated concentrations of COCs, the operational status of the groundwater extraction system will be evaluated sooner.

### 3.5.2 Bldg3 Footer Drain Monitored Shutdown

The Bldg3 Footer Drain System pre- and post-shutdown monitoring results were documented in the report titled "Results of NPBA Extraction System and Bldg3 Footer Drain Monitored Shutdown Tests for Part 2 of the Supplemental Groundwater Remedial Investigation" (GSC, 2014b). The monitoring results indicated that the deactivation of the Lift Station pump in June 2013 resulted in a rise of the water level in the Lift Station that equilibrated to 2 to 2.5 feet higher than the pumping level (see graph of the continuous water level data for the Lift Station in **Appendix Q.4**). In July 2013, the water level in the Lift Station rose an additional foot during a significant 3.7-inch rain event before quickly dissipating. Follow-up measurements five months later confirmed that non-pumping water levels in the Lift Station were appropriately characterized during the monitored shutdown observation period. In addition, no discernable water level or seepage condition changes were observed during the Lift Station shutdown. The groundwater levels were confirmed to remain well beneath the paint sludge pit and the FD3 area near the press/equipment pits, which were considered to be the most vulnerable areas within Bldg3 (**Figure 3.5-1**).

Because no adverse water level or seepage condition changes were observed during the pre- and post-shutdown monitored shutdown of the Bldg3 Footer Drain system, continued deactivation of the Lift Station was recommended for a period of two years. This plan was approved by the EPA in April 2014 contingent on the monitoring showing no adverse effect during a heavy precipitation event outside of the growing season, which was defined as approximately 2.5 inches or more in a 24-hour period.

In April 2015, the results for the first year of the Bldg3 Footer Drain System monitored shutdown test were documented in the "First Year Progress Report of the Building 3 Footer Drain System Shutdown Monitoring" (GSC, 2015b). The 2014 monitoring included automatic recording of water levels in the Lift Station, monthly downloads of the recorder and the analysis of a groundwater sample from the Lift Station for laboratory analysis of VOCs and 1,4-Dioxane in October 2014. Second year monitoring was performed in 2015. Manual measurements of the water levels at the Lift Station, Footer Drain Cleanouts 1 and 3 (FD1 and FD3) and well CW-19 were also collected on a monthly frequency beginning in July 2014.

The groundwater elevations from the 2014 and 2015 water level measurements showed that there were no adverse effects to Bldg3 from the continued shutdown of the Footer Drain System. The October 2014 and 2015 groundwater samples from the Lift Station had no detections of VOCs and 1,4-Dioxane and documented the continued absence of dissolved COCs above the applicable regulatory standards in the Lift Station water. A period of heavy precipitation outside of the growing season did not occur during the 2014 or monitoring period. However, the largest daily precipitation event in 2014 (2.03 inches on March 30) or in 2015 (2.15 inches on June 1) did not show any adverse effects (e.g., ground surface seepage) (see hydrograph for the Lift Station in **Appendix Q.4**).

Based on the first and second year results from 2014 and 2015, it was recommended that manual monitoring be discontinued until there is a precipitation event of approximately 2.5 inches in 2016. Automatic water level monitoring will continue at the Lift Station..

### 3.5.3 SW-WPL Extraction Well Capture Testing

Extraction system shutdown testing and dye tracer testing was conducted to determine the effectiveness of the groundwater extraction system in capturing the deeper karst solution network in the SW-WPL. The Part 1 SRI concluded that the groundwater extraction system captured and prevented off-Site migration of Site-impacted groundwater in the WPL, but the depth to which the shallow groundwater extraction wells controlled flow in the network of solution channels was a concern, with the SW-WPL considered to be the area of greatest concern.

#### 3.5.3.1 WPL and CPA Extraction Well Shutdown Testing

A relatively short 19-day groundwater extraction system shutdown test, designated as the Vertical Extent Shutdown Test, was conducted prior to the two extensive shutdown tests described in Section 2.3.7. This shorter shutdown test was conducted in April and May 2013, prior to deepening of the newly installed vertical extent wells MW-136A, MW-137A, MW-139A and MW-140A, as shown on the timeline in **Figure 2.3-1**. The depths and open intervals prior to deepening these wells are listed in Table 3.1-2. Selected wells in the carbonate aquifer across the Site and at the levee area were monitored by continuous water level recorders during the period to assess vertical gradients near the new wells under non-pumping conditions to assess whether the extraction system causes drawdown and capture of the deep groundwater at the WPL and CPA. This shutdown test is described in Addendum #8 to the FSP, included in **Appendix A.** Graphs of all of the data from the testing are provided in **Appendix Q.5** and graphs for the specific wells listed below are shown on **Figures 3.5-2** through **3.5-6**. The drawdown impacts in the deep wells are summarized below.

- Vertical extent well MW-136A, located in the SW-WPL, had approximately 5 feet of groundwater recovery and drawdown due to the extraction system shutdown and subsequent re-start (**Figure 3.5-2**).
- Vertical extent wells MW-137A and MW-140A, located in the CPA, both had approximately 2 feet of groundwater recovery and drawdown (**Figures 3.5-3 and 3.5-4**) during the shutdown-re-start.
- Vertical extent well MW-139A, located in the CPA, had about 1 foot of groundwater recovery and drawdown (**Figure 3.5-5**).
- 6.5 feet of groundwater level recovery and drawdown were observed in monitoring well CW-20 (not in operation as an extraction well during this testing), screened from 205 feet to

215 feet bgs and located in the SW-WPL. This well is approximately 200 feet from extraction well CW-9 (**Figure 3.5-6**).

Results of the testing indicated measurable upward vertical gradients (**Table 3.1-2**) and that pumping of the extraction wells in the WPL and CPA causes drawdown at the depths of the new wells (270 to 320 feet bgs prior to deepening). This confirms that the largest deep conduit located during the investigation (in MW-137A) is interconnected with the shallow karst system penetrated by CW-8.

#### 3.5.3.2 **Dye Tracer Testing Under Pumping Conditions in the SW-WPL**

A dye tracer test was conducted at the SW-WPL to demonstrate the interconnection between a deep conduit feature in well CW-20 and nearby extraction wells. The connection was indicated by the recovery and drawdown of water levels in this well discussed in the previous subsection. Fluorescent dye SRB was injected and slowly flushed into the karst conduit system intersected by well CW-20, an extraction well installed as a potential addition to the groundwater extraction system but, not connected to the system. CW-20 intersects an open and sand-filled solution channel at a depth of 213 to 217 feet bgs. This activity is shown on **Figure 2.3-1** and lab reports of the dye testing are included in **Appendix E.2**.

The groundwater extraction system, consisting of extraction wells CW-9, CW-13, CW-15A and CW-17 in the WPL, and CW-8 in the TCA Tank Area (in the CPA) had been operating as designed for months prior to the injection. The extraction wells were pumping a total of 318 gpm, compared to the average annual pumping rate total of 283 gpm reported for 2012 (Leidos, 2014; SAIC, 2013). The configuration of the groundwater table under these pumping conditions is represented by **Figure 2.2-9**. The shallow groundwater contours in the SW-WPL under pumping conditions indicate a gradient toward extraction well CW-9, but observation points to the west are somewhat distant, and the hydraulic influence of CW-9, with an open gravel-filled solution feature at 50 to 70 feet bgs, on karst solution features at 200 feet bgs in CW-20 was the subject of the test.

Within 24 hours after injection in well CW-20, the tracer was detected in active extraction well CW-9, in the groundwater treatment plant, and in Codorus Creek, as a result of the treated groundwater discharge (see **Figure 3.5-7**). Dye was visible along the east bank of Codorus Creek from the discharge of the groundwater treatment system in Johnsons Run, for 2,900 feet, where the creek takes a near right-angle bend to the right (east). The bend resulted in the channelized flow in Codorus Creek being mixed, which resulted in the dye being diluted below visible concentrations.

The map provided as **Figure 3.5-8** illustrates the route and the timing of the SRB tracer being pumped by CW-9 and discharged through the GW treatment plant. In addition to detection in CW-9, the tracer reached MW-8, which is 350 feet northeast of CW-9 within nine days, possibly a result of pumping influence from CW-8 in the complex conduit system. Detections were also recorded in MW-93D one month after injection. MW-93D is 190 feet north-northwest of CW-20. This would have been two weeks after shutdown of the groundwater extraction system, and it is expected that dye reached that well under natural lateral and vertical gradients after pumping-imposed gradients dissipated. The results of this tracer test indicate that the groundwater extraction system as operated on an interim basis since 1994 appears to be capturing the deeper conduit system in the SW-WPL that is intersected by CW-20.

Further indication of the hydraulic connection between the relatively shallow extraction system and the deeper karst-enhanced solution channels is shown on **Figure 3.2-2**. This figure shows the recovery of water levels in the deeper water bearing fractures monitored in Waterloo installation MW-136A, located in the SW-WPL 80 feet northwest of CW-20, upon shutdown of the groundwater extraction system on November 25, 2013. This figure includes hydrographs of adjacent wells MW-37D and MW-93D, screened in the relatively shallow karst system, in addition to the Waterloo ports in MW-136A. Specific findings depicted by the hydrographs are listed below:

1. Both standard wells MW-37D and MW-93D are screened in solution-enhanced conduits at depths of 137 and 142 to160 feet bgs, respectively. Prior to shutdown, water levels in these wells are lower than the water levels in the deeper Waterloo ports, indicating an upward gradient throughout the aquifer under pumping conditions to the depth of observations (459 feet bgs). Upon shutdown of the extraction system, water levels begin to rise instantaneously in these wells. There is also a noted upward response to a subsequent rainfall event that occurred on November 26.
2. Likewise, there is a clear upward shift in piezometric water levels in Waterloo ports 3 and 4, representing water bearing zones at 372 feet bgs and 356 feet bgs, respectively. The water

bearing zones monitored by these ports have been solutionally enhanced, and thus are most likely connected to the karst network. The positive response strongly suggests the pumping of the extraction system captures groundwater this deep in the aquifer, particularly combined with the upward vertical head.

3. A response to shutdown of the groundwater extraction system is not evident in the two deepest MW-136A Waterloo ports 1 and 2, monitoring water bearing zones at 459 feet bgs and 434 feet bgs, respectively. These zones have low hydraulic conductivity, based on yields during sampling, and represent the portion of the aquifer below the solution-enhanced flow channels. While these zones responded strongly to the rainfall event, that is the result of compression of the low hydraulic conductivity bedrock due to the weight of water entering the overlying karst network. It is expected that a response from the cessation of pumping was delayed, and was comingled with the rainfall influence. This concept is supported by the higher water levels in ports 1 and 2 that were sustained after rainfall influence had dissipated.

### 3.5.4 Impacts of Extraction System Shutdown and Pumping on Codorus Creek and Springs

All wells in the CPA (CW-8 and CW-15A) and the WPL (CW-9, CW-13 and CW-17) were shut down between November 25, 2013 and April 7, 2014, shown on **Figure 2.3-1** as the Wet Season Extraction System Shutdown. This test provided an opportunity to observe changes in the aquifer and creek under non-pumping conditions through late fall, winter, and early spring seasonal conditions. One hundred thirty-three (133) days later on April 7, 2014, previously inactive groundwater extraction well CW-20 in the SW-WPL was turned on, and pumped at a rate of 97 gpm. This well was pumped for 109 days, until extraction well CW-9 was turned on and pumped at 27 gpm, providing a combined extraction rate of 124 gpm from the south end of the WPL for a pumping period of 19 days.

Extraction wells CW-20 and CW-9 were shut down on August 11, 2014, marking the start of the Dry Season Extraction System Shutdown (**Figure 2.3-1**). The shutdown conditions were monitored for 169 days.

The groundwater extraction system was restarted on January 27, 2015. Extraction well CW-8 was not reactivated. The wells that were restarted include formerly active extraction wells CW-9, CW-13, CW-15A and CW-17, plus formerly inactive well CW-20. Total production from these five wells averaged 240 gpm through the first three months, the observation period covered by this report.

A primary objective for conducting the groundwater extraction system shutdown and pumping tests was to monitor changes in COC concentrations in the groundwater and surface water during complete shutdown and during different groundwater extraction scenarios. From that information, the impact of not operating the groundwater extraction system on Codorus Creek, and the effectiveness of individual extraction wells in controlling groundwater discharges to the creek, was evaluated.

**Figure 2.3-10** shows the surface water, spring and groundwater sampling locations. These stations are the same locations used for the levee tracer tests. Surface water chemistry results are presented on **Tables 2.3-1a through 2.3-1c** for stations sampled since August 2013. **Appendix L.5** includes graphs of chemistry concentration vs. time for surface water stations. Specific graphs that are discussed in the text are repeated as figures. The graphs have been updated with analytical results through October 2015. Superimposed on the graphs is a light blue line illustrating Codorus Creek flow from the United State Geological Survey (USGS) gauging station 4 miles upstream. The creek flow, in cubic feet per second (cfs) is shown on the right axis using a log scale. Those concentrations below method detection limits are posted on the graph as zero, to distinguish them from the low actual detections.

**Upstream of Site (SW-6) – Figure 3.5-9** is a graph of PCE series compounds (PCE, TCE, cis12DCE and VC) on the top of the page, and TCA series (TCA, 11DCA, 11DCE and chloroethane [CEA]) series compounds on the bottom of the page from water samples collected in the Codorus Creek at station SW-6, which is upstream of the Site and near the east bank. SW-6 is approximately 200 feet upstream and south of where the Rt. 30 bridge crosses over Codorus Creek.

1. Concentrations of TCE and cis12DCE are between 0.2 and 0.4 µg/L prior to shutdown of the extraction system. After shutdown, cis12DCE concentrations are non-detect and TCE concentrations are 0.4 µg/L or less.

2. After CW-20 start-up and continuing through the addition of CW-9 pumping, there were no detections of these compounds at this upstream station.
3. During the second shutdown period, starting on August 11, 2014, consistent TCE concentrations of approximately 0.2 µg/L were detected.
4. After full extraction system restart (1/27/15), up-gradient concentrations return to below method detection limit.

Although upgradient concentrations of cis12DCE and TCE at station SW-6 were initially thought to be sourced from upstream, the responses to the pumping of CW-20 suggest that the source may be Site related, and controlled by pumping of previously inactive extraction well CW-20.

**Downstream of Site (SW-8) – Figure 3.5-10** is a graph of TCE and TCA series compounds from water samples collected in the Codorus Creek at station SW-8, which is downstream of the Site and near the east bank of the creek. This station was placed downstream of the limit of the carbonate aquifer in order to capture all carbonate aquifer groundwater discharging to the Codorus Creek.

1. Concentrations of TCE and cis12DCE prior to shutdown of the extraction system are similar to upstream concentrations at SW-6 (0.4 µg/L or less), although PCE was detected at this location, and not in SW-6.
2. During shutdown of the groundwater extraction system, concentrations, particularly PCE, increased, with a number of samples indicating concentrations of 1.2 µg/L.
3. After CW-20 start-up, and continuing through the operation of CW-9, there was a noticeable drop in concentrations of all parameters, PCE in particular.
4. Upon system shutdown for the dry season, PCE, TCE and cis12DCE concentrations increased, with PCE concentrations up to 2.2 µg/L and TCE up to 1.2 µg/L.
5. After full extraction system restart, concentrations of PCE, TCE and cis12DCE drop to below 0.3 µg/L.

**Submerged Spring West of SW-WPL (SW-17) – Figure 3.5-11** is a graph of TCE and TCA series compounds from water samples collected from SW-17, a submerged spring that discharges along the east bank of Codorus Creek west of the SW-WPL. As shown in **Figure 3.5-12**, piping has been installed into this point of discharge to facilitate sampling of the undiluted spring discharge.

1. There were detectable concentrations of PCE, TCE and cis12DCE prior to system shutdown. PCE concentrations ranged from 19 to 45 µg/L, and TCE concentrations ranged from 13 to 20 µg/L.
2. This graph illustrates a marked change in concentrations, particularly PCE after extraction wells were shut down. PCE concentrations peaked at 390 µg/L. TCE, cis12DCE and TCA concentrations also increased proportionally absent extraction system operation.
3. After CW-20 start-up, there was a marked decrease in PCE, TCE and cis12DCE, as well as TCA. Response time for the reduction after initiating the pumping was between two and four weeks.
4. After dry season system shutdown, concentrations of the four compounds mentioned above increased over a five-month period. Peak PCE concentrations never exceeded the peak concentrations measured during the previous shutdown.
5. One month after full extraction system restart, SW-17 concentrations decreased to values similar to those measured during the operation of the groundwater extraction system prior to the shutdown testing (prior to November 2013).
6. While there may be other smaller springs or diffuse discharges along the east side of the creek, SW-17 appears to represent the most significant, and appears to account for the majority of the chlorinated VOC mass discharging to the creek. Two other surface water sampling stations are located on the east side of the creek downstream of SW-17 and upstream of SW-8. These two stations (SW-16 and SW-13 [see **Appendix L.5** for graphs]) show similar patterns consistent with SW-17 being the source of the majority of mass discharging from the east side of the creek.

**Spring on West Side of Codorus Creek (SW-15) – Figure 3.5-13** is a graph of TCE and TCA series compounds from water samples collected from SW-15, a spring that discharges along the west bank of Codorus Creek in front of the York City wastewater treatment plant. This spring discharges at an elevation above the normal level of Codorus Creek, but occasionally becomes submerged by the creek during high surface water runoff events. This spring occurs in a collapse feature (sink hole) on the bank of the creek, an indication that it is well-connected to the karst solution channel network in the carbonate aquifer that underlies the stream.

1. PCE and TCE concentrations ranging from 2 to 4 µg/L were detected in SW-15 during the summer of 2013, while the full groundwater extraction system operated. Cis12DCE concentrations paralleled TCE concentrations, ranging from approximately 1 to 2 µg/L.
2. Upon shutdown, concentrations of these compounds increased, with TCE rising above 10 µg/L and cis12DCE rising above 15 µg/L. PCE increased more modestly, with the maximum concentration exceeding 7 µg/L. TCA and related degradation compounds also increased.
3. CW-20 start-up, including the CW-9 restart, had a modest to questionable downward effect on the concentrations of these three compounds, and no apparent effect on TCA related compounds.
4. During the dry season shutdown, cis12DCE concentrations, in particular, increased to a maximum of 23 µg/L, while TCE and PCE appeared to increase modestly.
5. Upon full system restart, there is a response in the form of lower cis12DCE concentrations, and a possible decrease in concentrations of TCE and PCE.

Although concentrations of chlorinated organic compounds in this spring were initially considered to potentially be from an off-Site source, the strong increases that occurred after the initial full extraction system shutdown appears to indicate a Site connection. Responses to changes in pumping, particularly the pumping of CW-20 and CW-9 are not nearly as clear as in other sampling stations. It is speculated that this may be because there is a more circuitous or longer pathway between this location and Site groundwater. The higher proportion of degradation product cis12DCE compared to other stations may be related to the circuitous pathway, or may indicate the source of the COCs are from a deeper portion of the aquifer (greater than 200 feet bgs) where cis12DCE concentrations predominate. Pumping of CW-20 and CW-9 does not appear to have been effective at reducing concentrations in this discharge, suggesting one of the other collection wells that was still turned off was more effective at partially capturing some of the Site-impacted groundwater that discharges at this spring. CVOC chemistry in this spring is not similar to the wells on the levee, which suggests Site related groundwater may take a deeper pathway under and across the creek prior to discharging on the west side of the creek.

**Submerged Spring South of Site (SW-26) – Figure 3.5-14** is a graph of TCE and TCA series compounds from water samples collected from SW-26, a submerged spring discharge to Codorus

Creek on the west side of the creek immediately upstream and south of the I-83 bridge. This sample station is approximately 2,500 feet upstream of SW-17 and 1,400 feet upstream of SW-6, considered to be upstream of the Site. This spring was discovered during reconnaissance after the start of the shutdown test, and thus the record of sampling is not as long as some of the other stations.

1. There were no samples taken at this station prior to the first shutdown test.
2. 1 to 2 µg/L of PCE and traces of TCE were detected in samples after the shutdown. Because of the location, it was suspected that there may be a source independent of fYNOP.
3. After CW-20 start-up, there was a consistent decrease in PCE and TCE. The response occurred in the first sample after the pumping started (within two weeks).
4. Two weeks after CW-20 and CW-9 were shut down for the dry season shutdown test, PCE increased from less than 1 µg/L to greater than 6 µg/L, TCE increased more modestly but consistently, and cis12DCE was detected at this station for the first time. During this shutdown period, TCA was detected occasionally.
5. In the sample round immediately prior to the full extraction system restart, concentrations of PCE, TCE and cis12DCE dropped to below 1 µg/L. This, of course cannot be attributed to the extraction system, but is most likely caused by dilution from high surface water runoff in the creek that occurred on that day. However, subsequent results after the system restart through July 2015 were also markedly reduced, with one exception that occurred in late March 2015. PCE spiked during this sampling, which corresponded with a significant runoff event, indicated by the peak in the creek hydrograph. After July 2015 concentrations of PCE, TCE and cis12DCE increased to levels similar to the dry season shutdown. This gradual increase occurred coincident with the decline of CW-20's pumping rate. The pumping rate of CW-20 is posted on **Figure 3.5-15,** which shows an initial pumping rate of 85 gpm in January 2015, declining to nearly 30 gpm in September 2015.

The changes in concentrations of Site related COCs in response to pumping of the fYNOP groundwater extraction system suggest that there is a karst conduit connection between this spring at SW-26 and Site groundwater. Dye tracer testing results were inconclusive with regard to a Site connection (no positive detections of dyes). While this spring is 3,750 feet upstream of the Codorus 2 monitoring station, its elevation in January 2015 prior to restart of the extraction system was approximately 340 feet amsl (assumes an average creek slope of 0.0004 and a measured creek stage of 338.5 feet amsl at Codorus 2). This creek stage is lower than non-pumping piezometric levels in well MW-136A in the SW-WPL, as shown on **Figure 3.5-16**, a hydrograph of the wells in the SW-WPL. On the far left of this graph, the piezometric water levels in MW-136A have elevations between 341 to 345 feet amsl, indicating that head potentials greater than 340 feet amsl are sufficient to deliver water to the spring through the conduit system. Note that when the groundwater extraction system is activated, water levels in all wells in the SW-WPL except the deepest port in MW-136A drop below 340 feet, which removes the head potential necessary to drive the groundwater from the SW-WPL area towards SW-26. While not conclusive, this analysis provides a reasonable explanation for the observations made regarding SW-26.

Spring SW-26 is located very near the contact with the Kinzers Shale, (reference **Figures 2.3-10 and 2-1.1**), and therefore represents the western limit of the carbonate aquifer in this location. The occurrence of a spring juxtaposed in the carbonate aquifer next to the shale is tangible evidence that the westward development of karst solution channels and the westward migration of Site-impacted groundwater are thwarted by the Kinzers Shale, resulting in groundwater being pushed to the surface in this location.

**Codorus Creek Downstream of Site (SW-29) –** Station SW-29 is located approximately 2,100 feet downstream of SW-8. This station was positioned at this location because it was observed during dye testing that laminar flow in the creek is mixed as a result of the sharp bend in the creek. Laminar flow in the creek is also supported by comparing the differences in chemistry of the three sets of side-by-side station pairs, (SW-16 and SW-27; SW-13 and SW-28; and SW-8 and SW-9) which indicate that groundwater discharges to the east side of Codorus Creek tend to flow down the east side of the creek channel and groundwater discharges to the west side of the creek flow down the west side of the creek channel. Sampling at this station was initiated to represent a more completely mixed concentration of Site-related compounds in the surface water of the creek. This station was established just prior to the end of the Wet Season Extraction System Shutdown test (March 2104), so the record is shorter than many of the other stations.

**Figure 3.5-17** is a graph of TCE and TCA series compounds from surface water samples collected at SW-29.

1. When the CW-20/CW-9 extraction wells are shut down, concentrations of, PCE, TCE and cis12DCE increase. For example, PCE increases from 0.4 µg/L to greater than 1.2 µg/L; TCE increases from 0.4 µg/L to 0.8 µg/L; and cis12DCE increases from 0.4 µg/L to 0.6 µg/L.
2. When the full groundwater extraction system is restarted, concentrations of these compounds drop below 0.4 µg/L. Subsequent analyses through October 2015 continue this trend. PCE remains below 0.3 µg/L, TCE is estimated at 0.3 µg/L or less, and cis12DCE is detected intermittently.

### 3.5.5 Dilution of Stream Concentrations by Surface Water Runoff

As mentioned in the introduction to the surface water chemistry graphs discussed in the previous subsection, a hydrograph of the creek flow in cfs, is superimposed on these graphs. The flows are from USGS gauging station no. 01575500 located 2 miles south of the city of York, and approximately 4 miles upstream of the Site. Stream flow is made up of surface water runoff and groundwater discharge from the aquifer to the creek. The groundwater discharge component of stream flow is referred to as base flow. The degree to which surface water runoff impacts concentrations in Codorus Creek was evaluated and is discussed in this section. The analysis conducted in this section assumes that baseflow/runoff patterns in the basin at the Site are similar to the upper portion of the basin where the USGS gauge is located.

**Figure 3.5-18** is a hydrograph of the Codorus Creek stream flow at the USGS gauging from January 2013 through March 2014, covering the time period during which Codorus Creek was monitored, as discussed in the previous subsection. The stream flow data was processed through a base-flow separation program developed by the USGS called PART. The PART program separates the stream flow, shown as a blue line, into surface water runoff and groundwater discharges (base flow) based on modeled responses to precipitation events. The green line separates the base flow from surface water runoff, with the area beneath the curve of the green line representing groundwater discharge and the area between the green line and the blue line representing surface water runoff. This program calculates base flow for each day of the period of record. Based on that separation, percent base flow was calculated. Percent base flow is the proportion of stream flow that is made up of groundwater. For example, when there is no surface water runoff and the natural flow in the stream is from groundwater discharge, percent base flow would be 100%.

**Figure 3.5-19** shows PCE and TCE concentrations over time at Codorus Creek station SW-8, which is downstream of the Site on the east side of the channel. Percent base flow is also plotted on the secondary axis of this graph. Shifts in the concentration and percent base flow lines during changes in extraction system operating status show predictable similarity, although the amplitude of changes in concentration is generally greater than that for the percentage of base flow. For example, when there is a drop in the percent base flow as that observed between January and March 2014, there is a corresponding dip in PCE and TCE concentrations. This pattern indicates that a higher proportion of surface runoff dilutes the concentrations of Site related compounds in the creek. This pattern is repeated for the other stream samples, for instance, in SW-13, a few hundred feet upstream from SW-8 (**Figure 3.5-20**).

**Figure 3.5-21** is a time versus concentration graph for station SW-29, located downstream from SW-8, where flow from the east and west sides of the creek have mixed. The graph for SW-29 shows the same similarity between the detected TCE and PCE concentrations and the percent base flow, indicating similar dilution effects from surface water runoff in the creek.

This analysis indicates that surface water chemistry changes for Site related COCs are related to percent base flow and higher creek concentrations are generally observed during periods of low surface water runoff. This relationship is used later in this report to evaluate surface water using base-flow corrected concentrations and to determine potential representative concentrations at some of the creek surface water stations.

**Figure 3.5-22** is a time vs concentration graph of TCE and PCE concentrations in the spring-water discharge at station SW-17, the station that monitors the submerged spring, and is not believed to be susceptible to comingling with surface water from the creek because piping for sampling extends into the spring. When the concentration plots for PCE and TCE are compared to percent base flow, a pattern that is similar to the surface water conditions described above is apparent. In other words, precipitation events that increase surface water runoff in the creek also cause dilution of groundwater. It is suspected that during precipitation events, the volume of water discharging through the spring increases, but concentrations go down. Because alkalinity concentrations also follow a similar pattern, it is suspected that water from precipitation events mixes with groundwater in the karstic flow systems and dilutes the groundwater discharge into Codorus Creek.

### 3.5.6 Surface Water Concentrations Under Non-Pumping and Pumping Conditions

Codorus Creek flow was calculated and surface water chemistry was analyzed at and downstream of the Site to evaluate the conditions during the shutdown of the groundwater extraction system when groundwater discharge from the Site into the creek was unimpeded. The results were used to calculate potential representative concentrations at seven stations along the creek for use in the human health and ecological risk assessment. 25 Pa. Code § Chapter 93 (relating to water quality standards) lists protected water uses for the streams in the Commonwealth. The listed protected water uses for the evaluated reach of Codorus Creek (Drainage Basin O, Codorus Creek from Oil Creek to the Mouth [Page 93-165]) were warm water fishes (WWF) that are indigenous to a warm water habitat and migratory fishes (MF) that move to or from flowing water to complete their life cycle in other waters.

Codorus Creek flow was calculated and surface water chemistry was analyzed at and downstream of the Site to also evaluate conditions during operation of the groundwater extraction system after the system was restarted on January 27, 2015.

#### 3.5.6.1 **Non-Pumping Conditions**

The monitoring during non-pumping conditions included two shutdown periods which represent both high and low runoff conditions (wet and dry seasons). The wet season shutdown occurred from November 25, 2013 through April 7, 2014 (more than 4 months) and the dry season shutdown occurred from August 11, 2014 to January 27, 2015 (more than 5 months).

Chemistry data from seven surface water stations along Codorus Creek were used for the evaluation that represents various stages of mixing from multiple discrete points of groundwater discharge into the creek. The other stations along the creek were not selected for evaluation because they represent spring-water discharges (SW-15, SW-17 and SW-26), flow from other sources into the creek (SW-10, SW-11, SW-12 and SW-20) and surface water conditions upstream of the Site (SW-6 and SW-7). The following is a description of the seven stations that were evaluated:

1. Six stations consisting of three station pairs located on the east and west sides of the creek were monitored. These stations represent water quality in the creek that has not undergone complete mixing. In order from upstream to downstream, the station pairs are SW-16/SW-27 (west of the WPL and downstream of the spring-water discharge at SW-17), SW-13/SW-28 (downstream of Johnsons Run and the unnamed western tributary) and SW-8/SW-9 (downstream of the fault that forms the northern limit of the carbonate aquifer, where presumably all Site-related groundwater has discharged to the creek).
2. One additional station, SW-29, is located approximately 2,100 feet downstream of station pair SW-8/SW-9 where surface water and groundwater with Site-related COCs is considered to be completely mixed in the creek downstream of the Site due to a sharp turn in the creek channel upstream of this station. Observations of dye discharged to the creek mixing with the entire creek at this sharp turn qualitatively support this consideration.

The locations of the creek stations are shown on **Figure 3.5-23** and the water quality analytical results for all stations sampled since August 2013 are presented on **Table 2.3-1a** (VOCs), **Table 2.3-1b** (metals) and **Table 2.3-1c** (alkalinity and common ions). For comparison, **Tables 2.3-1a** through **Table 2.3-1c** include PADEP fish and aquatic life, and human health water quality criteria that have been developed for specific parameters listed on Table 3 from 25 Pa. Code § Chapter 93 (e.g., alkalinity) and toxic substances listed on Table 5 from 25 Pa. Code § Chapter 93 (e.g., VOCs and metals). VOCs including cis12DCE, MC, PCE, TCE and VC, exceed the water quality criteria at the seven surface water stations. No metals were detected above any of the water quality criteria; however, the metals samples were collected prior to the initial shutdown test when the groundwater extraction system was operating.

Surface water sampling results from the seven stations during shut down are summarized on **Tables 3.5-1 through 3.5-7** along with calculated creek discharge, percent Base Flow, and the calculated mass of VOCs in the creek (mass flux). Laboratory results for non-detect concentrations are listed in the tables as 0.001 µg/L because the concentrations are detected are generally very low and using a standard non-detect concentration value of one-half of the detection limit would likely result in a high bias for the non-detect values.

Discharge in the creek was calculated for each station using published data from USGS gaging station No. 01575500 that was adjusted to reflect the drainage area at each station from the USGS StreamStats website (http://water.usgs.gov/osw/streamstats/pennsylvania.html) relative to the drainage area at the USGS gaging station. The StreamStats website was also used to determine normal creek flow (i.e., harmonic mean flow - $Q_h$) and low creek flow (i.e., lowest 7-day average flow that occurs once every ten years - $Q_{7\text{-}10}$) at downstream station SW-29, which are 113 cfs and 35 cfs, respectively.

Graphs showing concentrations versus calculated creek discharge for the sampling dates for each of the stations are included in **Appendix L.6**. Samples with non-detectable concentrations were assigned a concentration of 0.001 µg/L for graphing purposes and to distinguish them from the detected concentrations (the reporting limits for these samples are shown on **Table 2.3-1a**).

Calculated creek discharge and concentrations at each station were used to determine mass flux in the creek. The relationship of mass flux to creek discharge is shown on the graphs in **Appendix L.7**.

Surface water concentrations for cis12DCE, PCE and TCE (the primary COCs detected in the creek samples) were used to calculate arithmetic mean (average) concentrations for each of the seven stations. Average concentrations for 11DCA, 11DCE, TCA and VC were not calculated because they were either not detected or detected at low concentrations in the creek samples from the stations. As shown on the bottom of **Tables 3.5-1 through 3.5-7**, average concentrations were calculated using two sets of data for comparison. The first set of data included all of the shutdown concentrations and the second set of data consisted of only concentrations from the dry season (low flow) conditions (i.e., concentrations from October 6, 2014 samples and later). The more conservative (higher) average concentrations from the second data set representing low flow conditions for cis12DCE, PCE and TCE, are posted on **Figure 3.5-23**.

The following are observations from the surface water data evaluation for the seven stations:

1. Calculated creek flows were higher during wet season sampling dates (409 cfs to 655 cfs) than dry season sampling dates (94 cfs to 343 cfs).

2. Most of the dry season discharges were around $Q_h$ of 113 cfs and all of the discharges were above $Q_{7\text{-}10}$ of 35 cfs. Therefore, the calculated average concentrations for low flow conditions are representative of $Q_h$ conditions at the stations.
3. The average concentrations for low flow (non-pumping) conditions for PCE at five of the seven stations and for TCE at one of the seven stations exceed the PADEP Chapter 93 surface water criteria of 0.69 µg/L and 2.5 µg/L, respectively. The cis12DCE concentrations at all seven stations were less than the surface water criteria of 12 µg/L.
4. Average concentrations of cis12DCE, PCE and TCE of less than 1 µg/L were calculated for downstream station SW-29 where groundwater impacted by the Site has discharged to surface water in the creek and is completely mixed. The average cis12DCE and TCE concentrations do not exceed the PADEP Chapter 93 surface water criteria, but the PCE average concentration slightly exceeds the screening criteria at 0.98 µg/L.
5. Higher concentrations were generally detected at stations located along the east side of the creek (SW-16, SW-13 and SW-8) than the west side of the creek (SW-27, SW-28 and SW-9), which suggests a more significant contribution of COC mass in the groundwater discharge along the east side of the creek from fYNOP.
6. The highest concentrations of cis12DCE, PCE and TCE were detected at station pair SW-16/SW-27, which are located to west of the WPL and downstream of station SW-17 where spring-water with elevated COC concentrations is discharging into the creek. Surface water concentrations generally decrease with distance downstream of station pair SW-16/SW-27

7. Mass flux in the creek in pounds per day is typically higher during high creek flows and lower during low creek flows (see loading versus creek discharge graphs in Appendix L.7). However, for stations located along the east side of the creek (SW-16, SW-13 and SW-8) and at downstream station SW-29, higher concentrations were detected in most cases when creek discharges were lower. This is illustrated on the concentration versus creek discharge graphs in Appendix L.6. The relationship between concentrations and creek discharge does not hold true at the stations located along the west side of the creek (SW-27, SW-28 and SW-9), but those concentrations are generally lower than eastern stations.

#### 3.5.6.2 Pumping Conditions

Codorus Creek monitoring during the operation of the groundwater extraction system occurred from March 10, 2015 to September 9, 2015 when the 2015 Comprehensive Sampling event samples were collected from the creek. A total of eight surface water sampling events occurred – two in March and then one per month through September. Note that the groundwater extraction system had been operating for 42 days prior to the first sampling to allow hydraulic conditions to equilibrate. Data from March 10, 2015 was excluded from data analysis as PCE, TCE and cis12DCE were all undetected during this sampling event, but the creek discharge was high. Multiplying the high creek discharge rate by the assigned non-detect concentration of 0.001 µg/L produced chemical mass flux values that were most likely biased high; and therefore, the data from March 10th was excluded.

Chemistry data from the same seven surface water stations as described in subsection 3.5.6.1 above were used for analysis during pumping conditions and are shown on Figure 3.5-. Twenty-four (24) surface water sampling results from the stations after system restart and during operation are summarized on Tables 3.5-8 through 3.5-14 along with calculated creek discharge, percent Base Flow and the calculated mass of VOCs in the creek (mass flux). Time versus concentration graphs for the surface water sampling stations are provided in Appendix L.5 and graphs showing concentrations versus calculated creek discharge after system restart for the sampling dates of each station are included in Appendix L.6 on the same graphs with the non-pumping data for comparison purposes.

Calculated creek discharge and concentrations at each station were used to determine the mass flux in the creek. The relationship of mass flux to creek discharge is shown on the graphs in Appendix L.7 on the same graphs with the non-pumping data for comparison purposes.

The following are observations from the surface water data evaluation for the seven stations during pumping conditions:

1. Codorus Creek discharges measured at the USGS Gage No. 12575500 (Gage) during the eight sampling dates ranged 108 cfs to 1,151 cfs; however, the second highest discharge after 1,151 cfs was equal to only 314 cfs. The average discharge of the seven sampling dates, excluding the highest, was 237 cfs.

2. Most of the discharges measured at the Gage were above the $Q_h$ of 113 cfs. Therefore, the calculated average concentrations during pumping conditions represent conditions when discharges are somewhat higher than $Q_h$ at the stations.
3. The average concentrations for pumping conditions for PCE, TCE and cis12DCE are all less than the PADEP Chapter 93 surface water quality criteria (WQC) for each of these parameters at all seven of the monitoring stations.
4. While the extraction system was pumping, the only station that contained discrete detected concentrations higher than the WQCs was Station SW-27, located on the western side of Codorus Creek. On March 24, 2015, PCE was detected at 2.3 µg/L (compared to the WQC of 0.69 µg/L), and TCE was detected at 3.5 µg/L (compared to the WQC of 2.5 µg/L). On April 21, 2015, PCE was detected at 0.71 µg/L. All subsequent sample results at SW-27 did not exceed the WQCs.
5. CVOC concentrations in the creek are reduced significantly at monitoring stations located on the east side of the creek when the groundwater extraction system is operating. As illustrated on the graphs in Appendix L.6 and L.7 (and also on the time versus concentration graphs in Appendix L.5), the concentrations and mass loading of PCE, TCE and cis12DCE are distinctly lower during pumping conditions at monitoring stations SW-16, SW-13, SW-8, and SW-29.
6. **Figure 3.5-24** shows the arithmetic mean concentrations of PCE, TCE and cis12DCE under pumping conditions which can be compared with the concentrations under non-pumping conditions on **Figure 3.5-23**. While the CVOC concentrations are all lower in stations located on the western side of the creek compared to their adjacent eastern stations, the PCE, TCE and cis12DCE at western locations SW-27, SW-28, and SW-9 do not show as much of a distinct reduction after the restart of the groundwater extraction system as compared with the east side of the creek. This data indicates that operation of the groundwater extraction system does not affect creek discharges to the western side of the creek as effectively as discharges to the eastern side of the creek. This may be due to a delayed impact as a result of the longer or slower travel path, or a result of secondary sourcing, which the operation of the GWTS will not impact on a short term basis.

## 3.6 Restart and Reconfiguration of Groundwater Extraction System

After the dry season shutdown, the groundwater extraction system was reactivated on January 27, 2015. Based on the results of the Part 2 SRI testing, the configuration of pumping was changed. Extraction well CW-8, in the TCA Tank area, was not reactivated. Extraction well CW-20 which was first operated from April to August 2014 in the SW-WPL, was activated, and nearby extraction well CW-9 was pumped at a reduced rate compared to pumping rates that were used prior to the Part 2 SRI investigations. Extraction wells CW-13 and CW-17 in the WPL, and CW-15A in the NBldg4 area, were returned to normal service.

Groundwater samples were collected from pumping wells for quantitative dye analyses. The samples were collected daily for the first two days of pumping, then at incrementally longer intervals through July 15, 2015, a period of 24 weeks. The results are in **Table 3.6-1**.

### 3.6.1 New Pumping Configuration

Changes to the pumping configuration of the groundwater extraction system were made as a result of the testing conducted between the monitored shutdowns of the groundwater extraction system for the following reasons:

- Testing showed well CW-20 to be well-connected to the karst conduit system, both shallow and deep, indicating this well has the ability to control groundwater migration in a large portion of the aquifer impacted by Site COCs. The proximity of CW-20 to the DNAPL source area in the SW-WPL will provide an opportunity to examine the impact of pumping immediately within this source area, to determine if source reduction can contribute to the final remedy.
- Extraction well CW-8 was originally installed and pumped to prevent the migration of TCA that was spilled in that area. The high concentrations of TCA would have been pulled into the extraction wells in the WPL had this well not been pumped. For a number of years, that TCA source has been depleted, and pumping of CW-8 was continued because it had captured groundwater from a TCE contaminant source, presumed to be the Bldg58 Area. In preparation for reuse of the CPA property that will most likely involve a large warehousing facility over much of this area, CW-8 was turned off. There is a potential that groundwater

passing through the Bldg58 area will migrate southward under this new configuration, without the influence of CW-8 pulling it toward the west.

### 3.6.2 Recovery of Dye After Restarting Extraction System

As discussed in Subsection 3.2.5, SRB dye was injected into the large cavern in well CW-17 during non-pumping conditions on two separate events. The first injection occurred on March 7, 2014 when 26 pounds of SRB were injected at a depth of 47 feet bgs into the solution cavern feature in CW-17 and on September 12, 2014, 34 pounds of SRB were injected into the solution cavern. Dye tracer monitoring was performed during both testing events to investigate the potential existence of a conduit system extending from the north-central portion of the WPL to Codorus Creek. After both of these injections, dye was detected in samples from several of the monitored wells and in Codorus Creek (see **Figure 3.2-5**), but concentrations were lower than expected.

After the extraction system was reactivated, pumped effluent from CW-17 and adjacent extraction well CW-13 reversed groundwater migration, and removed dye from the aquifer. To determine the degree to which SRB dye was retained in the aquifer after injection into CW-17, the mass of the dye removed by these two extraction wells was calculated. The extraction well pumping rates and concentrations of SRB detected in samples from the extraction wells after restart of the extraction system were used to calculate the mass of SRB removed by pumping. The trend of dye depletion was extended for ten years, at which point an insignificant amount of dye would remain in the aquifer. The calculations are included in **Appendix T**.

The calculations determine that approximately 14 pounds of the 60 pounds of tracer dye injected into CW-17 were retained in the aquifer. As a result of these calculations, it is concluded that most of the 60 pounds of SRB dye injected into CW-17 moved through the aquifer and beyond the capture area of the extraction system.

Although the large open water-filled cavern penetrated by CW-17 suggested the potential for a solution channel that may discharge directly to a discrete location on Codorus Creek in a short period of time, the limited appearance of dye in the creek 52 days after the second injection does not support the existence of such a connection. However, the determination that the dye was not retained in the aquifer combined with the relatively slow migration velocities, suggests migration of the groundwater from this large cavern occurs through fractured bedrock or sediment-filled solution channels. Rather than a discrete open channel discharge to Codorus Creek, the groundwater most likely discharges over a large area of the stream, distributed by the diffuse flow system of small fractures, and sediment-filled solution channels. Diffuse flow is also suggested by the shotgun pattern of dye travel shown on **Figure 3.2-5,** as discussed previously.

### 3.6.3 Capture of Eosine

Eosine dye was injected into well MW-100D located along the east side of the Codorus Creek levee on December 17, 2013 under non-pumping conditions. This was part of the Levee Area Dye Tracer testing task shown on **Figure 2.3-10**, and discussed previously in subsection 3.1.4.3. When the groundwater extraction system was re-started on January 27, 2015 after the second (dry season) shutdown test, grab samples were collected for dyes from each of the operating groundwater extraction wells (CW-9, CW-13, CW-15A, CW-17 and CW-20). Results are included in **Appendix E.3**. Eosine was detected in the groundwater samples from wells CW-9, CW-17 and CW-20. **Figure 3.6-1** shows the position of the eosine injection point and the three extraction wells that tested positive for the tracer. **Figure 3.1-35** shows the known migration paths for eosine, along the east side of the creek. It is apparent from these detections that these extraction wells pump water from as far down-gradient as the Levee (a lateral distance of over 800 feet). While drawdown as a result of operating the groundwater extraction system has been measured in the levee wells, whether capture and reversal of flow reached as far as the levee was not confirmed until this observation.

### 3.6.4 Impact of Karst Loss on the Groundwater Extraction System

The potential that karst loss, the influx of surface water (storm water runoff) into the aquifer through swallets, sinkholes, exposed karst openings in bedrock and epikarstic openings in the bedrock surface beneath the overburden, would result in the loss of groundwater capture during storm events was examined.

From June 1, 2015 to June 2, 2015, a concentrated rainfall event of 2.15 inches total was monitored by the on-site weather station with rain having begun to fall at around 3pm the 1st and finishing just after midnight on the 2$^{nd}$ (a duration of approximately 9 hours). This event was chosen as it was the largest rain event recorded after the extraction system was restarted with the configuration described in the previous subsection. Water level recorders had been placed surrounding the groundwater extraction wells in the WPL, with particular attention paid to wells with conduit features that showed a positive connection to the surface and the conduit network, as discussed in Subsection 3.2.2. The changes in groundwater elevation that occurred as a result of the rain event were graphed, plotting groundwater elevation versus time against precipitation vs time. These graphs for all wells with recorders are included in **Appendix Q.7**.

**Figure 3.6-2** illustrates that most wells west of the WPL, the down-gradient side of the cone of depression, reached peak groundwater elevation around 12 noon on June 3, 2015. Levee wells showed a quicker response and peak with most water levels declining by noon on the 3rd. This time period, June 3, 2015 at noon, was chosen for contouring as it represented the highest water levels in the WPL and WWPL wells, and therefore the most likely time that the extraction system may be overwhelmed by the extra volume of water flowing through the aquifer. The groundwater elevation contours for this event can be seen on **Figure 3.6-3**.

The contour mapping provides strong evidence of groundwater capture by the extraction system during larger precipitation events. Two-foot contour intervals showed sufficient capture throughout all of WPL and WWPL with a large depression centering around CW-13 and radiating outwards encompassing all wells with transducers throughout the WPL and WWPL. However, an area of continuing uncertainty is the SW-WPL near CW-20. The presence of open sink holes receiving surface water run-off during rainfall events in the area immediately east-southeast of CW-20 on the former 84 Lumber property, may compromise groundwater capture in the southwest corner of the WPL. The concern is compounded by the reduced pumping rate of CW-20 discussed previously. At the time of this assessment (June 1, 2015), the pumping rate was approximately 55 gpm, down from 85 gpm in January 2015. A related discussion in subsection 3.5.4 regarding the water quality in springs SW-17 and SW-26 suggests that the pumping rate of this well is important to its ability to maintain capture.

The SW-17 hydrograph was examined for indications that the extraction system may have been overwhelmed by karst loss. **Figure 3.5-11** shows a spike in the concentrations of PCE, TCE and cis12DCE in a sample collected on March 24, 2015 that occurred after a large surface water runoff event indicated by the Codorus Creek hydrograph. **Figure 3.5-15** indicates that the CW-20 pumping rate at this time was approximately 80 gpm. **Figure 3.6-4** was constructed by adding the water level recorded in MW-37D, a well immediately adjacent to pumping well CW-20 to **Figure 3.5-11**. This groundwater elevation in this well represents the drawdown in the aquifer in the SW-WPL as a result of operating the groundwater extraction system. This figure shows that the water level in MW-37D spiked to an elevation of 341.1 feet amsl during the runoff event, and nine days before the March (date) sampling of SW-17 that showed the spike in concentrations. The elevation of the spring discharge, as reported in Subsection 2.3.7.4.1 is approximately 339 ft amsl, which apparently provides sufficient gradient to result in loss of capture at this pumping rate.

## 3.7 Summary of GWRI Data Gaps Addressed in Part 2

The following **Table 3.7-1** is a listing of the data gaps identified after the GWRI Part 1 report, and issues subsequently identified while the Part 2 investigation was being conducted. These data gaps were all addressed during the Part 2 investigations. In the table below they are grouped in five categories, plus the additional task regarding VI south of the SPBA. The first column identifies the data gap. The second column summarizes the Part 2 field tasks or analyses of facts and data that were used to investigate each data gap. The third column summarizes the Part 2 results.

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 1: Nature and Extent of COCs** | | | |
| | **Vertical Extent of Chlorinated Solvents in Source/DNAPL Areas** | Six deep borings (MW-136A thru -141A) were drilled in suspected DNAPL source areas in two phases of drilling. Dedicated sample pumps or multilevel samplers were installed in each location to sample discrete water-bearing zones throughout the borehole. Groundwater samples were analyzed. Piezometric levels were measured and observations were made during pumping tests and extraction system monitored shut downs. | The vertical extent of TCE, PCE and cis12DCE at the source areas and across the Site was determined and illustrated on cross sections. Observations were made regarding the suspected penetration of DNAPL through the karstified portion of the aquifer and into the underlying fractured portion of the aquifer against an upward vertical piezometric head. The vertical extent of COCs exceeding Residential Used Aquifer Medium Specific Concentrations (RUA MSCs) in the six investigated areas range from 220' bgs (150' amsl) to 550' bgs (-160' msld). |
| | **Lateral Extent of Chlorinated Solvents in the NPBA** | Two nested well pairs were installed along the northern property boundary, developed and sampled for COCs. Natural (non-pumping) gradients were determined during a monitored shutdown of the NPBA groundwater extraction system, and groundwater flow directions were interpreted. | Recent groundwater chemistry data determined that concentrations of COCs in off-Site former residential wells to the north were below RUA MSCs. Post-shutdown groundwater elevations and potentiometric contours showed a gradient to the southwest with a groundwater flow path that would transport Site-related COCs exceeding the RUA MSC parallel to and potentially across the property line to the west and then return to the Site within approximately 1000 feet. No water supplies are within this potential pathway. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 1: Nature and Extent of COCs** | | | |
| | **Horizontal and Vertical Extent of Off-Site Migration from the SPBA** | Two single wells and one multilevel well were installed south of US Rt. 30. The wells were positioned to characterize the karst aquifer and the extent of COCs using fracture trace analysis, chemistry data, groundwater potentiometric contours and bedrock surface elevation contours. Groundwater was analyzed for COCs. The extent of dye migration from a tracer test initiated in 2000 was determined. | The extent of TCE exceeding RUA MSCs extended approximately 400 feet south of US Rt 30. PCE is distributed under Old Arsenal Road on the north side of Rt 30 and in a small area 300 to 700 feet south of Rt 30. |
| | **Potential for Migration of Site Groundwater Under and West of Codorus Creek and the existence of a deep conduit system separate from the shallow karstified aquifer** | Groundwater elevation data were obtained for wells located west of the Site and west of Codorus Creek. | Groundwater elevations indicated groundwater flows eastward toward the creek, and suggests that shallow groundwater from the Site does not flow westward past Codorus Creek. |
| | | A persistent layer of Kinzers Shale was confirmed to run along the west side of Codorus Creek by field mapping of the local geology. This was corroborated by reviewing drillers logs of wells located in the vicinity. The shale defines the westward extent of the carbonate aquifer, and eliminates the potential for development of interconnected solution channels between carbonate aquifers beneath the Site and west of the shale. The continuity of the shale is interrupted in one location northwest of the Site (the "Northwest Passage"), where a multi-level monitoring well was installed. | Confirmation of the location and persistence of the shale eliminates the potential for the existence of a deep karst solution channel system and the westward migration of groundwater from the Site past this barrier. The multi-level monitoring well installed in the Northwest Passage confirmed a relatively thin, shallow carbonate interval in which no solution features were encountered. Water levels and groundwater chemistry indicated no westward migration of groundwater. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 1: Nature and Extent of COCs** | | | |
| | **Potential for Migration of Site Groundwater Under and West of Codorus Creek and the existence of a deep conduit system separate from the shallow karstified aquifer (cont'd)** | Two springs (SW-15 & SW-26) were discovered near the western edge of Codorus Creek during dye tracer testing and surface water characterization and monitoring activities. The springs were determined to contain concentrations of Site-related COCs that vary during changes in operation of the GWTS, evidence that they are connected to the Site through the karst solution channel network. | The discharge of Site-impacted groundwater from springs on the west side of Codorus Creek is evidence that COC migration from the Site occurs in karst solution channels and that the Kinzers Shale serves as a barrier to karst solution channel development and further westward migration of Site groundwater. |
| | | Tracer dyes were injected into karst solution channels in the top 250 feet bgs of the aquifer intersected by three wells on the east side of Codorus Creek. Surface water and wells were monitored for dyes. | Tracer testing indicates that under non-pumping conditions groundwater migrates parallel to the creek (upstream and downstream) to wells along the east side of the creek, travelling vertically upward and downward in solution channels. There is a generally upward hydraulic gradient, and in all cases the injected dyes discharged to the creek. Dyes were not detected in the springs discharging on the western edge of Codorus Creek. |
| | **On-Site and off-Site Horizontal Extent of COCs** | After installation of additional wells, groundwater, surface water and springs were sampled for COCs with the groundwater extraction system operating (2013 Comprehensive Sampling) and during GWTS monitored shutdown (2014 Comprehensive Sampling). The results were interpreted on maps and cross sections. | The lateral extents of PCE, TCE and cis12DCE were illustrated at three depths within the carbonate aquifer (50-70' bgs, 150-170' bgs and 250-270' bgs). These maps show that the highest and most wide-spread concentrations of COCs are located in the intermediate horizon, where numerous karst solution features were encountered. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 2: Hydraulic Characteristics of the Karst Aquifer** | | | |
| | **Extent of carbonate aquifer and depth of karst solutioning (stratigraphy and structural geology, depth of solution activity)** | Vertical extent borings penetrated the extent of the carbonate aquifer in a number of locations. The frequency of solution features with depth was characterized. Geophysical logging of boreholes determined the orientation of bedding planes, resulting in a projection of the extent of the carbonate aquifer. | The structure of the carbonate bedrock underlying the WPA (Vintage Formation limestone and dolostone) is a syncline (u-shaped down fold) plunging 10 to 20° to the west and the carbonate is underlain by quartzitic sandstone. A fault north of the Site creates a south dipping contact between phyllite and the carbonate. Based on that geometry, depth of the carbonate under the SW-WPL is between the extent drilled into the carbonate (468') and 600', and a similar depth beneath the Codorus Creek. |
| | | | The frequency of open (water-filled) and sediment-filled solution cavities in the rock in the top 170 to 200 feet bgs is extremely high (15 to 19% compared to reported percentages of 5% in nationally recognized karst areas in Kentucky and Illinois). Below 200 feet bgs, that percentage drops to 2%, and the hydraulic conductivity of the aquifer is much reduced. However, one solution cavity capable of transmitting large volumes of groundwater was encountered at 293' bgs. The deepest solution feature encountered was at a depth of 374' bgs in the SW-WPL. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 2: Hydraulic Characteristics of the Karst Aquifer** | | | |
| | **Interconnection between surface, surface water, and the karst aquifer** | Stream flow measurements were performed on Codorus Creek and its tributaries, comparing upstream and downstream flow volumes. The GWTS in the WPA was operating at the time. | Upstream and downstream flow measurements in Codorus Creek suggest a loss of flow from upstream to downstream. It was concluded, however that the flow measurements did not provide the precision necessary to assess the upstream-downstream difference. Flow measurement results do not agree with observations of groundwater discharges to the creek, such as the discharge of three springs, and the results of dye tracer testing, indicating discharge of groundwater from deep and intermediate depths in the aquifer. Johnsons Run is fed by a spring or springs located north of the NPBA, and springs and seepage from the sandstone/quartzite bedrock that occurs along the base of the hill in the vicinity of former buildings 14, 15 and 30, which feed a southern tributary to Johnsons Run that originates on Site. Johnsons Run and the unnamed tributary on the west side of Codorus Creek lose water from their stream beds to the underlying carbonate aquifer, thus are disconnected from the groundwater table. |
| | | During shutdown of the GWTS, tracer dyes were injected into deep (>200' bgs) and intermediate depth karst solution channels intersected by three wells (MW-99D, -110D and -147A) on the east side of Codorus Creek. Surface water and wells were monitored for dyes. | Tracer testing indicates that under non-pumping conditions groundwater migrates parallel to the creek (upstream and downstream) to wells along the east side of the creek, travelling vertically upward and downward in solution channels. There is a generally upward hydraulic gradient, and in all cases the injected dyes discharged to the creek. Dyes were not detected in the springs discharging on the western edge of Codorus Creek. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 2: Hydraulic Characteristics of the Karst Aquifer** | | | |
| | **Interconnection between surface, surface water, and the karst aquifer** | During shutdown of the GWTS, tracer dye was injected into a deep karst conduit (213-216' bgs) in the SW-WPL (CW-20, prior to activation as an extraction well). Surface water and wells were monitored for dyes. | Dye was detected in a deep well (MW-147A at 210' bgs) and shallow spring (SW-17) confirming a connection between the deep karst feature in the SW-WPL and the shallow karst features along the east side of the creek. The connection between CW-20 and the deep conduit in MW-147A further demonstrates a well-connected karst solution channel network to the creek, since MW-147A was the subject of its own dye tracer injection that showed groundwater in that well discharging to Codorus Creek. |
| | | During shutdown of the GWTS, tracer dye was injected into a very large shallow karst conduit (32-64' bgs) in the north end of the WPL (CW-17) under non-pumping conditions. Surface water and wells were monitored for dyes. | Tracer results suggest that the large cavern is not connected to the creek by an open conduit, but discharges to the creek through a series of plugged solution features or bedrock fractures. |
| | | Two shallow (25' bgs) residuum wells (MW-144 & MW-146) were installed in the levee area to investigate the role of Codorus Creek as a discharge boundary. Two shallow wells (MW-155 & MW-156) were also installed near the wetlands area between the WPL and the levee area. | Water levels in the shallow wells near the wetlands are consistently lower than the water level in the wetlands during non-pumping conditions, indicating that the wetlands are not fed by groundwater. |
| | | Multi-parameter recorders were placed in 9 wells that intersected karst conduit features. Recorded data were reviewed during a large precipitation event. | The results indicate a karst conduit system in the aquifer in the levee area and the WPL that is well connected to the surface, and impacted by precipitation events. Data indicates there may be times during high creek stage when creek water could flush into the aquifer through karst conduits. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 2: Hydraulic Characteristics of the Karst Aquifer** | | | |
| | **Potential for the existence of a deep conduit system separate from the shallow karstified aquifer** | Water quality profiling and point dilution testing was performed on the deep (283-293' bgs) karst conduit intersected by MW-137A in the TCA Tank area. The open solution channel produced 600 gpm when drilled, and natural velocity was measured at 2.07 feet per minute, indicative of turbulent flow. Extraction well CW-8 in the TCA Tank Area, was shut down during the Vertical Extent Shutdown Test, while water levels were recorded in the deep (283-293') karst conduit intersected by MW-137A. | MW-137A had approximately 2 feet of groundwater recovery and drawdown during the re-start. This confirms that the largest deep conduit located during the investigation is interconnected with the shallow karst system penetrated by CW-8. |
| | | Tracer injections into deep and intermediate conduits in levee area wells (described above under Potential for Migration of Site Groundwater under and west of Codorus Creek and the existence of a deep conduit system separate from the shallow karstified aquifer). | In all cases injected dyes discharged to the creek, indicating a connection between deep conduits and the surface. |
| | | During shutdown of the GWTS, tracer dye was injected into a deep karst conduit (213-216' bgs) in the SW-WPL (CW-20, prior to activation as an extraction well). Surface water and wells were monitored for dyes. | Dye was detected in a deep well (MW-147A at 210' bgs) and shallow spring (SW-17) confirming a connection between the deep karst feature in the SW-WPL and the shallow karst features along the east side of the creek. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 2: Hydraulic Characteristics of the Karst Aquifer** | | | |
| | **Establish natural lateral and vertical gradients (non-pumping hydrostatic conditions)** | Water levels in vertical extent wells and adjacent wells were monitored after Phase 1 drilling during a brief shutdown of the groundwater extraction system. | Upward vertical gradients were measured in the fractured portion of the aquifer below 150' to 200' bgs, where the frequency of solution cavities diminishes. |
| | | Using water level measurements taken during GWTS shutdown, groundwater contours were constructed on cross sections. | There is a lateral gradient beneath the WPA from east to west toward Codorus Creek. For the top 150' to 200' of the carbonate aquifer, there is a slight to unmeasurable vertically upward gradient. An upward vertical gradient is apparent below 150' to 200' bgs in the carbonate aquifer. Along the east side of Codorus Creek, two feet of upward vertical gradient was measured within the top 250 feet of aquifer. |
| | **Assessment of karst loss (surface water runoff directly entering the groundwater) on the aquifer** | Multi-parameter recorders were placed in 9 wells that intersected karst conduit features. Recorded data were reviewed during a large precipitation event. | The results indicate a karst conduit system in the aquifer in the levee area and the WPL that is well connected to the surface, and impacted by precipitation events. Data indicates there may be times during high creek stage when creek water could flush into the aquifer through karst conduits. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 3: Fate of Site Chemicals of Concern** | | | |
| | **Natural attenuation of chlorinated solvents** | Analysis of MNA parameters was performed on samples from 30 well locations across the Site to assess the degree of reductive dechlorination within various portions of the aquifer and the groundwater plume. Also, pie diagrams, showing the relative proportions of parent and daughter compounds were plotted on maps and cross sections to illustrate degree of degradation. | In the NPBA (sandstone aquifer), reductive dechlorination is occurring under anaerobic conditions in the shallow and deep bedrock wells. In the SPBA (carbonate aquifer), high DO and the lack of cis12DCE indicates reductive dechlorination is not an active mechanism in the shallow bedrock wells. In the WPA (carbonate aquifer), reductive dechlorination at and down-gradient of the source areas is evident at varying degrees, that is likely due to variable DO from karst recharge conditions. In the deep wells that are screened within the diffuse portion of the carbonate aquifer not penetrated by a karst solution channel, there is evidence of reductive dechlorination occurring under anaerobic conditions. |
| | **DNAPL penetration of the aquifer and natural degradation of dissolved CVOCs in the SW-WPL** | A detailed analysis was performed of groundwater chemistry sample results from the multilevel ports in MW-136A in the SW-WPL, combined with geological observations during drilling and piezometric information. | DNAPL penetrated through the highly karstified zone of the aquifer (from 150 - 200' bgs), the fractured and minimally karstified zones from 200 to 375' bgs, and the fractured zones of low hydraulic conductivity from 375' bgs to the extent of drilling (460' bgs) and potentially some depth beyond. The penetration of TCE and PCE as a DNAPL into the low permeability deepest zone and subsequent reductive dechlorination of dissolved phase CVOCs is the most likely way that degradation product cis12DCE could have reached these depths, since cis12DCE could not have been transported downward with groundwater due to the consistently upward hydraulic gradient. |

| Table 3.7-1 Summary of Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 4: Source Area Investigations** | | | |
| | **Bldg58 and WBldg2 Corridor** | Ten shallow wells (MW-126 thru -135) were installed in the WBldg2 corridor and Bldg58 area to locate the source of high concentrations of CVOCs where no past manufacturing activity or release was known to occur. Groundwater from the wells was sampled and the results used to select locations for 54 MIP borings, used to screen for VOCs in the shallow subsurface (21-37 feet). Soil and shallow groundwater sampling and analyses were done to further assess the concentrations of VOCs in locations with high MIP responses. | DNAPL sources were not identified in the shallow subsurface or below the water table. The investigation demonstrated that the methodology would have the ability to identify such a source area, but areas of elevated concentrations in the unsaturated zone either does not exist, or are of limited size. No further investigations are recommended at this time at the Bldg58 area, west of Bldg2, or in the northern portion of the Bldg2 pad. CVOCs in the shallow groundwater in these areas are being captured by the groundwater treatment system and CVOC concentrations detected in soil samples in these areas were below the MSCs. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 5: Groundwater Extraction System Evaluations** | | | |
| | **NPBA Groundwater Extraction System Monitored Shutdown** | Water level recorders were installed in wells surrounding the extraction wells. The extraction system was shut down. Water levels and chemistry changes before and after shutdown were compared to evaluate the need for continued operation. | The shutdown monitoring results indicated that COCs present in the groundwater beneath the NPBA are expected to migrate towards the interior of the Site. A comparison of pre- and post-shutdown groundwater laboratory analytical results showed that COC concentrations decreased or remained undetected in the majority of the NPBA sampled wells (16 of 23 sampling locations) and that cessation of pumping in the NPBA did not result in an increase in COC concentrations in these wells during the monitoring period. In April 2014, EPA approved a recommendation to continue the monitored shutdown of the NPBA groundwater extraction system for a period of five years to provide a sufficient amount of data to determine if COC concentrations are rebounding or migrating off-Site. Evaluation of the groundwater elevations and VOC analytical data for the first year of post-shutdown monitoring indicated stable (unchanged) conditions. No changes to the plan for the second year of NPBA post-shutdown monitoring in 2015 were recommended based on the first year results. |
| | **Bldg3 Groundwater Extraction System Monitored Shutdown** | Water level recorders were installed in wells, the lift station and footer drain. The lift station pumping system was shut down. Water levels and chemistry changes before and after shutdown were compared to evaluate the need for continued operation. | The monitoring results indicated that the deactivation of the Lift Station resulted in no discernable water level or seepage condition changes. The groundwater levels were confirmed to remain well beneath the paint sludge pit and the FD3 area near the press/equipment pits, which were considered to be the most vulnerable areas within Bldg3. Continued deactivation of the Lift Station was approved by the EPA in April 2014 contingent on the monitoring showing no adverse effect during a heavy precipitation event outside of the growing season, which was defined as approximately 2.5 inches or more in a 24-hour period. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 5: Groundwater Extraction System Evaluations** | | | |
| | **WPL Extraction System Capture of Deep Karst System** | Tracer dye was injected into a deep karst conduit (213-216' bgs) in the SW-WPL (CW-20) while the extraction system was operating to test whether pumping of the relatively shallow extraction wells would capture groundwater in this deep karst solution channel. | The results of this tracer test indicate that the groundwater extraction system as operated on an interim basis since 1994 appears to be capturing groundwater in the deeper conduit system in the SW-WPL that is intersected by CW-20. |
| | | The water level responses in wells in the SW-WPL to shutdown of the WPL groundwater extraction system (prior to pumping of CW-20) were graphed. | A strong and consistent upward vertical gradient was apparent throughout the aquifer (to a depth of 459' bgs) during pumping. After shut down, water levels in all wells intersecting karst features, including the deepest discovered anywhere during the investigation (356 and 372' bgs) responded by a rise in water levels, indicating an interconnection between the shallow pumping wells and the deepest potion of the karst network. |
| | **Impact of WPL Extraction Well Shutdown on Codorus Creek** | Codorus Creek, tributaries and spring discharges to Codorus Creek were sampled for COCs during two periods (Wet Season and Dry Season) of shutdown of the groundwater extraction wells, followed by restart. | Numerous sample locations in the creek and in spring discharges to the creek showed increases in the concentrations of CVOCs correlating with the timing of both shutdowns. |
| | | Codorus Creek surface water chemistry was analyzed at (6 stations) and downstream of the Site (1 station) to evaluate the conditions during the shutdown of the groundwater extraction system when groundwater discharge from the Site into the creek was unimpeded. | Mass flux in the creek in pounds per day is typically higher during high creek flows and lower during low creek flows. However, for stations located along the east side of the creek (SW-16, SW-13 and SW-8) and at downstream station SW-29, higher concentrations were detected in most cases when creek discharges were lower. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 5: Groundwater Extraction System Evaluations** | | | |
| | **Impact of WPL Extraction Well Shutdown on Codorus Creek** | | The average concentrations for low flow conditions for PCE at five of the seven stations and for TCE at one of the seven stations exceed the PADEP Chapter 93 surface water criteria of 0.69 µg/L and 2.5 µg/L, respectively. The cis12DCE concentrations at all seven stations were less than the surface water criteria of 12 µg/L. |
| | | | Average concentrations of cis12DCE, PCE and TCE of less than 1 µg/L were calculated for downstream station SW-29 where groundwater impacted by the Site has discharged to surface water in the creek and is completely mixed. The average cis12DCE and TCE concentrations do not exceed the PADEP Chapter 93 surface water criteria, but the PCE average concentration at 0.98 µg/L slightly exceeds the screening criteria. |
| | | | Higher concentrations were generally detected at stations located along the east side of the creek (SW-16, SW-13 and SW-8) than the west side of the creek (SW-27, SW-28 and SW-9), which suggests a more significant contribution of COC mass in the groundwater discharge along the east side of the creek from fYNOP. |
| | | | The highest concentrations of cis12DCE, PCE and TCE were detected at station pair SW-16/SW-27, which are located to west of the WPL and downstream of station SW-17 where spring-water with elevated COC concentrations is discharging into the creek. Surface water concentrations generally decrease with distance downstream of station pair SW-16/SW-27. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 5: Groundwater Extraction System Evaluations** | | | |
| | **Restart and Reconfiguration of Groundwater Extraction System** | After the Wet Season shutdown test, previously unused extraction well CW-20 was pumped at a rate of 97 gpm for 109 days, then CW-9, which is connected to CW-20 with an efficient karst conduit, was added at a rate of 27 gpm. | Pumping of CW-20 improved the water quality in a number of surface water stations, in some cases to a greater degree than the full extraction system prior to activating CW-20 (e.g. SW-6). However, CVOC concentrations in some stations were not markedly changed by pumping CW-20 alone (e.g. SW-15). |
| | | After the Dry Season shutdown, the GWTS was restarted with a new configuration at an average pumping rate of 240 gpm for the first 3 months. Wells pumped were formerly active extraction wells CW-9, CW-13, CW-15A and CW-17, plus formerly inactive well CW-20. CW-8 was not restarted. | Under pumping conditions, operation of the GWTS captures Site-impacted groundwater, preventing off-Site migration of COCs. The average concentrations for pumping conditions for PCE, TCE and cis12DCE are all less than the PADEP Chapter 93 surface water quality criteria (WQC) for each of these parameters at all seven of the monitoring stations. |
| | | | Concentrations of CVOCs in surface water stations appeared to match pre-shutdown concentrations using the old configuration, with minor improvements to some stations. However, as the pumping rate of CW-20 has diminished, the CVOC concentrations in some stations have risen. |
| | | During restart, quantitative dye concentrations were monitored in the effluent of extraction wells. | 14 of 60 pounds of tracer dye injected into the large cavern in CW-17 were recovered by the extraction system, indicating most of the dye moved through the aquifer beyond the capture area of the extraction system, and presumably discharged to Codorus Creek through a diffuse flow system of small fractures, and sediment-filled solution channels. |
| | | | Tracer dye injected into MW-100D along the east side of the Codorus Creek levee was detected in CW-9, CW-17 and CW-20 after restart of the GWTS, indicating groundwater capture and reversal of flow reached as far as the levee area. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **Part 1 Data Gap Category 5: Groundwater Extraction System Evaluations** | | | |
| | **Impact of Karst Loss on the Extraction System** | Water level and water quality recorder data were examined to evaluate the impact of infiltrating surface water on the capture effectiveness of the groundwater extraction system during a 2-inch rainfall event that occurred in 9 hours. A groundwater contour map was constructed at the peak of influence of the storm | The contour mapping indicates groundwater capture by the extraction system during this large precipitation event throughout the WPL and west of the WPL with a large depression centered on CW-13. However, there is an area in the SW-WPL near CW-20 close to the edge of the closed contours where capture is questionable. |
| | | Chemistry vs time graph of spring SW-17 was examined along with hydrographs of wells in the SW-WPL during a surface water runoff event. | A spike in the CVOC concentrations coincides with a rise in the water level in the aquifer near CW-20 during pumping of the GWTS, indicating the extraction system may have been overwhelmed by karst loss. |

| Table 3.7-1 Summary of GWRI Data Gaps Addressed in Part 2 | | | |
|---|---|---|---|
| **Data Gaps Addressed** | | **Part 2 Tasks** | **Part 2 Results** |
| **SPBA Vapor Intrusion Investigation** | | | |
| | **USEPA requested evaluation of VI pathway for Site COCs to enter neighboring residences** | Fifteen shallow monitoring wells were installed in the SPBA and the residential area on Canterbury Lane south of the Site. The wells screened the top of the saturated zone to assess the potential for vapor intrusion into residences. Soils were sampled and gradation analyses performed. Water levels in wells were measured and two rounds of groundwater samples were collected and analyzed for VOCs. The results were evaluated using USEPA's VISL Calculator. | No groundwater chemistry results in off-Site wells in the residential area exceed USEPA screening criteria, indicating that neither the TCR nor the target HI have been exceeded in groundwater sampled in the Canterbury Lane neighborhood. As a result, USEPA determined that "VI is not expected to be a significant exposure pathway for the off-site residential area downgradient of the SPBA at this time." |

# 4 CONCEPTUAL SITE MODEL

The previous sections of this report detailed the results of the groundwater investigations performed at the fYNOP in 2012 through early 2015 to address data gaps in site characterization that were identified during the Part 1 SRI (GSC, 2011). This section provides a summary of the findings and conclusions of the environmental investigations involving the groundwater, conducted at fYNOP located in York, Pennsylvania from 1984 through October 2015, and incorporates the answers to the data gaps. The conceptual site model (CSM) summarizes the description of physical characteristics of the study area, the source, nature and extent of contamination, and the mechanisms affecting contaminant fate and transport of COCs.

**Figure 4.0-1** is a map of the project area showing the areal extent of the combined TCE and PCE plumes. Also depicted in this figure is a petroleum plume located in the northeastern corner of the West Campus. The TCE and PCE plumes were taken from Plates 1 and 2.

**Figure 4.0-2** is conceptualized cross section A-A' that incorporates the components that influence and control groundwater migration and contaminant transport beneath and from the Site under natural (non-pumping) conditions, excluding the SPBA. Conceptualized cross section A-A' essentially represents the groundwater flux conditions for all groundwater passing through the WPL(the vast majority of the groundwater flow through the Site).

**Figure 4.0-3** is conceptualized cross section A-A' that incorporates the components that influence and control groundwater migration and contaminant transport beneath and from the Site under pumping conditions.

**Figure 4.0-4** is a conceptualized cross section that summarizes the components that influence and control groundwater migration and contaminant transport in the SPBA and south of the Site. **Figure 4.0-1** shows that the trace of this conceptualized cross section takes a curved course, following the path of groundwater flow. **Figure 4.0-4** and the SPBA/SPA areas will be reexamined in a subsequent report after completion of additional investigations.

These figures incorporate most of the points described in Section 4, and can be referred to as this section is read.

## 4.1 Physical Characteristics

The Site is located in central York County, north of the City of York, PA (**Figure 1.0-1**). The area of the Site is drained by the Codorus Creek, a tributary to the Susquehanna River with a 237 square mile drainage area above the point where it intercepts the Site. Hills rim the Site on the north and east, forming somewhat of a bowl-shaped configuration. The eastern one third of the Site is fairly steeply sloping to the west (4 to 20%), forming an upland area to the east of the flat-lying CPA. From the base of the hills to the Codorus Creek, the land surface within the CPA slopes very gently (0.5%) to the west.

### 4.1.1 Geology

Unconsolidated overburden materials have developed from the underlying bedrock throughout the Site. These overburden materials range in thicknesses from 15 feet to greater than 60 feet. Portions of the Site have alluvial deposits, which include more coarse-grained sediments transported and deposited by flowing water interspersed among the predominantly fine-grained residual soils.

Two bedrock formations underlie the Site (**Figure 2.1-1**):

- Quartzitic sandstone and phyllite underlie the more steeply sloping hills present on the northern and eastern parts of the Site. A thin mantle of residual material derived from the weathering of parent material overlies the bedrock. Bedding planes, joints, and fractures are tight.

- Solution-prone (karst) limestone and dolomite (carbonate) underlie the western flat-lying CPA of the Site. Weathering, more specifically called karst development, has taken place along fractures and bedding planes within the carbonate bedrock. The high degree of variability in the elevation of the top of bedrock, called a "cutter and pinnacle" bedrock surface (**Figure 4.1-1**), and the occurrence of numerous caverns and solution channels within the bedrock at the Site indicate processes that are described as karst development. Karst development was evidenced by numerous voids encountered during the drilling of borings and monitoring wells within the carbonate bedrock. The natural (non-fill) overburden materials in the carbonate terrain range in thickness from 15 feet to 60 feet bgs, and are comprised of silt and clay, some or all of which had formed as the residual material from carbonate bedrock weathering, and transported alluvial sediment. In addition, numerous sinkholes have occurred on the fYNOP property, which are a typical occurrence within areas of soluble carbonate rocks. The solution cavities and fractures often contain mud, silt, and rounded 0.5 to 2-inch diameter quartz and limestone gravels and cobbles, as recorded in numerous boring logs from wells drilled at the Site.

The bedrock formations have been folded into a series of downfolds (synclines) and upfolds (anticlines). The CPA and WPL are underlain by a syncline that dips downward (plunges) to the west. The southeastern portion of the Site is underlain by an anticline, and a second syncline that both plunge to the southwest (**Figure 2.1-1**)

The extent of the carbonate underlying the Site and adjacent areas has been defined in detail, which is important because it provides a limit to the extent of solution feature-controlled groundwater migration. The lateral extent is limited to the north and east by ridges underlain by phyllite, quartzite and quartzitic sandstone. These noncarbonate formations also underlie the carbonate formation, dipping at angles of approximately 15 to 20 degrees toward the carbonate, and form the lower limit of the karstified aquifer in the northern and eastern portions of the CPA and WPL. The thickness of carbonate was determined by drilling through it into the underlying phyllite and quartzitic sandstone. The thickness increases southward and westward. The thickness of the carbonate in the CPA at the Bldg58 Area is 315 feet, at the TCA Tank Area it is 410 feet and at the SW-WPL, the carbonate thickness is estimated to be 470 to 600 feet.

The top of the carbonate bedrock surface was examined by reviewing well logs, contouring, and 3-D modeling (**Appendix S**). **Figure 4.1-2** is a bedrock contour map constructed using all bedrock elevation points available through January 2015. The wells and borings completed during the Part 2 investigation were added to the previous bedrock contour map (**Figure 1.3-2**). The added data provides more detail in the CPA area, generally supporting the bedrock observations made during the Part 1 report. A deep broad cutter (depression) follows the contact between the quartzitic sandstone and the carbonate underlying the CPA. The broad depression, shown as 200 to 900 feet in width, has a general north to south orientation. The depression contains some of the localized bedrock depressions or sinking points into which concentrated groundwater recharge has formed the deeply penetrating solution conduits which pervade the bedrock. The substantial dissolution of the bedrock surface in this area, up to a depth of approximately 80 feet, has likely been created by the interaction of corrosive groundwater recharge and storm water runoff from the quartzitic sandstone and phyllite upland area in the northern and eastern portions of the Site with the lower-elevation carbonate bedrock area beneath the western portion of the Site.

Other depressions in the karst bedrock surface were delineated underlying the NPA, north of Former Building 42, west of the North End of Bldg4 and two areas in the WPL. The lower elevation of the karst bedrock surface and solution cavities associated with these features also generally correlate with concentrated fracture trace patterns. Well locations exhibiting karst features (open or sediment-filled solution cavities) are frequent and well-distributed across the Site.

The frequency of open (water-filled) and sediment-filled solution cavities in the rock in the top 170 to 200 feet bgs is extremely high (15 to 19% compared to reported percentages of less than 1% in recognized karst areas throughout the world (GSC, 2011, pp. 40, 41). Below 200 feet bgs, percentages drop to 2%, and the hydraulic conductivity of the aquifer is much reduced (Note #3 on **Figures 4.0-2**). However, one solution cavity capable of transmitting large volumes of groundwater was encountered at 293 feet bgs in the CPA. The deepest solution feature encountered was at a depth of 374 feet bgs in the SW-WPL.

### 4.1.2 Hydrogeology

Groundwater under the Site, excluding the southeastern corner, generally migrates from east to west, from the high topographic areas underlain by quartzitic sandstone to the carbonate aquifer that underlies the western half of the Site (see Note #1 on **Figure 4.0-2**). Aquifer transmissivity, the property of the aquifer that describes the ease with which groundwater moves through the saturated subsurface materials, is very different between these two geologic materials. The quartzitic sandstone transmissivity is lower due to the groundwater migrating through small partings associated with bedding planes, joints and fractures with relative higher resistance compared to the carbonate aquifer because the openings are not solution-enhanced. Because the minerals in the carbonate aquifer are prone to dissolution by migrating groundwater, transmissivity in this aquifer is greatly enhanced, and groundwater moves with relative ease through this aquifer.

Water table gradients are steep (6 to 10%) in the upland regions underlain by quartzitic sandstone and diminish to a relatively flat gradient (0.5% or less) once the groundwater flows into the area underlain by carbonate rocks (**Figure 2.3-13**). Groundwater in the upland area flows mainly through the interconnected network of fractures, joints and bedding planes. Once the groundwater encounters the carbonate rocks, groundwater flow is directed along fractures, dissolution cavities, interconnected conduits, and weathered zones in the rock (Note #2 on **Figure 4.0-2**).

The regional groundwater flow through the CPA and the WPL follows a general west-southwesterly direction. The conceptual cross section illustrated in **Figure 4.0-2** is oriented west to east, and runs through the CPA and WPL, generally parallel to the regional groundwater flow direction. Locally, the groundwater flow direction through the karst bedrock is widely variable, following preferential pathways of the karstic conduits (Note #2 on **Figure 4.0-2**). Results of tracer testing and the responses to pumping indicate a highly interconnected network of conduits. Between these conduits the aquifer is further interconnected by fractures and bedding plane partings throughout the rock, resulting in a diffuse groundwater flow system between the conduit pathways. Under natural (non-pumping) conditions, groundwater can migrate parallel to the creek in upstream and downstream directions along the eastern levee of Codorus Creek. Under pumping conditions (**Figure 4.0-3**), minimal artificial gradient has the ability to change flow directions at lateral distances of over 2,000 feet from the pumping center.

Site groundwater has an upward hydraulic gradient with respect to Codorus Creek. Under natural (non-pumping) conditions, there is very little measurable vertical gradient throughout the top 200 feet bgs of the carbonate aquifer due to the highly permeable, well connected karst conduits, however, the occurrence of spring discharges and the observation of dye tracer discharges to the creek from injections in this zone demonstrate the upward gradient. Below 200 feet bgs, hydraulic conductivity is much lower, and there is an overall upward vertical gradient across the Site, toward the permeable, well-drained upper portion of the aquifer. Deep conduits (>200 feet bgs) are connected to the shallow conduit system (Note #4 on **Figure 4.0-2**). This upward gradient is most prominent west of the WPL, along the Codorus Creek levee, illustrated on **Figures 3.1-1 and 3.1-2** and summarized on **Figure 4.0-2,** Notes 5 and 7. While there are irregularities to a consistent vertical upward gradient, all piezometric levels at depth are higher than the creek, indicating the potential for Site groundwater to discharge to the creek.

In the southeastern portion of the Site, groundwater flows southward toward the SPBA (**Figure 3.1-25**). The area to the north of the SPBA is underlain by quartzitic sandstone, but underlying the SPBA is the solution-prone carbonate aquifer, described in the CPA and WPL areas of the Site, as illustrated on **Figure 4.0-4** Notes #1 and 2. Due to the hydraulic conductivity contrast between the aquifers, localized groundwater flow from the low hydraulic conductivity quartzitic sandstone aquifer is directed vertically downward through the unconsolidated materials to the underlying highly permeable carbonate aquifer (**Figure 3.1-23** and **Figure 4.0-4** Note #2). In the carbonate aquifer, groundwater flow is towards the southwest beneath Rt. 30, and then migrates westward toward Codorus Creek (**Figure 4.0-4** Note #3). Mill Creek, a tributary to Codorus Creek that parallels the south side of Rt. 30 in this area, is a losing stream most of the year, and does not receive groundwater from the carbonate aquifer (**Figure 4.0-4** Note #4).

#### 4.1.2.1 **Role of Codorus Creek as a Discharge Boundary**

Under natural conditions (without the operation of the groundwater extraction system), groundwater flowing through the majority of the Site flows westward toward and discharges into Codorus Creek (**Figure 4.0-2**, Note **#7**). For Site-related groundwater to pass under Codorus Creek to the north or west, it would require the existence of a large pumping center or a deep conduit isolated from the shallow aquifer (down to 200 feet). Noncarbonate rocks to the north eliminate the potential for northerly migration beneath the creek (**Figure 3.1-28**).

No water supply wells were found in the search area to the west of the Site. The Roosevelt quarry, a large pumping center 12,000 feet to the west was considered, but ruled out as a potential influence. The distance and the occurrence of the Kinzers Shale between the creek and the quarry prevents the influence of dewatering from reaching the Codorus Creek at the fYNOP Site. This was corroborated by measuring water levels in existing wells west of Codorus Creek between the quarry and the Site, and determining that groundwater elevations in these wells are higher than Site groundwater elevations, and that an eastward trending groundwater gradient exists on the west side of Codorus Creek across from fYNOP. This indicates groundwater on the west side of the creek flows eastward toward the creek, not westward toward the quarry.

The potential that a deep conduit-controlled pathway (named the "Northwest Passage") could exist under the valley of the unnamed tributary on the west side of Codorus Creek was investigated. This area is northwest of the Site. The Kinzers Shale which forms the geologic barrier between carbonate aquifer to the west and the carbonate aquifer underlying the Site, is breached by a complicated series of faults in this location (**Figure 3.1-28**). A well that was installed in the valley revealed a relatively thin, shallow carbonate interval in which no solution features were encountered, indicating a deep karst conduit not connected to the surface is unlikely. In addition, an upward vertical gradient with respect to the creek indicated upward and eastward groundwater migration. No Site-related COCs were detected in groundwater samples that were collected from the well.

Wells were installed that intersected deep (greater than 200 feet bgs) conduits on the levee along the east side of Codorus Creek. The existence of a vertical upward hydraulic head potential between these deep conduits and Codorus Creek under non-pumping conditions was established. In addition, dye tracers were injected into deep and intermediate conduits intercepted by wells on the eastern levee, and in all cases, dye was detected in Codorus Creek, indicating deep conduits discharge to the creek (**Figure 3.1-37** and **Figure 4.0-2,** Note #7).

Two groundwater discharges (springs) to Codorus Creek (SW-15 and SW-26 shown on **Figure 2.3-10**), located on the west side of the creek, were discovered and monitored. As a result of chemistry responses in these springs to operation of the Site groundwater extraction wells, it appears that Site groundwater has the ability to migrate to the west side of Codorus on its way to discharging to the creek. This conduit-directed pathway cannot extend westward past the Kinzers shale, which is not solution-prone and forms a geologic barrier to conduit formation and further westward migration. This is illustrated at Note #9 on **Figure 4.0-2**.

The potential that deep karst conduits may not be connected to the shallow network of conduits and could transport COCs from the Site to undiscovered locations was tested. Tracer dye was injected into the deep conduit (220 feet bgs) in well CW-20 in the SW-WPL. Dye was traced to spring SW-17, which discharges to Codorus Creek and to deep conduit well MW-147A (**Figure 3.2-3**). MW-147A was the subject of its own tracer dye injection into a karst solution feature between 211 and 216 feet bgs, which showed groundwater in that well discharges to Codorus Creek (**Figure 3.1-31**).

While the potential existence of a deeper pathway that does not discharge to Codorus Creek cannot be ruled out completely by the individual tests conducted, there is no indication that such a pathway exists. Numerous deep conduits were intersected and shown to be connected to the shallow karst solution channels and the creek. Based on the data collected, absent the groundwater extraction system, Site groundwater from the CPA and WPL discharges to Codorus Creek. Some groundwater migrates under and west of Codorus Creek and discharges at springs on the west side of the creek due to the geological barrier caused by the Kinzers Shale, and the opposing hydraulic gradient (**Figure 4.0-2**, Note **#8**).

## 4.2 Nature and Extent of Groundwater Contamination

Industrial activities have been widespread throughout the Site, and have resulted in over twenty suspected and confirmed source areas for the groundwater constituents of concern. Overall, these activities and associated suspected and confirmed source areas have resulted in seven general areas of the Site where COCs have been identified in groundwater. A summary of these seven areas is included below. The areas are identified in **Figure 1.1-1**:

- **Northern Property Boundary Area** – Vapor degreaser wastes were distributed along the perimeter road and fence line in the NPBA and poured into groundhog burrows. TCE and PCE have historically been the predominant VOCs detected in groundwater at the NPBA. Three former off-Site residential wells to the north were discovered to contain concentrations of TCE in 1986.
- **Eastern Area –** Vapor degreaser wastes were distributed along the perimeter road and fence line in the Eastern Area and poured into groundhog burrows. Also include in the Eastern Area are a former cyanide spill, and a landfill. COCs are primarily TCE, PCE and their degradation products.
- **Southern Property Boundary Area** – The COC presence in groundwater in this portion of the Site is due to similar dust control and rodent control activities as were performed in the NPBA and the Eastern Area.
- **North End Test Track** –Leaks and spills from the drums of liquid wastes stored in this area resulted in groundwater contamination (TCE, PCE, TCA and their degradation products). Also, bomb line grease, cyanide waste and liquid waste were reportedly disposed in open pits.

- **North Plant Area** – Locations that likely contributed COCs in this portion of the Site include: the Old Waste Containment Area that was used to store liquid wastes; the IWTP that was used to treat wastewater; a former metal chip bin area that resulted in releases of cutting oils, and a gasoline underground storage tank (UST) area where gasoline was released from subsurface piping.
- **Central Plant Area** – Locations that likely contributed COCs in this portion of the Site include: the former Bldg2 vapor degreaser (near MW-55) and the TCA tank area (near CW-8) in the southern half of Bldg2; cutting oil tank, the former wastewater sumps located in the corridor east of Bldg2; the former chrome/zinc plater area and the area of Bldg58 near the southeast corner of Bldg2; the corridor west of Bldg2; and the NBldg4 plating/sludge and vapor degreaser area. A highly concentrated plume of chlorinated solvents occurs in the groundwater between Bldgs 2 and 4 north of Building 91. This plume commingles with a plume with similar constituents caused by activities involving the former northern vapor degreaser in the northwestern corner of Bldg4. A plume of PCE trends northwestward from the southwestern corner of Bldg4, also the former location of a vapor degreaser. Also commingled with this plume is chromium, which is a result of spills and leaks from a plating operation in Bldg4, just south of the former northern vapor degreaser.
- **West Parking Lot** – The western boundary and the western edge of the WPL were landfilled and used as a disposal area for liquid and solid waste. The highest concentrations of chlorinated solvents (42 parts per million) in the groundwater on Site occur in the SW-WPL. Prior to the operation of the interim groundwater extraction system in the WPL, TCE, PCE and TCA reached wells that are located along the levee on the east side of Codorus Creek, a distance of approximately 500 feet from the property line.

CVOCs are widely distributed in the groundwater across the Site. The solvents were released in the form of DNAPL which is, by definition, immiscible in water and exhibits a higher specific gravity than water. In addition, metal plating-related inorganic compounds, petroleum hydrocarbons (gasoline) and semi-volatiles were detected at concentrations that exceed PADEP groundwater MSCs and were delineated in limited areas of the Site.

The distribution and extent of chlorinated solvents in the groundwater is depicted on isoconcentration contour maps (**Plates 1, 2 and 3**) and a composite of the TCE and PCE extent was constructed and shown on **Figure 4.0-1**. The results of these efforts have defined the source areas and delineated the lateral extent of CVOCs in groundwater at the Site as follows:

1. In the higher elevation areas of the site underlain by the noncarbonate rocks, TCE and PCE are distributed in the groundwater near the northeast, east and southeast fYNOP property lines. These chemicals dissolved in groundwater were pulled off-site in the NPBA by former residential water supply wells. Cis12DCE is distributed less extensively in the area, but occurs near the northeastern property line. TCE and PCE also migrated downgradient of the Site to the south from the SPBA.

2. Highest concentrations of CVOCs are distributed throughout the carbonate aquifer beneath the NETT, CPA and the WPL.

3. Concentrations of CVOCs were detected in groundwater in the wells installed off-Site on the east side of Codorus Creek. Extensive investigations and testing establish Codorus Creek as the limit of off-Site migration to the west.

In the NPBA, flow directions were locally modified by pumping groundwater extraction wells, operated from 1989 until 2014. Pumping of these wells has resulted in the northern extent of CVOCs to be drawn southward and is now within the fYNOP property boundary. Post-shutdown groundwater elevation and potentiometric contours established the existence of a natural (non-pumping) groundwater gradient to the southwest in the area of MW-18S&D (**Figure 3.1-18**). A potential exists for the groundwater contaminant plume to flow along a pathway that crosses the Site property line. If that were to occur, the plume would migrate back on-Site within approximately 1,000 feet downgradient.

CVOCs originating in the SPBA migrate vertically downward with the groundwater through the unconsolidated materials to the underlying karst aquifer (**Figure 4.0-4**, Note # 2). CVOCs then migrate off-Site with the natural groundwater flow in a southwesterly direction beneath Rt. 30 (**Figure 4.0-4**, Note # 3). The extent of TCE and PCE exceeding PADEP MSCs (5 µg/L) has been defined, and reaches approximately 410 feet and 770 feet, respectively, south of Rt. 30 (**Figure 4.0-4**, Note #5). Cis12DCE does not exceed the PADEP MSC (70 µg/L) in the SPBA (**Plate 3**).

The vertical extent of CVOCs was determined in six locations across the Site that were identified as areas of elevated concentrations of chlorinated solvents in the groundwater. These areas are the Bldg58 Area, the TCA Tank Area in Building 2, the WBldg2 Corridor, the NBldg4 Area, the SPBA and the SW-WPL. The vertical extent of CVOCs in these areas is shown on cross sections (**Figures 3.1-5 through 10, and 3.1-12 through 17**). The greatest depth of CVOCs detected occurred in the SW-WPL, and extended to a depth of 460 feet bgs, and presumably beyond. The depths of CVOCs in the other locations tested ranged from 200 to 350 feet bgs. The distribution of TCE, PCE and cis12DCE at three horizons (elevations) in the aquifer beneath the CPA and WPL are illustrated on **Figures 3.1-38 through 46**. The maps show diminished areal extent of the three CVOCs in the deepest zone (110 feet amsl). The highest concentrations and most widespread areal extent of TCE and cis12DCE occur in the intermediate zone (210 feet amsl). The most widespread lateral extent of PCE is similar in both the shallow (above 310 feet amsl) and intermediate zones.

## 4.3 Contaminant Fate and Transport

An analysis of the mechanisms that apply in the carbonate and non-carbonate bedrock aquifers at the Site are depicted as **Figures 1.3-6, 1.3-7** and **1.3-8.** These mechanisms are addressed in this subsection.

### 4.3.1 DNAPL Transport

CVOCs in the form of DNAPLs were discharged on the ground surface and traveled vertically downward through the subsurface materials, leaving a trail of residual material or forming accumulation zones. Remnants of this process (after 60 or more years) are illustrated on **Figures 4.0-2** and **4.0-3**, where residual DNAPL is shown as a red hatch pattern below the western corner of the WPL. At the fYNOP Site, the factors affecting the transport of a DNAPL release are highly dependent on the geologic characteristics at the location of the release. In the karst aquifer, DNAPL is directed along the pinnacled bedrock surface through vertical and lateral solution channels that are open (filled with water) or filled with water-saturated residuum and sediment (sand, silt, clay, gravels and rock fragments). Investigations in the WBldg2 Corridor and the Bldg58 Area did not identify DNAPL sources in the shallow subsurface or below the water table.

In the SW-WPL, DNAPL penetrated through the highly karstified zone of the aquifer (from 150 – 200 feet bgs), the fractured and minimally karstified zones from 200 to 375 feet bgs, and the fractured zones of low hydraulic conductivity from 375 feet bgs to the extent of drilling (460 feet bgs) and potentially some depth beyond (**Figure 4.0-2**, Note #5). The penetration of TCE and PCE as a DNAPL into the low deepest zone of low hydraulic conductivity and subsequent reductive dechlorination of dissolved phase CVOCs is the most likely way that degradation product cis12DCE could have reached these depths, since cis12DCE could not have been transported downward with groundwater due to the consistently upward hydraulic gradient (**Figure 4.0-2**, Note #6).

In the NPBA, SPBA, and other areas of higher elevation underlain by non-carbonate rocks, there is no evidence that DNAPL reached bedrock. It is suspected that distribution was not concentrated (used for dust control and weed control), and migration was limited to the residual soil horizon. COCs were then carried to the groundwater as a result of dissolution by precipitation.

### 4.3.2 Aqueous Phase Transport and Secondary Sourcing

Site-related COCs slowly dissolve into groundwater in the DNAPL source areas and are transported laterally and vertically as groundwater flows naturally or is captured by the extraction system. **Figures 4.0-2** and **4.0-3** indicate areas where higher concentrations of dissolved chlorinated hydrocarbons are expected to be a result of partitioning from mostly depleted DNAPL sources. These areas of higher concentrations are shown as orange shading. Under natural gradients, (when the groundwater extraction system is not operating) groundwater in the CPA/NPA/WPL migrates generally westward toward Codorus Creek through residuum, solution-enhanced pathways and fractures in the carbonate bedrock. Below 200 feet bgs, the hydraulic conductivity of the aquifer is much lower (**Figure 4.0-2**, Note #3), and there is an overall upward vertical gradient across the Site, toward the well-drained upper portion of the aquifer. There is no indication of the existence of a deeper groundwater flow pathway (a deep karst solution channel) that does not discharge to Codorus Creek. Codorus Creek is considered the western boundary for migration of COCs in the groundwater from the Site.

The aqueous phase chemicals that migrated with groundwater diffused into the rock matrix, and adsorbed onto organic carbon or mineral surfaces not originally impacted by DNAPL releases.

Desorption back into groundwater occurs slowly, and provides a continuing secondary source of contaminants outside of the source areas.

CVOCs originating in the SPBA migrate vertically downward, dissolved by water from precipitation through the unconsolidated materials to the groundwater and the underlying karst aquifer (**Figure 4.0-4**). Within the karst aquifer, CVOCs then migrate off-Site with the natural groundwater flow in a southwesterly direction beneath Rt. 30. The lateral extents of TCE and PCE exceeding PADEP MSCs (5 µg/L) have been delineated, and reach approximately 400 and 700 feet, respectively, south of Rt. 30.

Under the influence of the groundwater extraction system currently consisting of five wells in the WPL, Site-impacted groundwater flowing westward through the CPA and WPL is captured (**Figure 4.0-3**, Note #7). Capture of groundwater containing COCs in the deepest portions of the karst aquifer has been demonstrated by pumping of the relatively shallow extraction wells. Reversal of natural groundwater flow has been demonstrated from as far down gradient as the eastern Codorus Creek Levee Area by pumping of the groundwater extraction system (**Figure 4.0-3,** Note #8).

### 4.3.3 Transformation of CVOCs

The aqueous phase CVOCs diffused into the rock matrix, and adsorbed onto organic carbon or mineral surfaces. In the aqueous phase, anaerobic bacteria break down PCE and TCE to cis12DCE and VC and the TCA to 11DCA and chloroethane. TCA also abiotically transforms to 11DCE.

The process involving anaerobic bacteria is called reductive dechlorination, and MNA sampling analytical results were used to screen areas within the Site to determine the level of occurrence, which are described as follows:

1. In the NPBA (sandstone aquifer) reductive dechlorination is occurring under reducing (anaerobic) conditions to a limited extent, evidenced by the elevated concentrations of daughter product cis12DCE. In addition, the data indicates sulfate reduction and the presence of *dehalococcoides spp* population data and methane concentrations suggest limited methanogenesis.

2. In SPBA wells, elevated DO and the lack of cis12DCE suggest poor conditions to support reductive dechlorination in shallow bedrock wells. Deeper in the aquifer (200-300 feet bgs), there is evidence of limited biodegradation based on the detection of cis12DCE.
3. In the carbonate aquifer underlying the CPA and WPL, evidence of reductive dechlorination is variable. In the portion of the aquifer well connected to the karst conduits, DO is elevated during recharge events, which reduces the anaerobic bacteria population and retards reductive dechlorination. In the deep wells that are screened within the diffuse flow portion of the aquifer, there is adequate evidence of dechlorination, reducing PCE and TCE, transported as a DNAPL and subsequently dissolved into groundwater, to cis12DCE.

### 4.3.4 Codorus Creek Water Quality under Natural Groundwater Flow

Under natural groundwater flow conditions (absent the operation of the GWTS), Site-impacted groundwater discharges to Codorus Creek. Concentrations and mass flux of Site-related COCs in Codorus Creek vary seasonally, corresponding to stream flows. In general, mass flux is relatively higher and concentrations are lower during higher flows (late winter and early spring), while mass flux is relatively lower and concentrations are higher during lower flows (late summer and early fall). At Qh conditions (representing average flow conditions in the creek), the average concentrations of PCE and TCE exceeded PADEP Chapter 93 surface water criteria in stream samples immediately west of the Site, in conditions that represent groundwater partially mixed with creek water. Approximately 2,100 feet downstream, Site-impacted groundwater that discharged to the creek is fully mixed with the creek flow. At this location at Qh conditions the average concentration of TCE did not exceed surface water criteria, while PCE slightly exceeded it.

### 4.3.5 Codorus Creek Water Quality under Pumping Conditions

Under pumping conditions, operation of the GWTS captures Site-impacted groundwater, preventing off-Site migration of COCs. The average concentrations for pumping conditions for PCE, TCE and cis12DCE are all less than the PADEP Chapter 93 surface water quality criteria (WQC) for each of these parameters at all seven of the monitoring stations. Impacts of pumping on CVOC concentrations in sample stations on the west side of Codorus Creek did not show as much of a distinct reduction after restart of the GWTS compared with the east side of the creek. This may be due to a delayed impact as a result of the long travel path, or a result of secondary sourcing, which the operation of the GWTS would not impact on a short term basis.

# 5 INTERIM REMEDIATION PROGRESS AND CONSIDERATION OF FINAL SITE REMEDY

The Site has been the subject of a lengthy remedial investigation that was accompanied by the implementation of a number of interim remedial actions that have had a significant positive impact on the environmental conditions and the potential for exposure to Site-related COCs. Over the last 20 years, CVOC concentrations in the groundwater have reduced 90 to 99% in most of the wells at the Site. The reduction is primarily a result of removal of DNAPL by dissolution into the groundwater that migrates from the source or is captured and removed by the pump and treat systems, removal of mass by excavation in specific areas, natural degradation of dissolved-phase CVOCs by reductive dechlorination, diffusion of the dissolved phase into the solid matrix of the aquifer, and sorption onto carbon particles located on the surface and within the solid matrix of the aquifer.

Although greatly reduced, concentrations of chlorinated solvents nonetheless exceed PADEP groundwater MSCs across most of the Site (GSC, 2011, p. 183). Several facts indicate the persistence of the COCs in groundwater at fYNOP, including:

- Chlorinated solvents have not been used on-Site since 1994;
- There has been no known release of chlorinated solvents in over 30 years; and
- The groundwater pump and treat systems have been operating for over 25 years.

Estimates of the mass remaining in the aquifer conducted in 2009 using trend analysis exceed 60,000 pounds, and may be underestimated because DNAPL is likely present in the subsurface. On the order of 2,000 pounds of this total occurs as mass dissolved in groundwater (approximately 3%). The remaining majority of the mass is diffused into the matrix of the aquifer, adsorbed onto and within the matrix of the aquifer, or is in the form of suspected DNAPL accumulation zones. These undissolved sources of mass are very slowly released to the groundwater passing through the Site.

## 5.1 Interim Remedial Removal Actions

Considerable efforts have been expended since the beginning of the investigations toward removal of contaminant mass by excavation. Details of those activities are included in the Supplemental

Remedial Investigations Soils Report (SAIC, 2009). Post-soils RI removal actions occurred in the following areas:

- Bldg 67 and Metal Chip Bins removal/closure;
- UST Tank 009 removal;
- Building 51 Hazardous waste storage facility demo and closure;
- Former industrial wastewater conveyance line cleaning/abandonment;
- Former Bldg 41/WWTP demo/removal;
- Former vapor degreaser pit removals in NBldg 4; and
- Demolition and closure of the former Electrical Transformer Areas.

These interim remedial removal action efforts will be considered during the analysis of remedial alternatives. An important general observation however, is that while considerable mass has been removed by these actions, no meaningful reduction in groundwater concentrations has occurred as a result of these removal actions.

## 5.2 Groundwater Extraction Systems Evaluations

**NPBA** – In the NPBA, flow directions were locally modified by pumping of groundwater extraction wells, and resulted in reduction of off-Site COC concentrations to below PADEP MSCs for drinking water aquifers. Monitored shutdown testing results indicate that residual concentrations of COCs in the groundwater beneath the NPBA are expected to migrate to the south and southwest, towards the interior of the Site. A comparison of pre- and post-shutdown COC concentrations in groundwater showed that cessation of pumping in the NPBA in June 2013 did not result in an increase in COC concentrations in these wells. Conditions following the shutdown of the groundwater extraction system in the NPBA continue to be monitored and reported annually.

**Bldg3 Footer Drain** – Due to the low concentrations of CVOCs in the groundwater and the potential that water levels may not rise sufficiently to impact Bldg3 or equipment if the pumping station were deactivated, the Bldg3 Footer Drain was shut down and conditions were monitored. No adverse effects were observed. Therefore, continued deactivation was recommended, with monitoring to continue for a period of two years.

**WPL** – Groundwater flow is redirected locally by operating the system of capture wells in the WPL. The operation of groundwater extraction wells effectively limits groundwater flow from the WPL toward Codorus Creek.Tests performed on the aquifer and the groundwater extraction system in the WPL resulted in the following observations:

1. The groundwater extraction wells are relatively shallow, but the top 250 feet of the carbonate aquifer is well connected through a combination of solution channels and fractures. Capture of groundwater in a deep conduit (220 feet bgs) was demonstrated by pumping of a shallow (75 feet bgs) extraction well. Even deeper in the aquifer where diffuse (fracture) flow predominates, influence of pumping was sufficient to maintain off-Site migration of contaminants in this portion of the aquifer.
2. The groundwater extraction system may not completely prevent Site-related COCs from discharging into Codorus Creek at all times. At spring water discharge station SW-17, 700 feet west of the SW-WPL on the eastern bank of Codorus Creek, concentrations are reduced nearly 10X by operation of the groundwater extraction system, but PCE and TCE concentrations in this discharge remain above groundwater MSCs. This condition suggests that the presence of discrete flow channels in the karst aquifer results in the discharge of some Site-impacted groundwater into the creek.
3. Spring water discharge monitoring stations SW-15 and SW-26, on the west side of the creek generally showed concentrations of Site-related COCs below groundwater MSCs during operation of the extraction wells in the WPL. However, increased concentrations exceeding the groundwater MSCs for PCE and TCE occurred during shutdown of the extraction wells in the WPL. SW-15 concentrations of PCE and TCE increased approximately 2 to 5X, while cis12DCE increased 7 to 10X. PCE concentrations in SW-26 increased 3 to 6X during the dry weather shutdown in the late summer and fall of 2014.
4. The observations of the shutdown testing and the effects of reconfiguration of the groundwater extraction system, which included discontinuing pumping at CW-8 and adding CW-20, has resulted in optimization of the extraction system and a better understanding of the impacts that the various wells have on the groundwater and stream quality. As a result CW-8 was decommissioned, and pumping at CW-20 was incorporated into the ongoing interim groundwater remedy.

A concern that the groundwater extraction system could temporarily lose capture during storm events due to a condition called karst loss was investigated. Analysis of hydrographs of numerous wells and contour mapping of water levels during a large precipitation event indicates groundwater capture is maintained by the extraction throughout the WPL and WWPL. However, an area of question is the SW-WPL near CW-20 near the edge of the closed contours indicating capture. A spike in the CVOC concentrations in spring SW-17 coincides with a rainfall event and a rise in the water level in the aquifer in the SW-WPL during pumping of the GWTS. This observation indicates the extraction system can potentially be overwhelmed by karst loss.

## 5.3 Consideration of Final Site Remedy

The interim remedies of source removal and groundwater extraction and treatment have accomplished their goals of reducing mass in the aquifer and preventing off-Site migration of contaminants in the NPBA and the WPL. A considerable reduction in concentrations of COCs in the groundwater has also occurred over the last 25+ years since initiation of the GWTS operation, even to the extent that the NPBA extraction system operation has been shut down, and is under a post operation monitoring program. However, the results of investigations at this Site, particularly in the CPA and WPL, have led to the conclusion that the majority of COC mass in the aquifer is diffused into and sorbed onto and within the aquifer matrix, and will be slowly released to the groundwater by the slow processes of "back diffusion" and desorption. After nearly three decades of investigation and remediation it is apparent that continued removal actions and continued operation of the GWTS will not result in meaningful additional improvement to the groundwater quality under the Site and flowing through the Site.

The remedial alternatives analysis (RAA) for the Site will be conducted after completion of the groundwater risk assessment, which is being submitted concurrently with this report. The RAA will identify the Remedial Action Objectives (RAOs) for the Site, and will focus on identifying a final site remedy that can be successfully implemented to mitigate the risk or risks identified in the groundwater risk assessment.

Restoration of the entire aquifer to drinking water standards is not considered to be possible. Under Pennsylvania's Land Recycling (Act 2) program, there are provisions for implementation of remedial solutions that mitigate risks to receptors, without restoring the aquifer to appropriate

MSCs. CERCLA's technical impracticability (TI) ARAR waiver and Alternative Concentration Limits (ACLs) are USEPA's policy mechanisms to address a similar condition, and would involve a groundwater management/containment zone (CZ). RCRA regulations allow for flexibility in setting cleanup standards and designated points of compliance. These remedies are collectively referred to as alternative endpoints.

A TI ARAR waiver is expected to be a necessary component of the final remedy at fYNOP to deal with persistent concentrations of COCs exceeding RSLs and MSCs. The RAA process should include a TI evaluation and a remedy strategy involving alternate endpoints. The necessary components to support a TI determination by USEPA are available as a result of the investigations conducted to date on this site.

# 6 SUMMARY AND RECOMMENDATIONS

Implementation of the Part 2 SRI work scope and the numerous follow-up tasks performed for the fYNOP from 2012 through October of 2015 has resulted in sufficient information to address all data gaps that were raised by the Part 1 SRI. The results, along with information from previous investigations, were used to very completely characterize the various aquifers underlying the Site, with special attention given to the carbonate aquifer and the distribution of solution channels within the carbonate. The nature and extent of COCs has been determined, and the fate and transport of COCs is understood. The interaction of surface water and groundwater, particularly the dynamics between the Codorus Creek and groundwater in the karst aquifer was an important component of understanding the fate and transport. In addition, the tests and investigations resulted in the optimization of the interim groundwater extraction system.

As a result, a CSM for groundwater migration and transport of Site-related COCs has been developed and used to develop exposure scenarios for the human health risk assessment. The human health risk assessment relied on the information and conclusions of this report and other investigations referenced in this report. It is a separate companion document to this report.

Sufficient information is available as a result of this investigation to complete the remedial alternatives analysis for the Site, and it is recommended that it be completed upon review and acceptance of this report and the HHRA by USEPA and PADEP. Meanwhile, it is recommended that the GWTS be operated as modified and optimized. Periodic sampling of surface water (Codorus Creek) at established stations is recommended during this interim period. It is also recommended that the groundwater sampling program (key well sampling) be reevaluated to assure that appropriate information is collected to meet future monitoring objectives, now that characterization is completed.

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