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FINAL AREAS A AND C WELL PROFILING WORK PLAN FOR SOURCE AREA TREATMENT OPTIMIZATION NAWC WARMINSTER PA

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FINAL

Areas A and C Well Profiling Work Plan for Source Area Treatment Optimization at the Former NAWC Warminster, Pennsylvania

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ABBREVIATIONS AND ACRONYMS

bgs	below ground surface
BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CCl_4	carbon tetrachloride
COC	contaminant of concern
CSM	conceptual site model
DCE	dichloroethene
DNAPL	dense, non-aqueous phase liquid
DQO	data quality objective
gpm	gallons per minute
GWETS	groundwater extraction and treatment system
HPFM	heat-pulse flowmeter
H&S	H&S Environmental, Inc.
IC	institutional control
IDW	investigation-derived waste
LGAC	liquid-phase granular activated carbon
LTM	long-term monitoring
MCL	maximum contaminant level
NAWC	Naval Air Warfare Center
NPDES	National Pollution Discharge Elimination System
OU	Operable Unit
PCE	tetrachloroethene
PDB	passive diffusion bag
PID	photoionization detector
PM	project manager
POC	point of contact
RBC	risk-based concentration
ROD	Record of Decision
RPM	Remedial Project Manager
SAP	Sampling and Analysis Plan
SOP	standard operating procedure
TCE	trichloroethene
TEG	Technical Evaluation Group
TI	technical impracticability

U.S. EPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound
WMA	Warminster Municipal Authority

Section 1.0: INTRODUCTION

This work plan has been prepared to describe well profiling activities associated with source treatment optimization for Areas A and C at the former Naval Air Warfare Center (NAWC) in Warminster, Pennsylvania. These activities are designed to determine the chemical distribution within the open screened interval or borehole of selected extraction and monitoring wells located in the vicinity of the respective source areas within Areas A and C. The activities proposed within this plan are based on recommendations and information from prior optimization evaluations and investigations, and are focused on collecting data for planning and implementing aggressive source treatment at Area A, and refining plume architecture at Area C.

1.1 Background

The former NAWC Warminster is situated in a populated suburban area surrounded by private homes, various commercial and industrial activities, and a golf course. Commissioned in 1944, the facility's main function was research, development, testing, and evaluation for naval aircraft systems. NAWC Warminster also was used to conduct studies in anti-submarine warfare systems and software development. Historically, wastes were generated during aircraft maintenance and repair, pest control, fire-fighting training, machine and plating-shop operations, spray painting, and various materials research and testing activities in laboratories. These wastes, including paints, solvents, sludges from industrial wastewater treatment, and waste oils, were disposed of in several pits, trenches, and landfills throughout the facility property.

NAWC Warminster was listed on the Superfund National Priorities List in 1989. This list includes six sites where uncontrolled hazardous substance releases present the most significant potential threats to human health and the environment. These sites have been grouped within the following areas on NAWC property (Figure 1): Area A (Sites 1, 2, and 3); Area C (Sites 4 and 8); and Area D (Site 9). As a result of elevated chlorinated volatile organic compound (VOC) concentrations observed in groundwater, a groundwater extraction treatment system (GWETS) was installed at Area A to treat groundwater extracted from Areas A, C, and D. Pumping from Area D was discontinued in 2010 after the remedial goals (i.e., maximum contaminant levels [MCLs]) were achieved at the Area D extraction wells. Pumping from Areas A and C is currently ongoing. A technical impracticability (TI) waiver zone has been established within Area A (near Site 1) due to high concentrations of trichloroethene (TCE) and potentially carbon tetrachloride (CCl_4) and tetrachloroethene (PCE), which are indicative of the presence of dense non-aqueous phase liquid (DNAPL). A long-term monitoring (LTM) program is in place at Areas A, C, and D to monitor the presence of dissolved VOCs in groundwater.

1.2 Objectives

The objectives of this work plan are to:

- Conduct discrete-depth groundwater sampling for VOC analysis and evaluate the potential for vertical borehole flow in selected wells within the proposed study area at Area A to better define the source area treatment zone and to provide additional information for designing the pilot- and full-scale source area treatment approach.
- Conduct discrete-depth groundwater sampling for VOC analysis from selected Area C extraction and monitoring wells to determine the contaminant distribution within the open screen interval or borehole of each well, and evaluate the potential for vertical borehole flow in inactive and active extraction wells.

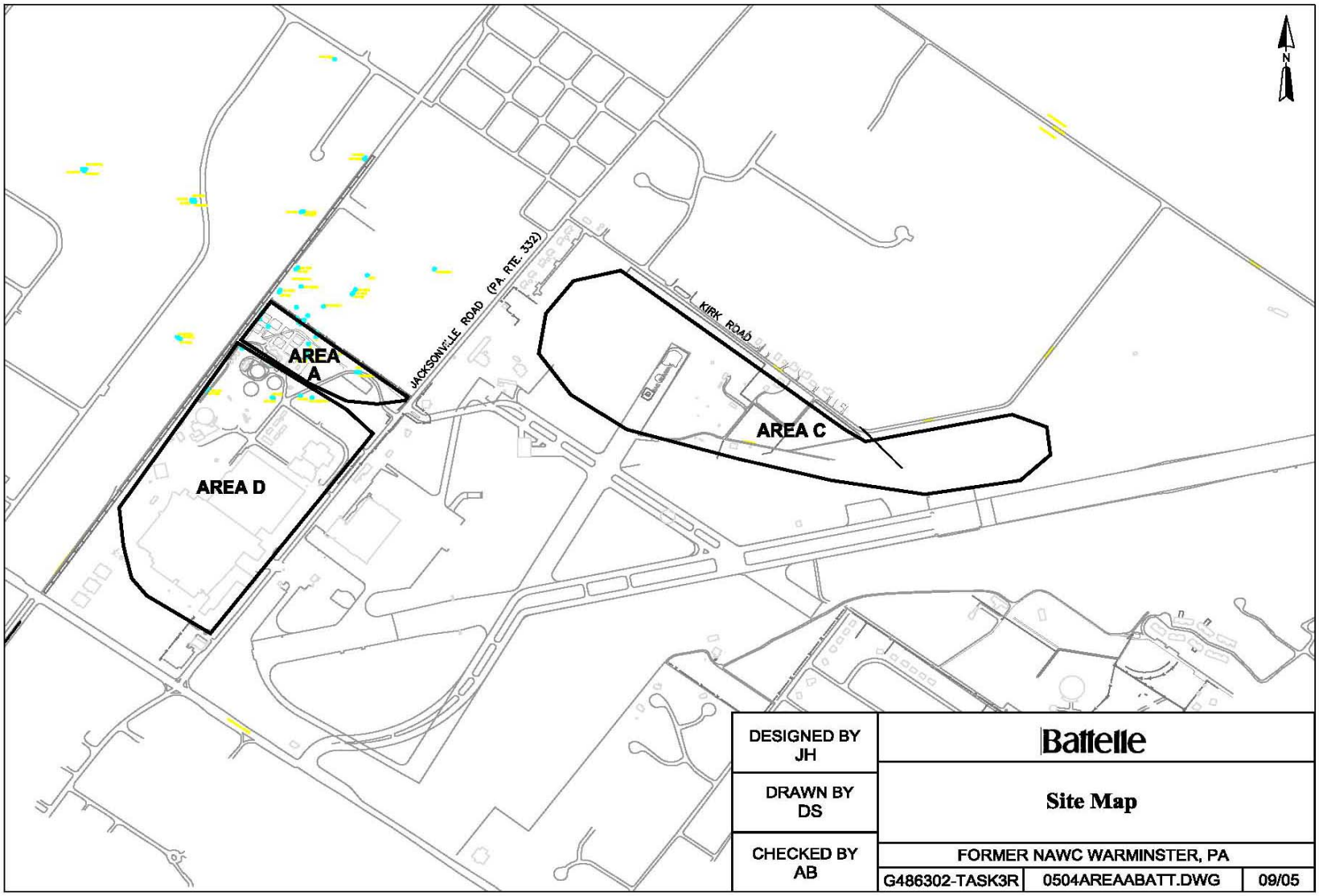

Figure 1. NAWC Warminster Site Map

- Collect discrete-depth groundwater samples to evaluate the potential for vapor intrusion into structures that are adjacent to the Area C dissolved groundwater plume.

A source treatment optimization plan (Battelle, 2012) was recently submitted, and serves as a consolidated plan for implementation of optimization efforts for aggressive source treatment at Area A, and for refinement of plume architecture in Area C. The plan provides a detailed description of the historic and current condition of Areas A and C, and provides a framework for efforts over the next two to three years to identify tasks for data collection and design of the proposed source area optimization efforts. This source treatment optimization plan also provides the data quality objectives (DQOs) for the discrete depth groundwater sampling and associated well profiling activities outlined in this work plan. The information collected from the activities outlined in this plan will be used to support the design of the aggressive source treatment activities at Area A and to refine the plume architecture in Area C.

1.3 Project Organization and Points of Contact

The majority of field activities outlined in this work plan, including extraction well shut off and startup, extraction well pump removal, groundwater-level elevation monitoring, and groundwater sampling, will be performed by H&S Environmental, Inc. (H&S), in accordance with its established Sampling and Analysis Plan (SAP) (H&S, 2011) and the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009). Borehole vertical groundwater flow measurements will be collected by the United States Geological Survey (USGS) according to heat-pulse flowmeter (HPFM) manufacturer specifications as utilized during the Area C geophysical investigation (USGS, 2008). Laboratory activities will be performed by TestAmerica Laboratories, Inc., under the direction of H&S, as outlined in the SAP. Battelle is responsible for preparation of this work plan, and for evaluation and reporting of field sampling data collected during implementation of the activities outlined in this plan.

Key NAWC Warminster project personnel and support staff have been identified and are listed below. Battelle's Project Manager (PM), Mr. Andrew Barton, will be the primary point of contact (POC) with the Navy and H&S, and will be responsible for overall project execution, cost control, and progress reporting. Mr. Barton will be responsible for communicating with the field sampling contractor (H&S) during field activities and for the technical evaluation of the information collected during the field activities. Mr. Barton will communicate regularly with the Navy during field activities and data evaluation.

Mr. Barton will report to the Battelle Program Manager, Mr. Russell Sirabian, P.E., P.M.P., who will assist with resource coordination within Battelle and provide assistance on technical issues. Mr. Barton also will receive assistance on technical issues and field oversight from the Battelle Project Engineer, Ms. Carolyn Scala, P.E. Additional appropriate technical staff will assist in evaluating vapor intrusion issues and producing project documents.

Key personnel from H&S include Mr. Patrick Schauble, P.E. (PM), Mr. Edward Kearney (Project Health and Safety Officer), Gregory Birch (Quality Assurance Manager), and Ms. Jennifer Good, P.G. (Project Field Operations Lead). Ronald Sloto, P.G., of the USGS, will conduct the borehole vertical groundwater flow measurement activities.

Key Navy personnel who will be involved in the NAWC Warminster well profiling effort include Base Realignment and Closure (BRAC) Environmental Coordinator, Mr. Willie Lin, and the Navy Remedial Project Manager (RPM), Mr. Jeff Dale.

1.4 Project Schedule

The well profiling and associated field activities outlined in this work plan will be performed immediately after the November 2012 LTM event. A draft technical memorandum summarizing the results of the well profiling field activities at Areas A and C will be submitted in April 2013. The data collected from the well profiling effort will be used to optimize the location of the rock cores and potential source area treatment locations at Area A. In Area C, the data collected from the well profiling sampling event will be used to evaluate the contaminant distribution within each well, the potential for vertical borehole flow in inactive and active extraction wells, and the potential for vapor intrusion into structures that are adjacent to the Area C dissolved groundwater plume.

1.5 Document Organization

This work plan is organized into the following sections:

- **Section 1.0, Introduction:** This section provides a brief introduction of the NAWC Warminster site, states the overall objective and summarizes the proposed source area characterization activities, presents the project organizational structure, and briefly discusses the anticipated project schedule.
- **Section 2.0, Area A Well Profiling Activities:** This section briefly describes background information for Area A, including the site conceptual site model (CSM) and historical remedial activities, identifies the study area, and presents the proposed approach for the well profiling and vertical borehole flow monitoring activities.
- **Section 3.0, Area C Well Profiling Activities:** This section briefly describes background information for Area C, including the site CSM and historical remedial activities, identifies the study area, and presents the proposed approach for the well profiling and vertical borehole flow monitoring activities, and data collection for the vapor intrusion evaluation.
- **Section 4.0, References:** This section provides a listing of the references used in the preparation of this document.

Section 2.0: AREA A WELL PROFILING ACTIVITIES

This section provides a brief description of the background conditions at Area A, including a discussion of the CSM and historical remedial actions. A detailed description of the CSM, remedial activities, and DQOs for the well profiling activities can be found in the *Areas A and C Source Treatment Optimization Plan for the Former NAWC Warminster, Pennsylvania* (Battelle, 2012). In addition, this section documents the approach for well profiling activities at Area A.

2.1 Background

Area A is comprised of three sites, Sites 1, 2, and 3, and lies within the northwest corner of the former Base, west of Jacksonville Road (Figure 2). Site 1 was operated as a burn pit, Site 2 consisted of two disposal trenches that received industrial wastewater sludges from the surface impoundments, and Site 3 was also reportedly used as a burn pit for solvents, paints, roofing materials, and other unspecified chemicals. Eight unlined lagoons used for storage of wastewater treatment plant sludges were formerly operated in the northern corner of Area A. These historical activities at Area A resulted in soil and groundwater contamination. Within Area A, the presence of TCE in the form of DNAPL has been inferred based on the concentrations detected in groundwater and confirmed through dye testing performed during extraction well drilling, yield testing, and sampling activities. A TI evaluation performed in 2000 estimated that approximately 75 to 374 gallons of TCE were potentially present as DNAPL in Area A. As a result of the evaluation, an 85-ft diameter TI zone was established in Area A focused around extraction wells EW-A6, EW-A7, EW-A9, and EW-A10 (Figure 2).

Pump and treat was selected as the final groundwater remedy in Area A, and a GWETS was installed and began operation in 1999. The cleanup goals identified in the Record of Decision (ROD) are MCLs throughout Area A, with the exception of the TI waiver zone where achieving these goals was determined to be technically impracticable. Details regarding the GWETS are discussed in *Remedial Action Evaluation Report* (Battelle, 2011).

2.1.1 Current CSM. The geology of Area A consists of alternating coarse- and fine-grained sedimentary bedrock units of the Stockton Formation underlying a thin veneer of clayey residual soils. The soils consist primarily of silt and clay, with minor amounts of sand and rock fragments. Typically, the soils transition gradually into weathered bedrock at depths of roughly 8 to 10 ft below ground surface (bgs), and to competent bedrock at an average depth of 15 ft bgs.

Groundwater in the vicinity of Area A occurs primarily within the underlying bedrock units. Groundwater is encountered in discrete fractures within the rock matrix, and interconnected networks of fractures within the bedrock serve as the primary groundwater migration pathways. Within the bedrock, the sandstone units function as the primary water-transmitting units, and the fine-grained mudstone units act as semi-confining layers to groundwater flow. Both sandstones and mudstones are fractured to varying degrees; however, fractures in the sandstones tend to have higher yields and, as a result, the sandstone units act as preferential zones of groundwater flow. Figure 3 presents a geologic cross section through the Area A source area, and also shows the fractured yield zones in select wells completed in the vicinity of the source area at Area A, as identified during previous investigation activities.

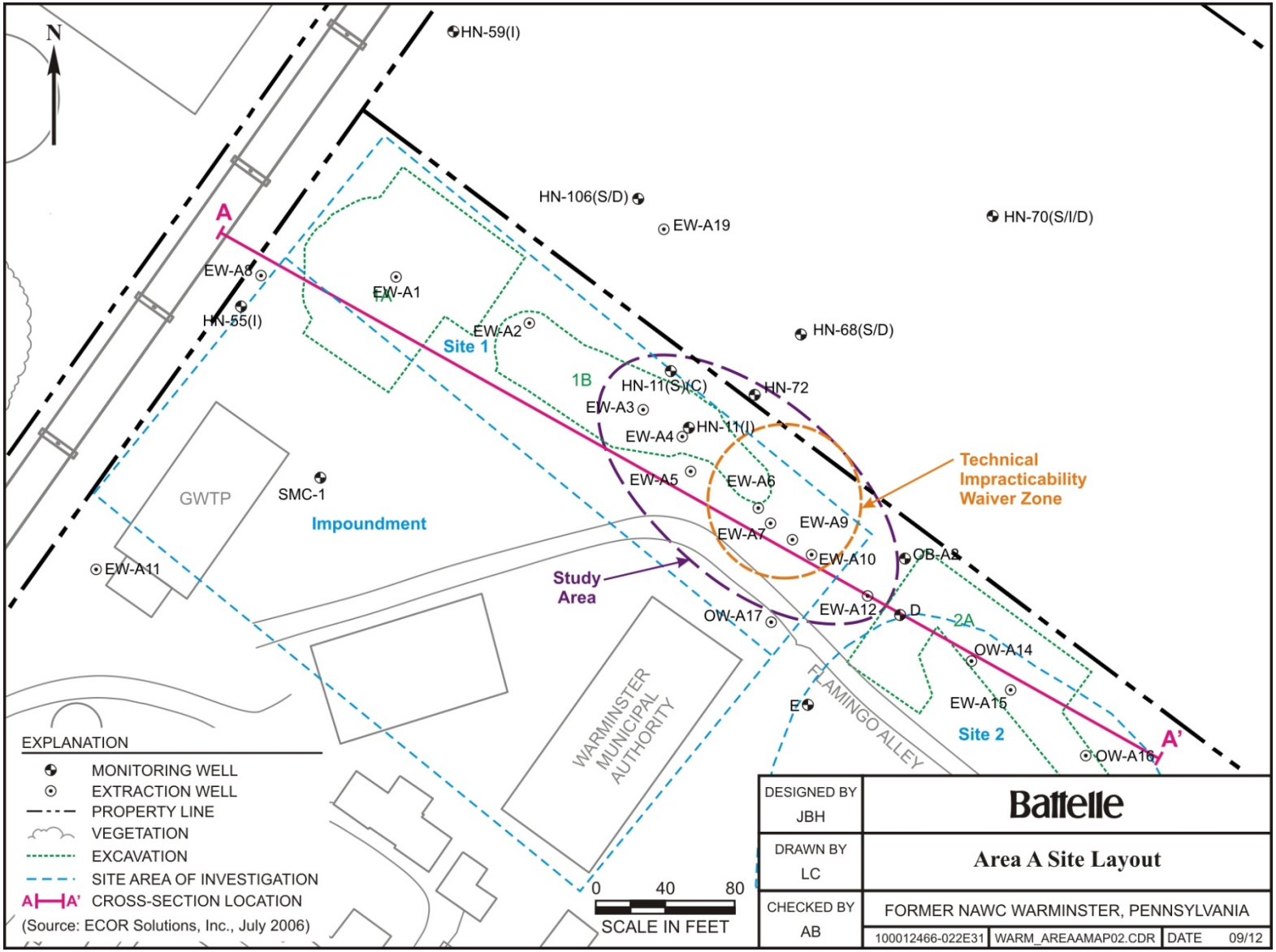

Figure 2. Area A Site Layout

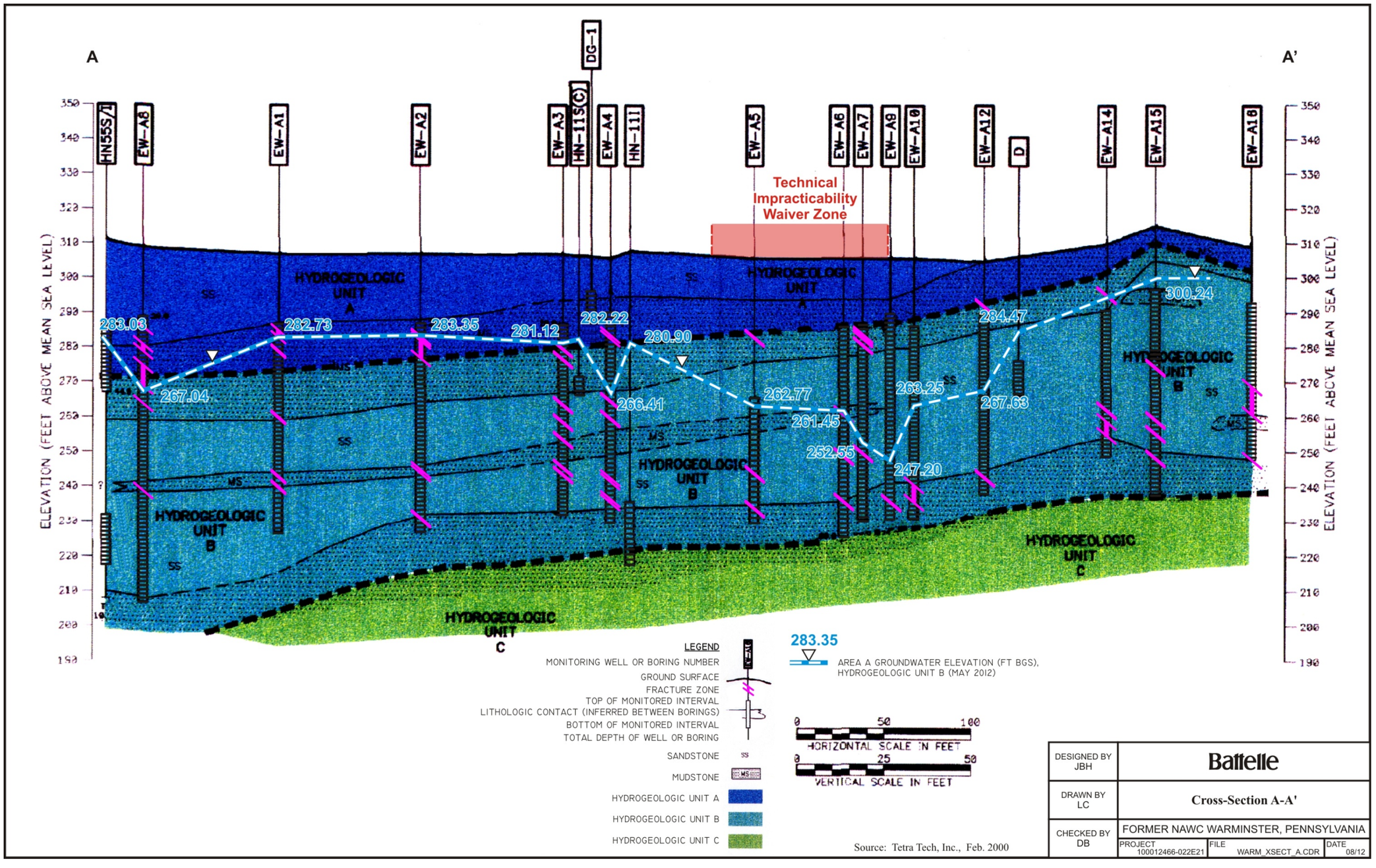

Figure 3. Geologic Cross Section from West to East across the Northern Edge of Area A (Tetra Tech NUS, Inc., 2000)

Groundwater at Area A has been divided into hydrogeologic units A, B, and C, representing sequential units with depth. Each hydrogeologic unit consists of one or more laterally extensive sandstone beds and adjacent mudstone units, which, based on hydrogeologic and water quality data, form an interconnected, discrete groundwater flow system. Figure 3 illustrates the presence of hydrogeologic units A, B, and C along an east-west cross section through the source area at Area A. Hydrogeologic unit B is the middle water-bearing unit and is the hydrogeologic unit of most importance in terms of groundwater contaminant occurrence and migration from Area A, and will serve as the target zone for source treatment in Area A. This hydrogeologic unit is comprised of the sandstone unit found at shallow depths and is generally found at depths of 15 to 100 ft bgs in Area A. Within Area A and in the near-downgradient area, the sandstone bed is locally split by a thin mudstone unit that pinches out further to the north and east. A potentiometric surface map created from groundwater elevations collected during May 2012 is presented in Figure 4. Groundwater flow within this unit is generally toward the north in Area A and has been significantly affected by operation of the groundwater extraction system. Operation of the groundwater extraction system has lowered the current water table to a depth below the shallow water-bearing fracture zone within the source area (Figures 3 and 4).

Historically, the majority of contamination has been present in hydrogeologic unit B; accordingly, the source area extraction wells are screened within this unit (see Figure 3). May 2012 TCE, PCE, and CCl_4 concentrations are presented in Figure 5. The most prevalent contaminant in the study area is TCE, and TCE is present at every well in the study area. TCE concentrations range from 0.17 (estimated) to 18,000 µg/L with an average of 1,850 µg/L and a median of 83.5 µg/L. The median and mean are considerably different because four of the wells in the study area exceed 1,000 µg/L (EW-A6, EW-A7, EW-A9, and HN-11I), thus skewing the mean. TCE was detected at concentrations exceeding its MCL (5 µg/L) at 12 of the 16 wells in the study area. Concentrations of TCE in GWETS extraction wells in the study area have been decreasing since the system was first installed in 1999.

In addition to TCE, concentrations of PCE and CCl_4 exceeded their MCLs (both are 5 µg/L) at a total of three and seven wells, respectively, screened in hydrogeologic unit B. The average concentration of PCE in the study area is roughly 10.8 µg/L, with a maximum concentration of 62 µg/L (EW-A6). All of the wells where the concentration of PCE exceeded the MCL were within the vicinity of the row of Area A extraction wells. The average concentration of CCl_4 in the study area is 20 µg/L, with a maximum of 140 µg/L (estimated) at EW-A6. All of the wells where the concentration of CCl_4 exceeded the MCL are within the vicinity of the row of Area A extraction wells.

2.1.2 Remedial Activities. Several remedial actions have been completed to address impacted soil and groundwater within Area A. Those activities pertinent to this investigation and identified study area within this report are described below.

Operable Unit 9. Contaminated soils at Area A were designated as Operable Unit 9 (OU 9) under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). In 1999, a soil excavation removal occurred in Area A (Sites 1, 2, and 3) to address the contaminated soil. A human health risk assessment and ecological risk screening were performed to determine potential risks to humans and environmental receptors from surface and subsurface soil at Area A, and cleanup goals were calculated. Excavations occurred in two locations at Site 1, one of which (Excavation 1B) lies adjacent to and within the proposed study area, with a small portion present within the TI waiver zone at Area A. After the excavations were completed, additional sampling and excavation were conducted until remedial cleanup goals were met. The result of each excavation was that there were no further human health risks given reasonably anticipated future commercial/industrial land uses. In June 2000, the Navy and U.S. Environmental Protection Agency (U.S. EPA) issued a ROD for OU 9, which found that no further action was necessary to address soil in Area A.

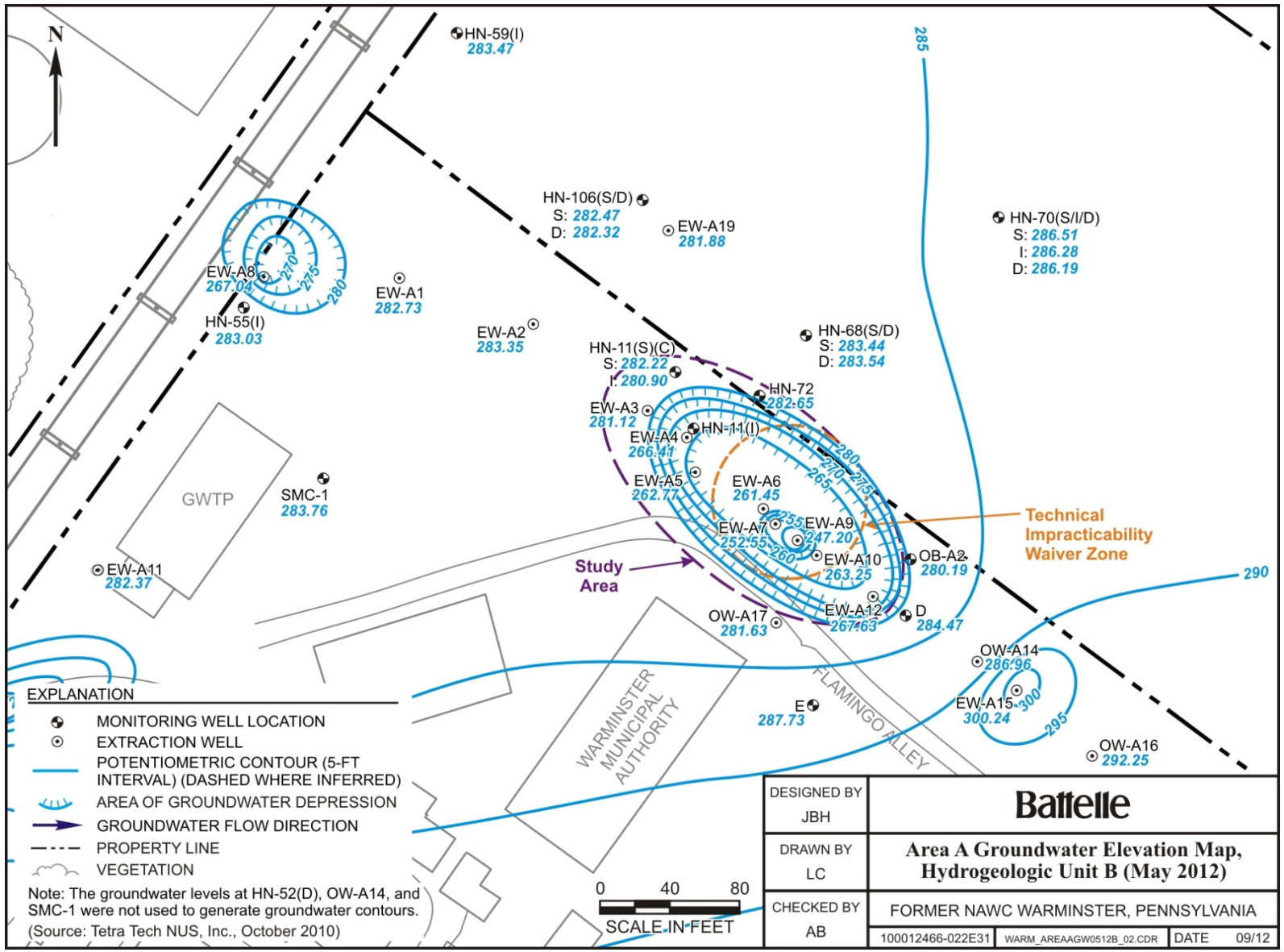

Figure 4. May 2012 Area A Groundwater-Level Elevation Map for Hydrogeologic Unit B

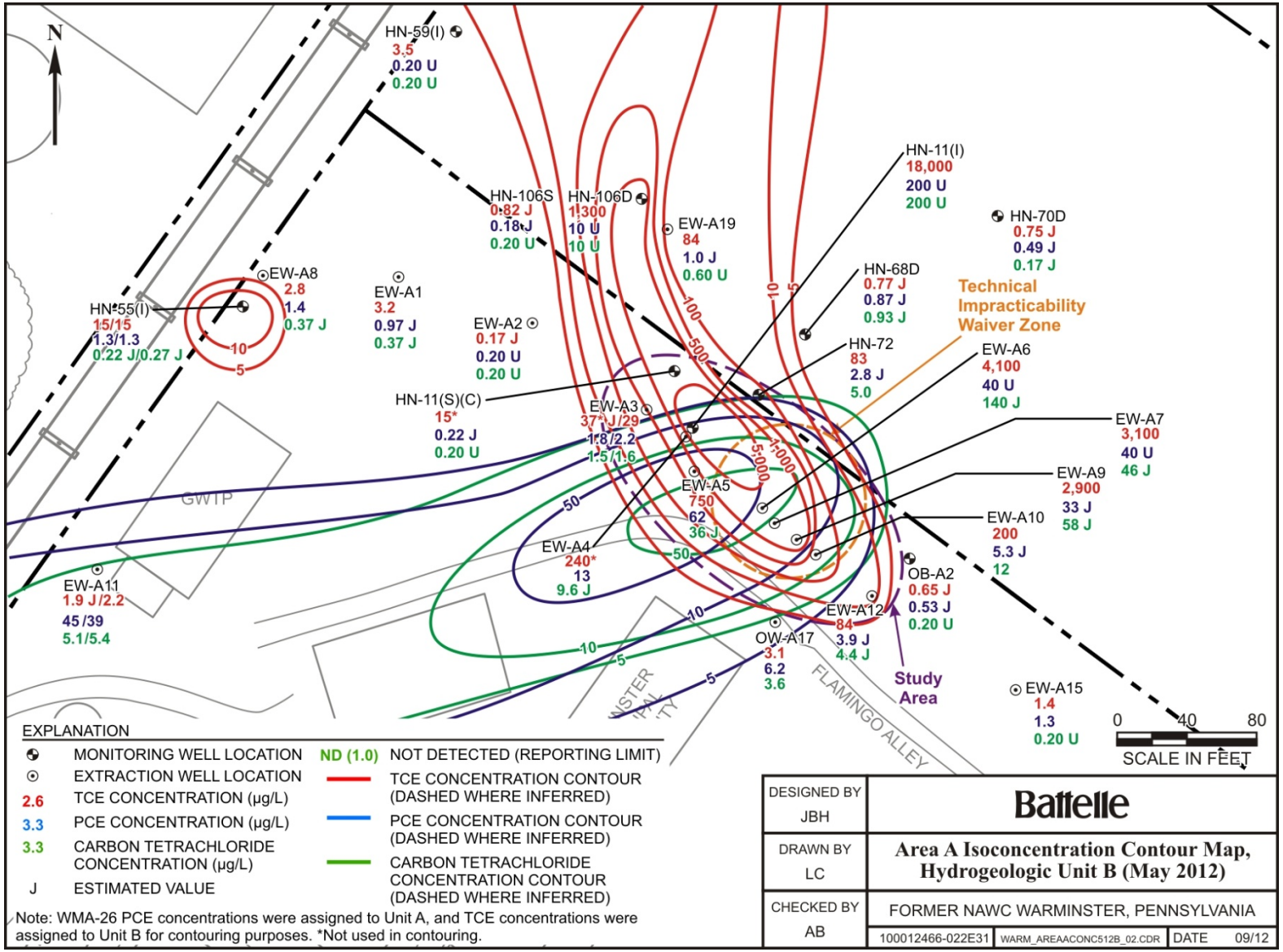

Figure 5. May 2012 Area A Dissolved TCE, PCE and CCl_4 Concentrations in Groundwater in Hydrogeologic Unit B

Operable Unit 1A. Groundwater also was identified as a media of concern at Area A and designated as OU 1A under CERCLA. The remedial action objective stated in the ROD for OU 1A is to restore contaminated groundwater to a level that is protective of human health and the environment and consistent with drinking water standards and to prevent downgradient migration to municipal production well WMA-26. However, these remedial action objectives are waived for TCE, PCE, and CCl_4 within the TI waiver zone. MCLs for other chemicals of concern (COCs) must be met within the TI waiver zone, and the ROD requires that contamination and DNAPL inside of the TI waiver zone be contained. The ROD specifies groundwater extraction and treatment as the remedial action, and also includes the use of institutional controls (ICs) to prevent the use of Area A groundwater as long as it presents an unacceptable risk, and to protect the integrity and effectiveness of the extraction well network. The ICs include the use of deed restrictions for property transferred from NAWC Warminster, and the use of municipal ordinances to restrict well drilling on private properties.

Implementation of the groundwater extraction and treatment began in 1999 in Area A. By design, and as stated in the Area A ROD, the diffuse contaminant plume not contained by the extraction well network in Area A is captured by the downgradient Warminster Municipal Authority (WMA) supply well (WMA-26). The current Area A GWETS includes a total groundwater extraction rate of approximately 53 gallons per minute (gpm) from 12 active extraction wells, and treatment for VOCs using an air stripper and liquid-phase granular activated carbon (LGAC). Although not identified as a COC, ion exchange treatment is also included for hexavalent chromium based on the GWETS discharge limits identified in the National Pollution Discharge Elimination System (NPDES) permit. An evaluation of the historical groundwater concentration trends estimated that the current GWETS will be operational for an additional 34 to 48 years to reduce TCE concentrations below the MCL in the source area. However, if source area treatment is applied, it is estimated that the GWETS would need to continue operation for an additional 15 to 25 years after treatment to reduce TCE concentrations below the MCL (Battelle, 2011).

2.1.3 Study Area. As part of this work, a study area was defined that includes wells surrounding the proposed treatment area. The study area was selected to include wells with elevated chemical concentrations, where well profiling can characterize the chemical distribution within the open screen or the borehole and better define the source area treatment zone to provide additional information for designing the pilot- and full-scale source area treatment approach. This study area is outlined in Figure 2, and includes the eight wells that will be profiled as part of this investigation: extraction wells EW-A3, EW-A4, EW-A5, EW-A6, EW-A7, EW-A9, EW-A10, and EW-A12, and monitoring well HN-72.

2.2 Approach

This section provides the approach for extraction and monitoring well profiling within the Area A study area, which will include Area A extraction well shut off, pump removal, groundwater-level elevation monitoring, borehole flow measurements, and groundwater sampling using passive diffusion bag (PDB) samplers, followed by subsequent reinsertion and startup of extraction well pumps. The wells included in the well-profiling investigation are summarized in Table 1, and include extraction wells EW-A3, EW-A4, EW-A5, EW-A6, EW-A7, EW-A9, EW-A10, and EW-A12, and monitoring well HN-72.

Field activities associated with the well profiling activities, including groundwater-level monitoring, groundwater sampling, field sampling documentation, investigation-derived waste (IDW) disposal, laboratory coordination, data quality assurance procedures, and data management, will be performed by H&S according to the standard operating procedures (SOPs) documented in the SAP (H&S, 2011). The borehole flow measurements will be collected by the USGS using a HPFM according to protocol established by the manufacturer and implemented by the USGS during historical borehole evaluations at Area C (USGS, 2008). It is further assumed that the field activities associated with the well profiling

Table 1. Area A Study Area Wells and PDB Sampler Configuration

Well ID	Top of Casing Elevation (ft amsl)	Estimated Static Water Depth[1] (ft btoc)	Screen Interval (ft btoc)	Screen Length (ft)	Pump Depth (ft btoc)	Fracture Depths (ft bgs)	May 2012 Concentration (µg/L)			No. of PDB Samplers	Approximate Midpoint Depth of PDB Samplers[2,3] (ft btoc)
							TCE	PCE	CCl_4		
EW-A3	306.87	9.42	25-75	50	NA	27, 30, 43, 48, 53, 61, 63	37 J	1.8	1.5	7	25.5, 33, 40, 45, 50, 59, 65.5
EW-A4	306.20	8.36	16-76	60	NA	22-23, 41, 46, 63-64, 69-70	240	13	9.6 J	7	19.5, 29, 38, 43, 52, 60.5, 66.5
EW-A5	305.77	6.32	16-76	60	69	23, 62, 72	750	62	36 J	8	20, 28, 36, 44, 52, 59, 64, 69
EW-A6	305.85	6.08	20-80	60	NA	45, 57, 70	4,100	ND	140 J	8	25, 33, 42, 48, 54, 60.5, 67, 72
EW-A7	305.60	5.75	20-75	55	65	22, 23, 25, 56	3,100	ND	46 J	8	20.5, 26, 31.5, 37, 45, 53, 60, 67
EW-A9	308.56	10.72	15-75	60	NA	70	2,900	33 J	58 J	8	22, 30, 36, 42, 48, 54, 61, 67
EW-A10	306.15	6.17	15-75	60	NA	65-67	200	5.3 J	12	7	21, 29, 38, 46, 52, 58, 63
EW-A12	305.37	4.72	27-67	40	59	13, 62	84	3.9 J	4.4 J	5	31, 38, 45, 52, 59
HN-72	308.10	NA	44-80	36	NA	NA	83	2.8 J	5.0	5	47, 53, 59, 65, 71

(1) Static water levels collected from extraction wells in September 2011 when the GWETS was not operating due to system maintenance for a period of 23 days.
(2) To calculate the fracture depths from below top of casing, the ground surface elevation was assumed to be 3 ft above the top of casing for extraction wells. For flush mount monitoring wells, PDB sampler depths were calculated based on the top of casing elevation.
(3) The placement of PDB samplers not associated with a historically identified fracture depth may be modified based on the identification of additional fractures detected during measurement of borehole flow conditions.

amsl = above mean sea level
btoc = below top of casing
bgs = below ground surface
NA = data not available
ND = not detected
J = estimated value

activities, as outlined below, will take place immediately following the November 2012 semiannual groundwater LTM event.

2.2.1 Extraction Well Shut Off and Pump Removal. All extraction wells in Area A will be shut off prior to profiling to allow groundwater levels in the study area to equilibrate to near static (ambient) conditions. All Area A extraction wells will remain off until all well profiling activities are complete, a period of roughly two weeks. The WMA will be notified in advance of the shutdown. The groundwater extraction well shut off will be performed by H&S according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009). To accommodate the groundwater sampling and borehole flow measurement activities, the pumps in the study area extraction wells (EW-A3, EW-A4, EW-A5, EW-A6, EW-A7, EW-A9, EW-A10, and EW-A12) will need to be removed according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009).

2.2.2 Groundwater-Level Elevation Monitoring. Groundwater-level elevations will be collected from each of the study area wells prior to extraction well shut off during the November 2012 LTM event. Profiling activities may begin once groundwater levels approach ambient conditions, after a period of approximately three days. As noted above, groundwater-level elevation monitoring will be performed by H&S according to SOP 005 as documented in the SAP.

2.2.3 Borehole Flow Measurements. Borehole flow measurements will be collected to determine the direction and rate of vertical groundwater movement within the study area extraction wells (EW-A3, EW-A4, EW-A5, EW-A6, EW-A7, EW-A9, EW-A10, and EW-A12). In fractured-rock investigations it is important to conduct flowmeter logging under non-pumping and pumping conditions; data collected under pumping conditions can be used to identify transmissive fracture zones with hydraulic heads that would not be identified without stressing the aquifer (USGS, 2011). Accordingly, a set of HPFM measurements will be made under both non-pumping and pumping conditions.

Once groundwater has returned to ambient conditions after extraction well shut off and the pumps have been removed, the non-pumping HPFM measurements will be collected to evaluate the natural groundwater flow within the borehole. The USGS will perform the HPFM measurements according to protocol established by the manufacturer and implemented during groundwater characterization activities conducted at Area C (USGS, 2008). The USGS will collect the borehole flow measurements using a Model #2293 HPFM (Mount Sopris Instrument Company, Inc.). HPFM measurements will be collected from each study area well at fracture depths (see Table 1), and at 5-foot increments across the entire length of the well screen to develop a vertical flow profile.

HPFM measurements under pumping conditions will be made immediately after the non-pumping measurements in each well. The range of flow measured by the HPFM is roughly 0.01 to 1.5 gpm in a 2- to 10-inch diameter borehole (USGS, 2011). Accordingly, each study area well will be independently pumped at a uniform low rate of approximately 1.5 gpm, keeping a constant drawdown. When the pumping rate is known, the relative contribution of each hydraulically active fracture can be determined. A small submersible pump will be deployed above the HPFM unit to extract groundwater during testing; all extracted water will be containerized and taken to the GWETS for treatment according to the IDW protocol established in the SAP. HPFM measurements will be collected at identical locations to those collected under non-pumping conditions. It should be noted that HPFM testing in screened wells is generally not preferred and results may be biased low.

2.2.4 Groundwater Sampling. Once groundwater levels have reached near ambient conditions after HPFM testing (approximately two to three days), groundwater sampling will be performed in study area wells using PDB samplers. As noted above, groundwater sampling will be performed by H&S according to SOP 004, as documented in the SAP. The proposed PDB sampler deployment depths for the study area wells are listed in Table 1. Historic static water elevations (see Table 1) suggest that the study area well screens will be fully saturated after the extraction wells are turned off. The PDB target sampling depths are focused on fracture zones identified during installation and testing of the Area A extraction wells (Foster-Wheeler Environmental Corporation, 1999). Each study area well will contain a minimum of five and a maximum of eight PDB samplers per well. If less than five fracture zones per well screen have been identified, PDB samplers will be evenly placed within all remaining screened intervals greater than 10 ft in length so that no screened interval of greater than 10 ft is left unmonitored. The placement of PDB samplers not associated with a historically identified fracture depth may be modified based on the identification of additional fractures detected during measurement of borehole flow conditions (see Section 2.2.3).

The PDB samplers will be deployed for a period of up to 7 days, after which they will be retrieved from the well for collection of groundwater samples.

2.2.5 Pump Reinsertion and Extraction Well Startup. Once all of the PDBs have been collected from the study area wells, the pumps will be reinserted into the extraction wells to the referenced depth by H&S according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009). After each pump has been installed, the extraction well will be activated to the pre-profiling pumping rate. WMA will be notified when all of the wells have resumed pumping.

2.2.6 Reporting. A detailed technical memorandum will be prepared describing the results of the well profiling and borehole flow activities. Validated analytical results from VOC analyses and vertical borehole flow measurements, in addition to chemical concentration and groundwater-level data collected during the GWETS performance monitoring event, will be used to determine the distribution of contaminants in groundwater within the source area. Existing geologic/hydrogeologic information will be used in conjunction with the borehole profiling results to identify which fracture zones within the source area have the highest contaminant concentrations to identify the target treatment zone for pilot- or full-scale treatment.

Section 3.0: AREA C WELL PROFILING ACTIVITIES

This section provides a brief description of the background conditions at Area C, including a discussion of the CSM and historical remedial actions. A detailed description of the CSM and remedial activities, as well as DQOs for the well profiling activities, can be found in the *Areas A and C Source Treatment Optimization Plan for the Former NAWC Warminster, Pennsylvania* (Battelle, 2012). In addition, this section documents the approach for well profiling and source area characterization activities at Area C.

3.1 Background

Area C is located along Kirk Road and Newtown Road in the north-central portion of the former NAWC Warminster (Figure 6), and was defined as Sites 4 and 8 and nearby locations where hazardous substance releases may have resulted in groundwater contamination. Several trenches at Site 4 were used to dispose of non-industrial solid waste, paints, waste oils, waste metals, construction debris, solvents, and sewage sludge from the sewage treatment plant, and Site 8 was used as a fire-training area. In addition, an area of the runway immediately south of the fire-training area was used to test the resistance of aviation suits to fire. The portion of Area C west of Site 8 has been transferred and redeveloped for residential use (a portion of Ann's Choice Retirement Community in the vicinity of Site 8 and other residential development west of Site 8). Other property adjacent to and in the vicinity of Site 4 is currently an open-space recreational park for Warminster Township.

Pump and treat was selected as the final groundwater remedy in Area C, and a GWETS was installed and began operation in 1996. The cleanup goals identified in the ROD are MCLs throughout Area C. Details regarding the GWETS are discussed in *Remedial Action Evaluation Report (*Battelle, 2011). An Explanation of Significant Differences also was signed for Area C, which adds ICs as an additional component of the remedy to prevent use of groundwater that presents an unacceptable risk to human health, and to protect the integrity and effectiveness of the extraction well network. The ICs include the use of deed restrictions for property transferred from the NAWC.

3.1.1 Current CSM. Historical investigations have shown that residual soils (mixtures of silt, clay, and sand) overlie highly weathered bedrock that starts at approximately 5 to 15 ft bgs. The weathered bedrock gradually transitions into competent bedrock of the Stockton Formation, which consists of alternating lithologic units of predominantly fine-grained gray to brown arkosic sandstone and red-brown siltstone/mudstone. Within Area C, bedrock strikes to the northeast and dips to the northwest. A comprehensive geophysical investigation was conducted by the USGS at Area C in 2007-2008 (USGS, 2008) to further describe the lithology at Area C and provide information about water-bearing fractures within the bedrock beneath the site. In general, the majority of bedrock fractures were identified between the depths of 21 to 40 ft, and the fractures became sparser as the depth increased. Geologic cross sections through Area C are presented in Figures 7 and 8.

Area C has been divided into shallow and deep hydrogeologic units. The shallow unit is comprised of sandstone and is the primary unit in which contaminant concentrations are observed. The deep hydrogeologic unit is defined as water-bearing bedrock beneath the shallow hydrogeologic unit, and typically exhibits artesian conditions. Shallow groundwater flow across Area C is to the north in the general direction of the slope of ground surface topography and has been affected by operation of the groundwater extraction system. A groundwater elevation contour map constructed using groundwater elevations collected during May 2012 is presented in Figure 9.

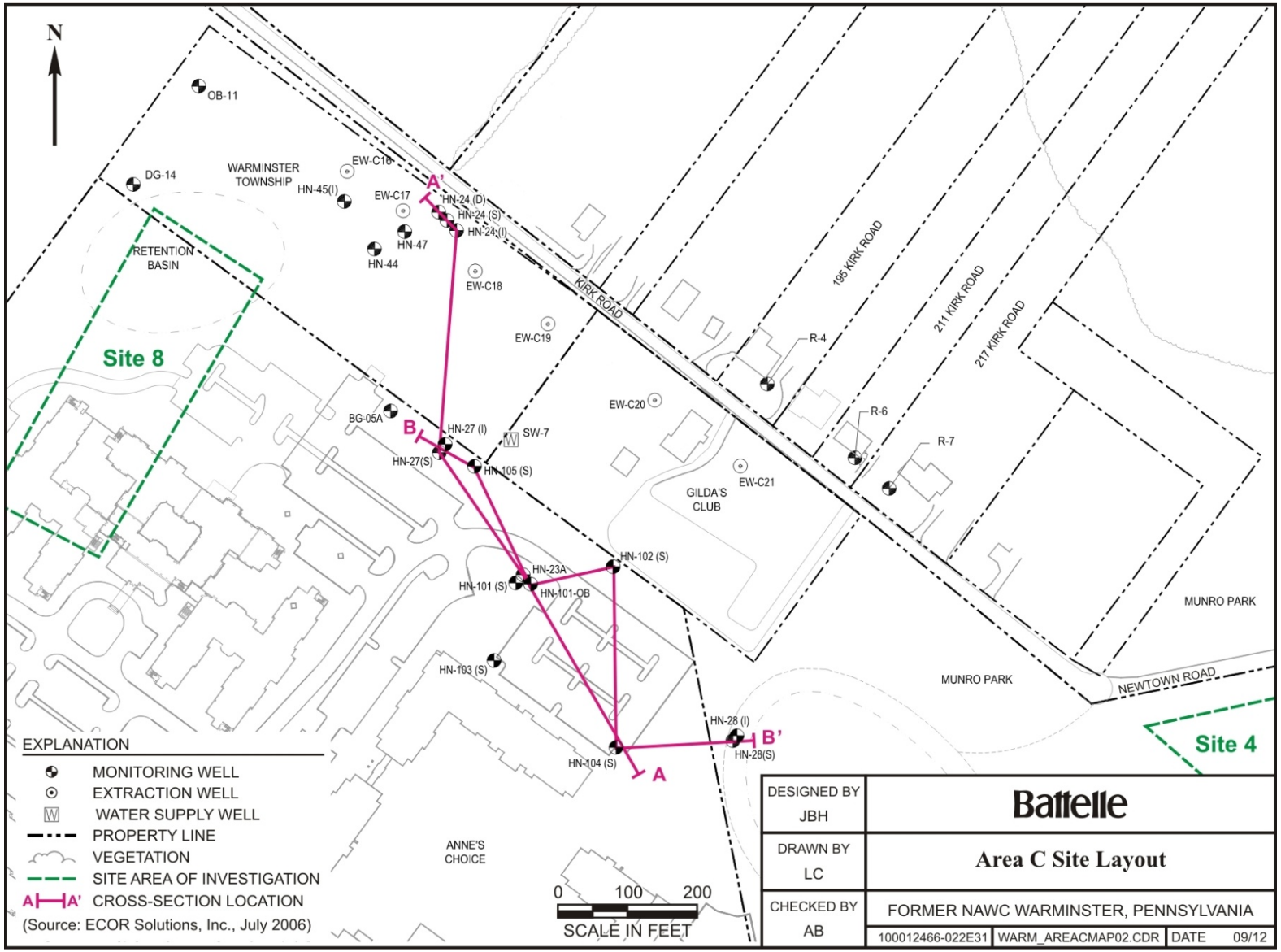

Figure 6. Area C Site Layout

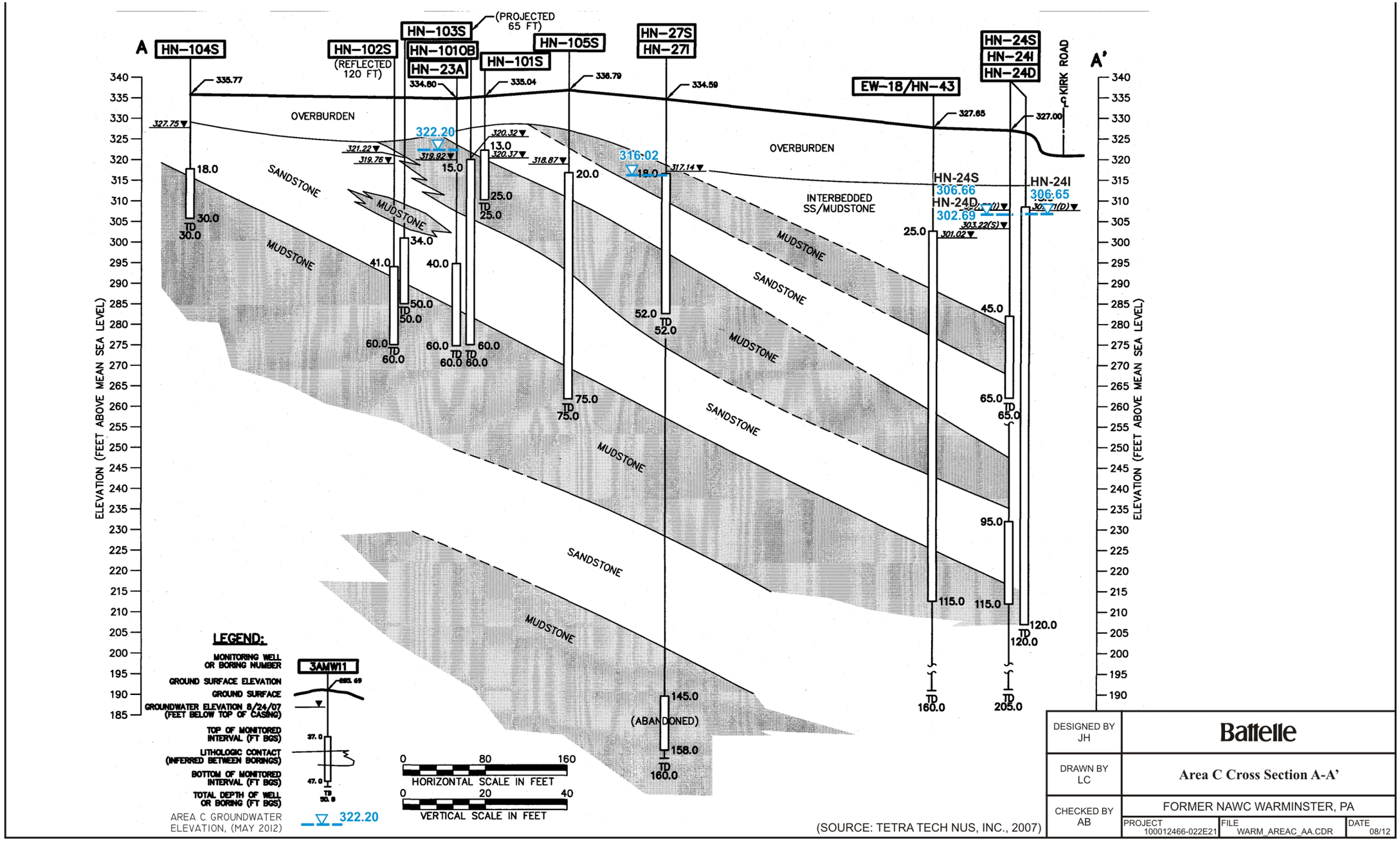

Figure 7. Area C Cross-Section A-A'

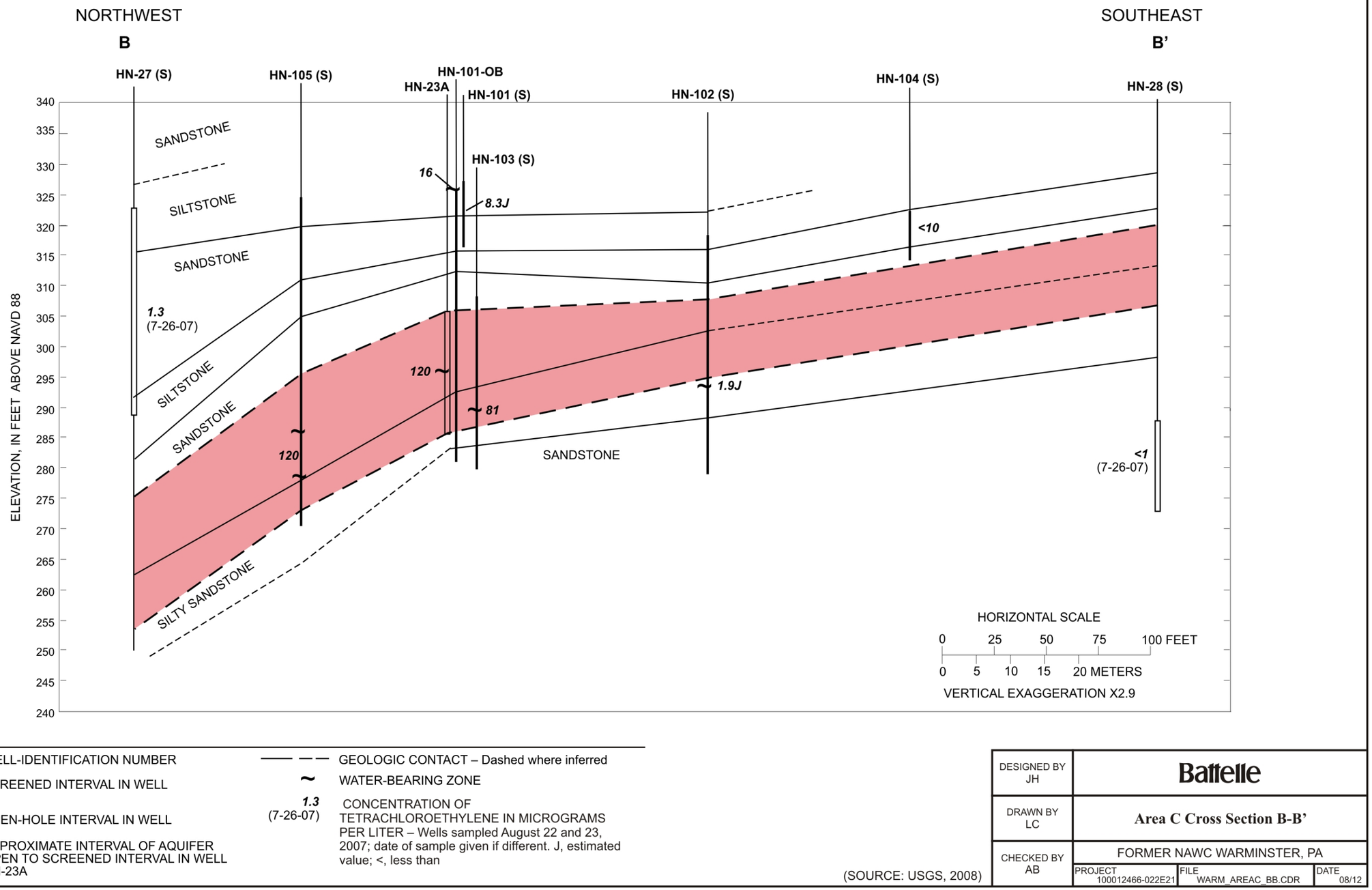

Figure 8. Area C Cross-Section B-B'

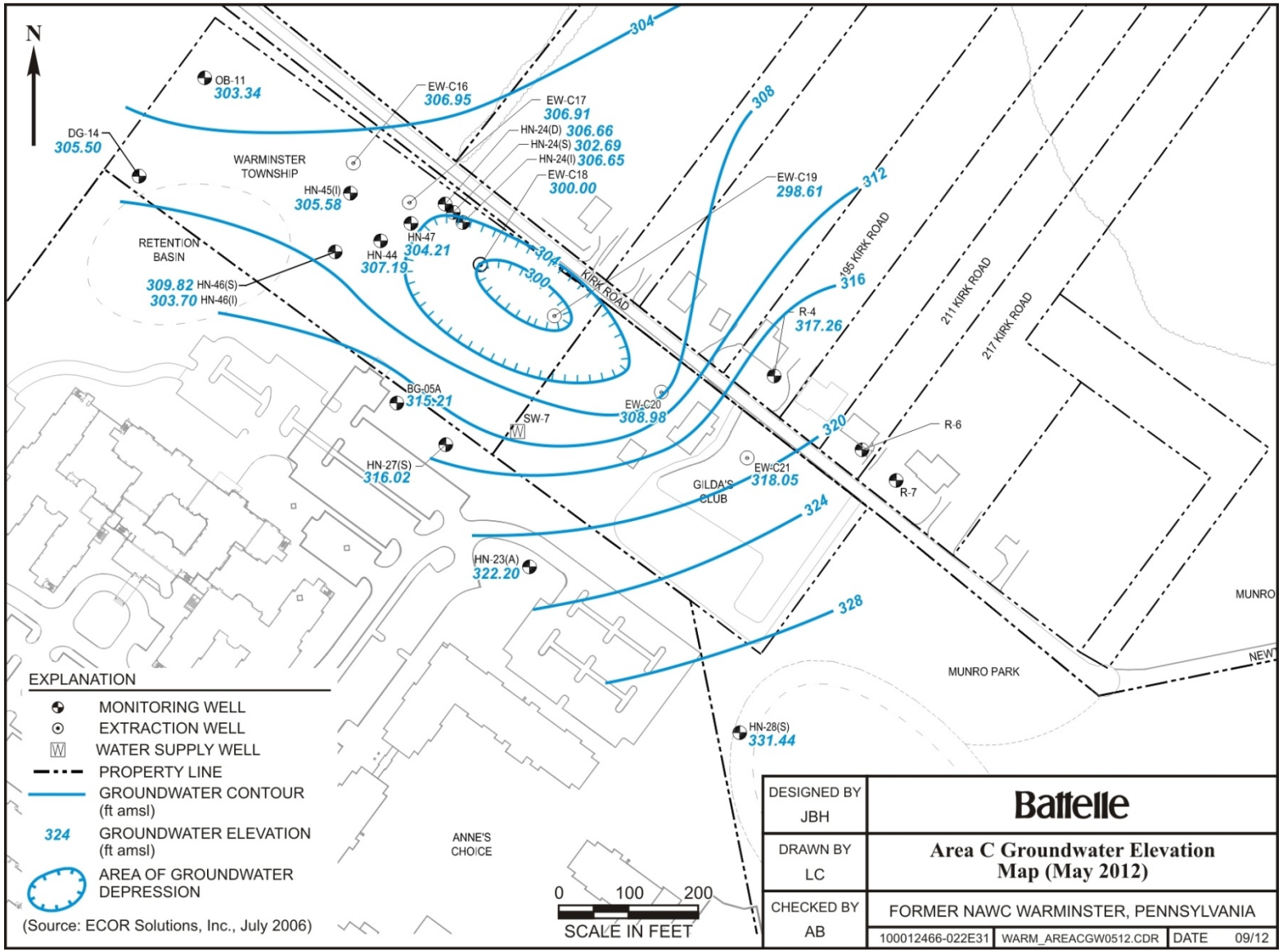

Figure 9. Area C Groundwater Elevation Map, Shallow Hydrogeologic Unit (May 2012)

Dissolved PCE is the main COC at Area C. The majority of contamination is found in shallow hydrogeologic unit wells at relatively shallow depths of less than 50 ft. Figure 10 illustrates an isoconcentration contour map for PCE in the shallow hydrogeologic unit at Area C during the May 2012 sampling event. The maximum PCE concentration of 65 µg/L was detected at HN-23A, which is approximately 400 ft from the nearest extraction well, indicating that a potential upgradient source of PCE contamination may still exist.

3.1.2 Remedial Activities. Several remedial investigations have been performed to identify the potential source for groundwater contamination at Area C. In addition to Sites 4 and 8, other areas of concern were also investigated, including the former maintenance area located immediately east of Site 8, the leach field associated with the former base commander's residence, and an old pistol firing range; however, none of these discrete investigations found significant levels of contamination or provided evidence suggesting a potential source for the PCE contamination in groundwater (Tetra Tech NUS, 2007).

The design of the extraction well system at Area C was developed by the NAWC Warminster Technical Evaluation Group (TEG), and has been optimized to prevent downgradient chemical migration and maximize mass removal. The current pumping rate of approximately 22 to 37 gpm is consistent with groundwater modeling data which suggested pumping at 27 gpm would contain the elevated groundwater contaminant concentrations.

In December 2002, monitoring well HN-23A was installed as a replacement monitoring well for HN-23S, which had been abandoned during construction of the Ann's Choice Retirement Community. Elevated PCE concentrations (up to approximately 300 µg/L) observed in this replacement well prompted a supplemental Area C source assessment investigation in 2007 (Tetra Tech NUS, 2007). The primary objectives of the Area C source assessment were to (1) delineate the extent of groundwater contamination in the vicinity of HN-23A, and (2) characterize any contaminant source areas identified.

Six monitoring wells were installed to delineate groundwater contamination in the vicinity of HN-23A, groundwater samples were collected, and an 8-hour aquifer pumping test was performed to better understand aquifer conditions. Results from the groundwater sampling conducted in conjunction with the pumping test indicated that PCE was detected in all but one of the newly installed wells, and TCE and dichloroethene (DCE) were detected in only two wells. The lack of TCE and DCE in other wells in the area indicate that neither TCE nor DCE were historically disposed of as waste products in this area (Tetra Tech NUS, 2007). The pattern of detected contamination, along with the northerly groundwater flow direction, suggested that the PCE is likely originating from an area south of HN-23A and newly installed well HN-103A (Tetra Tech NUS, 2007). A comparison of PCE concentrations collected from various aquifer depths during the study indicated that higher PCE concentrations are observed at deeper depths in this area, suggesting that the source of the contamination is not in the immediate vicinity of this well cluster, but is located some distance upgradient/updip (Tetra Tech NUS, 2007). Figure 8 illustrates that this deeper elevated PCE contamination is primarily confined within the sandstone/mudstone stratigraphic unit within which HN-23A is screened. Stratigraphic units above and below the screen interval of HN-23A contain lower concentrations of PCE.

A soil gas survey was also conducted in the vicinity of HN-23A as part of the investigation in an attempt to locate residual sources of PCE. A total of 60 sampling locations were selected surrounding HN-23A. Soil gas samples were field-analyzed for VOCs using a photoionization detector (PID), with a maximum reading of 1.5 parts per million. The pattern of low soil gas survey results did not indicate the local presence of a discrete source for the PCE contamination found in groundwater in this area (Tetra Tech NUS, 2007).

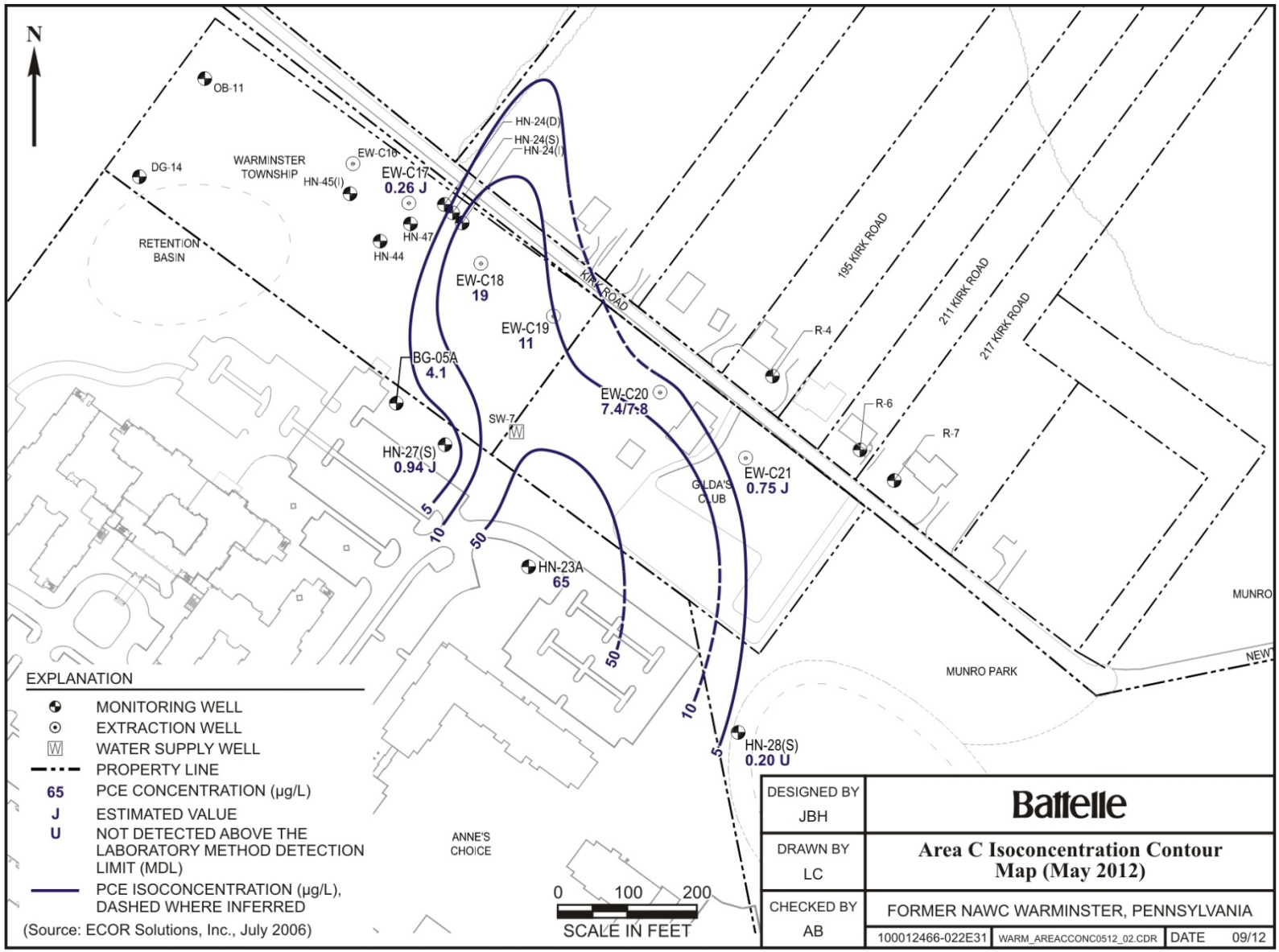

Figure 10. Area C PCE Isoconcentration Contour Map, Shallow Hydrogeologic Unit (May 2012)

3.1.3 Study Area. The study area was selected to include wells with elevated chemical concentrations, where well profiling can characterize the chemical distribution within the open screen of the borehole. In addition, wells were selected in the vicinity of Gilda's Club, so that the well profiling can provide information to evaluate the potential for vapor intrusion. The selected study area includes six wells that will be profiled as part of this investigation, including extraction wells EW-C18, EW-C19, EW-C20, and EW-C21, and monitoring wells HN-23A and HN-105S.

3.2 Approach

This section provides the approach for extraction and monitoring well profiling and source area characterization within the Area C study area, which will include Area C extraction well shut off, pump removal, groundwater-level elevation monitoring, borehole flow measurements, and groundwater sampling using PDB samplers, and subsequent extraction well pump reinsertion and startup. The wells included in the well-profiling investigation are summarized in Table 2, and include extraction wells EW-C18, EW-C19, EW-C20, and EW-C21, and monitoring wells HN-23A and HN-105S.

Field activities associated with the well profiling activities, including groundwater-level monitoring, groundwater sampling, field sampling documentation, IDW disposal, laboratory coordination, data quality assurance procedures, and data management, will be performed by H&S according to the SOPs documented in the Final SAP (H&S, 2011). The borehole flow measurements will be collected by the USGS using a HPFM according to protocol established by the manufacturer and implemented by the USGS during historical borehole evaluations at Area C (USGS, 2007). It is further assumed that the field activities associated with the well profiling and source area characterization activities, as outlined below, will take place immediately following the November 2012 semiannual groundwater LTM event.

3.2.1 Extraction Well Shut Off and Pump Removal. All extraction wells in Area C will be shut off prior to groundwater sampling to allow groundwater levels in the study area to equilibrate to near static (ambient) conditions. The WMA will be notified in advance of this work. The groundwater extraction well shut off will be performed by H&S according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009). The extraction wells will remain off until profiling activities are complete, a period of roughly three weeks. To accommodate the groundwater sampling and borehole flow measurement activities, the pumps in the study area extraction wells (EW-C18, EW-C19, EW-C20, and EW-C21) will be pulled according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009).

3.2.2 Groundwater-Level Elevation Monitoring. Groundwater-level elevations will be collected from each of the study area wells prior to extraction well shut off during the November 2012 LTM event. Profiling activities may begin once groundwater levels approach ambient conditions, after a period of approximately three days. As noted above, groundwater-level elevation monitoring will be performed by H&S according to SOP 005 as documented in the SAP.

3.2.3 Borehole Flow Measurements. Borehole flow measurements will be collected to determine the direction and rate of vertical groundwater movement within the study area extraction wells (EW-C18, EW-C19, EW-C20, and EW-C21). As discussed in Section 2.2.3, it is important to conduct flowmeter logging in fractured rock investigations under non-pumping and pumping conditions. Accordingly, a set of HPFM measurements will be made under both non-pumping and pumping conditions.

Table 2. Area C Study Area Wells and PDB Sampler Configuration

Well ID	Top of Casing Elevation (ft amsl)	Estimated Static Water Depth[1] (ft btoc)	Screen Interval (ft btoc)	Screen Length (ft)	Pump Depth (ft btoc)	Water Bearing Fracture Depths (ft bgs)	May 2012 PCE Concentration (µg/L)	No. of PDB Samplers	Approximate Midpoint Depth of PDB Samplers[3,4] (ft btoc)
EW-C18	323.65	25.14	25-115	90	NA	NA	19	9	27, 37, 47, 57, 67, 77, 87, 97, 107
EW-C19	325.06	27.52	25-100	75	NA	NA	11	7	27, 37, 47, 57, 67, 77, 87
EW-C20	326.63	20.85	18-83	65	46	NA	7.4	6	20[5], 25, 30, 40, 50, 60, 70
EW-C21	324.25	8.14	25-70	45	42	NA	0.75 J	2	10[5], 15
HN-23A	336.85	14.60[2]	40-60	20	NA	47	65	4	40.5, 44, 49, 54
HN-105S	336.46	17.59[2]	20-75	55	NA	29, 36, 43, 58, 70	NA	5	26, 33, 40, 55, 67

(1) Static water levels collected from extraction wells in September 2011 when the GWETS was not operating due to system maintenance for a period of 23 days. However, shallower historic water levels in Area C wells were reported in June 2008, all of which were above the top of the screened interval.

(2) Estimated static water levels collected after well completion in August 2007.

(3) To calculate the fracture depths from below top of casing, the ground surface elevation was assumed to be 3 ft above the top of casing for extraction wells. For flush mount monitoring wells, PDB sampler depths were calculated based on the top of casing elevation.

(4) The placement of PDB samplers not associated with a historically identified fracture depth may be modified based on the identification of additional fractures detected during measurement of borehole flow conditions.

(5) The shallowest PDB sampler will be deployed 2 ft below the groundwater interface, as measured immediately prior to deployment. The second PDB sampler will be placed 5-ft below the top sampler. In EW-C20, successive samplers will be placed at 10-ft increments.

NA = data not available

ND = not detected

J = estimated value

Once groundwater has returned to ambient conditions after extraction well shut off, and the pumps have been removed, the non-pumping HPFM measurements will be collected to evaluate the natural groundwater flow within the borehole. The USGS will perform the HPFM measurements according to protocol established by the manufacturer and implemented during groundwater characterization activities conducted at Area C (USGS, 2008). The USGS will collect the borehole flow measurements using a Model #2293 HPFM (Mount Sopris Instrument Company, Inc.). HPFM measurements will be collected from each study area well at fracture depths (see Table 2), and at 5-foot increments across the entire length of the well screen to develop a vertical flow profile.

HPFM measurements under pumping conditions will be made immediately after the non-pumping measurements in each well. Each study area well will be independently pumped at a uniform low rate of approximately 1.5 gpm, keeping a constant drawdown. A small submersible pump will be deployed above the HPFM unit to extract groundwater during testing; all extracted water will be containerized and taken to the GWETS for treatment according to the IDW protocol established in the SAP. HPFM measurements will be collected at identical locations to those collected under non-pumping conditions. It should be noted that HPFM testing in screened wells is generally not preferred and results may be biased low.

This vertical borehole flow measurement approach was performed in Area C study area well HN-105S during groundwater characterization activities conducted at Area C in 2007 (TetraTech NUS, 2007; USGS, 2008). HPFM measurements were made at 29, 36, 43, 58, and 70 ft bgs under non-pumping and pumping conditions. No vertical borehole flow was measurable under non-pumping conditions; when the well was pumped at 0.7 gpm, the fracture at 70 ft bgs produced all the water.

3.2.4 Groundwater Sampling. Once groundwater levels have reached near ambient conditions after HPFM testing (approximately two to three days), groundwater sampling will be performed in study area wells using PDB samplers. As noted above, groundwater sampling will be performed by H&S according to SOP 004 as documented in the SAP (H&S, 2011). The proposed PDB sampler deployment depths for the study area wells are listed in Table 2. Historic groundwater elevations (see Table 2) suggest that the study area well screens will be fully saturated after the extraction wells are turned off. The PDB target sampling depths in the two study area monitoring wells are focused on fracture zones identified during source area characterization activities conducted at Area C in 2007 (USGS, 2008). Each study area monitoring well will contain a maximum of five PDB samplers per well. If less than five fracture zones per well screen have been identified, PDB samplers will be evenly placed within all remaining screened intervals. PDB samplers will be placed in the study area extraction wells at 10-ft intervals, beginning 5 ft below the top of the screened interval. In addition, a PDB sampler will be placed 2 ft below the top of the measured water column in EW-20 and EW-21 to monitor shallow groundwater within the well and the potential for vapor intrusion from chemical concentrations in the shallow groundwater. The placement of PDB samplers will be modified based on the identification of additional fractures detected during measurement of borehole flow conditions (see Section 2.2.3).

The PDB samplers will be deployed for a period of up to 7 days, after which they will be retrieved from the well for collection of groundwater samples.

3.2.5 Pump Reinsertion and Extraction Well Startup. Once all of the PDBs have been collected from the study area wells, the pumps will be reinserted into the extraction wells to the referenced depth by H&S according to procedures established in the GWETS Operations and Maintenance Manual (Tetra Tech NUS, 2009). After each pump has been installed, the extraction well will be activated to the pre-profiling pumping rate. WMA will be notified when all of the wells have resumed pumping.

3.2.6 Reporting. A detailed technical memorandum will be prepared describing the results of the well profiling and borehole flow activities. Validated analytical results from VOC analyses and vertical borehole flow measurements, in addition to chemical concentration and groundwater-level data collected during the GWETS performance monitoring event, will be used to determine the distribution of contaminants in groundwater in the profiled wells. Existing geologic/hydrogeologic information will be used in conjunction with the borehole profiling results to identify which fracture zones within the source area have the highest contaminant concentrations with the goal of optimizing mass removal with the extraction well.

The evaluation also will include a discussion of where the plume is present at the water table surface, and how this could affect the potential for vapor intrusion into nearby structures. As part of this evaluation, a risk-based concentration (RBC) for PCE will be calculated using the U.S. EPA Johnson & Ettinger model for groundwater (Version 3.1, 2004). The Johnson & Ettinger model has a function that calculates RBCs in groundwater that are associated with acceptable risks for exposure to VOCs in indoor air using a substituted target risk level of 1×10^{-6}.

Section 4.0: REFERENCES

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H&S Environmental, Inc. 2011. *Final Sampling and Analysis Plan (Field Sampling Plan and Quality Assurance Project Plan) for Long-Term Groundwater Monitoring at Operable Units 1A, 3, and 4, Former Naval Air Warfare Center, Warminster, Pennsylvania*. October.

Tetra Tech NUS, Inc. 2009. Operations and Maintenance Manual for the Interim Remedial Groundwater Treatment System. June.

Tetra Tech NUS, Inc. 2007. *Area C Source Assessment Report, Former Naval Air Warfare Center Warminster, Warminster, Pennsylvania.* December.

United States Geological Survey (USGS). 2008. *Interpretation of Borehole Geophysical Logs at Area C, Former Naval Air Warfare Center, Warminster Township, Bucks County, Pennsylvania, 2007.* Open-File Report 2008-1207.

United States Geological Survey (USGS). 2011. http://water.usgs.gov/ogw/bgas/flowmeter/.

ATTACHMENT 1

COMMENT RESPONSE FORM

Author	Section	Comment	Response
JO	General	Was any thought given to profiling/testing wells HN-11I and HN-106D in Area A? They have contaminant concentration much higher than are now seen at EW-A12 and HN-72, which are in the testing program. Two things to consider r.e. testing 11I and 106D: they have limited screen intervals and are 2-inch diameter wells.	HN-11I was not selected because it has only 15 ft of screen at the base of the targeted treatment zone, and was profiled using 3 PDB samplers (one per 5-ft of screen) during the initial PDB sampling event. HN-72 was selected in its stead because it has 36-ft of screen that spans a majority of the target treatment zone. HN-72 also was profiled using PDB samplers during the initial PDB sampling event, but only 3 PDB samplers were so the profile was not as complete as we are proposing. HN-106D was not selected because although it would be interesting information, the well lies outside our target treatment zone. Text was updated to indicate that data collected from these wells during the performance monitoring event will be considered when evaluating the well profiling data.
JO	2.2.4 3.2.4	How soon will the PDBs be deployed for sampling after the wells recover from the HPFM testing under pumping conditions? It may be advisable to wait 2-3 days for well conditions to equilibrate, as immediately after the testing the VOC concentrations will be somewhat of a composite throughout the well	All PDBs will be deployed simultaneously following HPFM testing. PDBs will be deployed a minimum of 2-3 days after HPFM testing is complete. Text updated accordingly.
JO	Tables 1 and 2	Tables 1 and 2 - the footnote for the column r.e. fracture depths appears to be incorrect - I don't think a footnote is required there	Agree. The footnote from Tables 1 and 2 was removed.
JO	1.2	It would be useful to add a little text explaining the larger project goals and showing how this data will be used, i.e. per the Optimization Plan the data will be used to support sampling for bench-scale soil, rock core, and groundwater testing for a pilot-scale ISCO study	Agree with comment. Text in Section 1.2 was updated to indicate how data collected during implementation of this plan will be used to assist with the design of aggressive source treatment in Area A and plume refinement in Area C.
RS	2.2.1	Area A extraction wells should remain shut off while the PDB samplers are deployed. Turning on the extraction wells may cause flow in adjacent boreholes being monitored with PDB samplers and produce results that differ from those predicted by heatpulse-flowmeter measurements made while the extraction well system was shutdown. Conditions (all extraction wells shut off) should be kept constant throughout the entire well profiling study. This would eliminate the introduction of an extraneous variable. The approach for Area C (p. 22, sec. 3.2.1) does state that the Area C extraction wells will remain off during the entire profiling study. This would occur because the pumps will be removed from all the operating extraction wells.	Agree with comment. Text was updated accordingly to state that all Area A groundwater extraction wells will remain off through the duration of the well profiling activities. To minimize the time the extraction wells are not pumping, the PDB deployment time will be reduced from 14 to 7 days. The text in Sections 2.2.4 and 3.2.4 was updated to reflect the reduction in deployment time.

Author	Section	Comment	Response
RS	2.2.3 3.2.3	"*Accordingly, two sets of HPFM measurements will be made under non-pumping and pumping conditions*" could be interpreted as four sets of HPFM measurements, two sets under non-pumping and two sets under pumping conditions. "*A set of HPFM measurements will be made under both non-pumping and pumping conditions"* would be clearer.	Agree with comment. Text updated accordingly.