

1 **5.0 Contaminant Fate and Transport**

3 **5.1 Introduction**

4 Two major factors affecting the fate and transport of a chemical when released to the
5 environment are its mobility and its persistence. Mobility is a measure of the tendency for a
6 chemical to migrate through the environment and is affected by the physical/chemical
7 characteristics of the chemical. The major processes at work in the natural environment include:
8 aqueous solubility, volatilization, sorption, hydrolysis, photolysis, and oxidation rates.
9 Persistence, a measure of the time a chemical remains in the environment, is influenced by many
10 of the same factors affecting chemical mobility (e.g., photolysis, hydrolysis, and oxidation rates).
11 Persistence is also a function of chemical-biological interactions in the environment, such as
12 biodegradation and/or bioaccumulation.

14 Potential routes of transport and transport mechanisms that may be applicable to the
15 contaminants at Parcel 66(7) are presented and evaluated in Section 5.2. The persistence of
16 chemicals detected at the site and factors affecting the environmental fate and transport process
17 are presented in Section 5.3. Table 5-1 lists the physical and chemical properties of the organic
18 chemicals detected above ESVs or SSSLs at the site. Table 5-2 provides data on the distribution
19 coefficient for metals. Section 5.4 evaluates the direction and rate of contaminant migration at
20 Parcel 66(7) and includes Table 5-3, which summarizes the rate and distance of migration
21 estimated for organic chemicals cited in Table 5-1. Also included in Section 5.4 are geologic
22 cross sections of the site that show the vertical and horizontal distribution of total VOCs.

24 For the purposes of this RI report, only a qualitative evaluation of potential routes of migration,
25 contaminants of persistence, and contaminant migration is presented. Fate and transport
26 modeling were not included in the scope of work.

28 **5.2 Potential Routes of Migration**

29 Contaminants can be transported from their source(s) to other areas as a result of several
30 potential transport mechanisms and migration pathways. The migration of contaminants at a site
31 is dependent on factors that include 1) site characteristics such as soil and bedrock conditions,
32 groundwater and surface water conditions, and climatic conditions and 2) contaminant
33 characteristics. As part of the evaluation process for Parcel 66(7), potential migration pathways
34 to be considered are:

Table 5-1

**Physical and Chemical Parameters Affecting Environmental Fate and Transport of Selected* Organic Chemicals
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Compound	Molecular Weight (g/mole)	Water Solubility (mg/L@20C)	Vapor Pressure (mm Hg @20C)	Octanol-Water Partition Coefficient (Log K _{ow})	Adsorption Coefficient (Log K _{oc})	K _{oc} -Calc (mL/g)	Mobility	K _{oc} -Meas (mL/g)	Henry's Law Constant (atm-m ³ /mol)	Specific Gravity (g/cm ³)
Volatile Organic Compounds										
1,1-Dichloroethene	96.94 ^d	2.25 E+03 ^e	5.00 E+02	2.13 ^e	1.77 ^e	5.89E+01 ^e		6.50E+01 ^e	2.61 E-02 ^e	1.218 ^d
1,2-Dichloroethane	98.96 ^b	8.52 E+03 ^e	7.87 E+01 ^b	1.47 ^e	1.24 ^e	1.74E+01 ^e		3.80 E+01 ^e	9.79 E-04 ^e	1.2351 ^d
Cis-1,2-Dichloroethene	96.94 ^b	3.50 E+03 ^e	2.00E+02(35C) ^b	1.86 ^e	1.55 ^e	3.55 E+01 ^e		NA	4.08 E-03 ^e	1.2837 ^d
Trichloroethene	131.4 ^b	1.10 E+03(25C) ^b	6.9E+01 ^b	2.71 ^e	2.22 ^e	1.66 E+02 ^e	medium ^e	9.43 E+01 ^e	1.03E-02 ^b	1.4642 ^d
Vinyl Chloride	62.5 ^b	2.76 E+03(25C) ^e	2.66 E+03(25C) ^b	1.50 ^e	1.27 ^e	1.86 E+01 ^e		NA	2.70 E-02 ^e	0.9106 ^d
Semivolatile Organic Compounds										
Phenanthrene	178.2 ^f	1.2 ^f	6.80 E-04 (25C) ^f	4.45 ^f	4.15 ^f	NA		NA	2.56 E-05 ^f	0.980 ^d
Flouranthene	202.3 ^f	2.0 - 2.6 E-01 ^f	5.00 E-06 (25C) ^f	4.90 ^f	4.58 ^f	1.07E+05 ^e		4.91E+04 ^e	6.50 E-06 ^f	1.252 ^d
Pyrene	202.3 ^f	7.70 E-02 ^f	2.50 E-06 (25C) ^f	4.88 ^f	4.58 ^f	1.05E+05 ^e		6.80 E+04 ^e	1.14 E-05 ^f	1.271 ^d
Dibenz(a,h)anthracene	278.4 ^f	5.00 E-04 ^f	1.00 E-10 ^f	6.84 ^f	6.53 ^f	3.80 E+06 ^e		1.78 E+06 ^e	7.30 E-08 ^f	1.282 ^d
Benzo(a)pyrene	252.3 ^f	2.30 E-03 ^f	5.60 E-09 ^f	6.06 ^f	6.74 ^f	1.02 E+06 ^e		9.69 E+05 ^e	4.90 E-07 ^f	1.351 ^d
Benzo(b)fluoranthene	252.3 ^f	1.20 E-03 ^f	5.00 E-07 ^f	6.04 ^f	5.74 ^f	1.23 E+06 ^e		NA	1.22 E-05 ^f	NA
Indeno(1,2,3,-c,d)pyrene	276.3 ^f	6.20 E-02 ^f	1.00 E-06 to -11 ^f	6.58 ^f	6.20 ^f	3.47 E+06 ^e		NA	6.95 E-08 ^f	NA
Pesticides										
Endrin	380.92 ^d	2.50 E-01 ^e	2.00 E-07	5.06 ^e	4.09 ^e	1.23 E+04		1.08 E+04	7.52 E-06 ^e	1.65 ^d

* Chemical identified exceeding SSSLs or ESVs, as presented in Chapter 4.0.

References:

^a Howard, P.H. (1989)

^b Howard, P. H., (1990)

^c U.S. Environmental Protection Agency, (1986)

^d U.S. Environmental Protection Agency, (1992)

^e U.S. Environmental Protection Agency, (1996)

^f ATDSR, (1995a)

atm-m³/mol - Cubic meters per mole per atmosphere.

g/mole - Grams per mole.

g/cm³ - Grams per cubic centimeter.

K_{ow} - Octanol-water coefficient.

K_{oc} - Organic partitioning coefficient.

mg/L - Milligrams per liter.

mL/g - Milliliters per gram.

mm Hg - Millimeters of mercury.

NA - Not available.

Table 5-2

**Metals Distribution Coefficients, K_d
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Metal	K_d Geometric Mean	K_d Range	No. Values	Potential Groundwater Mobility
Antimony	45			Medium
Arsenic	200			Low
Arsenic (+3)	3.3	1.0-8.3	19	
Barium	60			Medium-Low
Beryllium	650			Low
Cadmium	6.4	1.26-26.8	28	Medium
Chromium	850			Low
Chromium (+3)	--			
Chromium (+6)	37	1.2-1800	18	Medium
Cobalt	47			Medium
Copper	35			Medium
Lead	900			Low
Manganese	65			Medium-Low
Mercury	10			Medium
Nickel	150			Low
Selenium	300			Low
Silver	46	10-1,000	16	Medium
Thallium	1,500			Low
Vanadium	1,000			Low
Zinc	38	0.1-8,000	146	Medium

K_d - Soil adsorption or distribution coefficient.

References:

- Baes and Sharp (1983)
- Baes et al. (1984)

Table 5-3

**Contaminant Migration Rates
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Contaminant	f _{oc}	K _{oc} (mL/g)	K _d	D _b (g/cm ³)	n	k (ft/day)	l (avg)	V (ft/day)	R _d	V _c (ft/day)	V _c (ft/yr)	Distance Migrated in 50 Years (ft)
Residuum												
1,1-Dichloroethene	0.006	65	0.39	1.6	0.4	0.0734	0.00908	0.002216	2.56	0.00087	0.32	15.8
1,2-Dichloroethane	0.006	38	0.228	1.6	0.4	0.0734	0.00908	0.002216	1.912	0.001159	0.42	21.15
Trichloroethene	0.006	94	0.564	1.6	0.4	0.0734	0.00908	0.002216	3.256	0.000681	0.25	12.42
Cis-1,2-Dichloroethene	0.006	35.5	0.213	1.6	0.4	0.0734	0.00908	0.002216	1.852	0.001197	0.44	21.84
Vinyl Chloride	0.006	18.6	0.1116	1.6	0.4	0.0734	0.00908	0.002216	1.446	0.001533	0.56	27.97
Bedrock												
Trichloroethene	0.015	94	1.41	2.43	0.2	0.0922	0.01271	0.007812	18.132	0.000431	0.16	7.86
Cis-1,2-Dichloroethene	0.015	35.5	0.5325	2.43	0.2	0.0922	0.01271	0.007812	7.4699	0.001046	0.38	19.09
Vinyl Chloride	0.015	18.6	0.279	2.43	0.2	0.0922	0.01271	0.007812	4.3899	0.00178	0.65	32.48

K_d, soil adsorption or distribution coefficient = (K_{oc})(f_{oc}); relation valid as long as solute present is at concentrations below about 1/2 of its solubility.

% organic carbon assumed at 0.6 % (f_{oc} = 0.006) EPA default for soils

% organic carbon assumed at 1.5% (f_{oc} = 0.015) for sedimentary rocks, Trask and Patnode, (1942)

V_c, average velocity of solute = V / R_d

V, average linear groundwater velocity = k (l) / n_e

l = horizontal hydraulic gradient

k = hydraulic conductivity

n_e = effective porosity = n - S, where S is specific retention or storativity

R_d, retardation coefficient = 1 + (K_d)(D_b/n)

D_b = bulk density g/cm³

D_b assumed for limestone @ 2.43 g/cm³

D_b assumed for shales @ 2.3 g/cm³

D_b assumed for sandstones @ 2.1 g/cm³

D_b assumed for residuum @ 1.6 g/cm³

n = total porosity

n assumed @ 40% for silts and clays

n_e estimated @ 30% for residuum, Walton (1988), Domenico and Schwartz (1990)

n assumed @ 20% for bedrock

n_e estimated @ 15% for limestone, Walton (1988), Domenico and Schwartz (1990)

avg - Average.

ft - Feet.

ft/day - Feet per day.

ft/yr - Feet per year.

g/cm³ - Grams per cubic centimeter.

mL/g - Milliliters per gram.

- Fugitive dust emissions and volatilization from soil
- Erosion and surface water runoff
- Surface water and sediment transport
- Infiltration and leaching from surface soils to subsurface soils to groundwater
- Transport within the groundwater flow system
- Discharge of groundwater to the surface
- Bioaccumulation.

5.2.1 Dust Emission and Volatilization

Site-related contamination could be released through volatilization into the air. This migration path would be limited primarily to volatile compounds in the surficial soil (0 to 2 feet). All of the potential source areas of contamination at Parcel 66(7) are located beneath asphalt. No major construction activities have occurred at the site, although contaminants adsorbed to surface soils could be released to the atmosphere through dust generated during construction activities. However, significant migration routes through volatilization or dust emissions to the air are not likely.

5.2.2 Erosion and Surface Water Runoff

Surface runoff has the potential to transfer contaminants either in a dissolved state or adsorbed to soil particulates or organic matter. Because the surface area of Parcel 66(7) is asphalt covered, erosion and surface runoff of adsorbed site-specific contaminants are not considered likely. Contaminant migration in a dissolved or adsorbed state would be more likely to result from the degradation of the asphalt covering the site. These compounds would likely be PAH compounds. Transport routes would follow local topography and any established site drainage systems.

5.2.3 Surface Water and Sediment Transport

There are no surface water bodies in the immediate vicinity of Parcel 66(7); therefore, surface water and sediment transport fate is not considered.

5.2.4 Leaching from Surface and Subsurface Soil to Groundwater

Migration of soil contamination via percolation of rainfall and subsequent entry of the leachate into the groundwater is considered the most probable route of contaminant migration at Parcel 66(7). Although the soil type present at Parcel 66(7) would allow infiltration of rainwater, the asphalt cover would significantly reduce the infiltration rate and the potential for vertical migration of the contaminants. Organic constituents presently found in the surface soils at the site are mainly PAHs and probably result from the degradation of the asphalt cover at the site.

1 The PAHs are restricted to surface soil and are present at elevated concentrations in only one of
2 the three surface soil samples. The PAH compounds identified as exceeding ESVs are:
3 benzo(a)pyrene, fluoranthene, phenanthrene, and pyrene. In addition, three other PAHs exceeded
4 SSSLs: dibenz(a,h)anthracene, benzo(b)fluoranthene and indeno(1,2,3-cd)pyrene. These
5 compounds have high molecular weight and low water solubilities; leaching of these compounds
6 to the groundwater is considered unlikely. However, these chemical characteristics may be
7 overridden by the strongly acidic nature of soils described for the site, and some leaching may
8 occur.

9
10 Three pesticides were detected in surface soils; only one, endrin, was detected at a concentration
11 above its ESV. Pesticides were not detected in the subsurface soil samples. Pesticides are
12 strongly adsorbed to soils and are not likely to leach to the groundwater.

13
14 Although VOCs were detected in surface and subsurface soil samples at Parcel 66(7), all but one
15 of the results were qualified as either estimated concentrations (“J” qualified) or present also in
16 the associated laboratory or field blank (“B” qualified). The results were at low concentrations
17 and none of the detected VOCs exceeded its SSSL or ESV. This may be interpreted as an
18 indication of an original limited release of volatiles, that degradation of volatiles has taken place,
19 or that leaching of contaminants from these media to the groundwater system has occurred.
20 Precipitation percolating through the soil in the unsaturated zone has partitioned contaminants
21 from the soil matrix into the leachate. The absence of significant concentrations of VOCs in the
22 upper soil profile and residuum may be considered as a qualitative indication of the relative ease
23 with which VOCs may partition.

24 25 **5.2.5 Groundwater Transport**

26 Contaminants in groundwater can be transported in either a dissolved phase or a soil-adsorbed
27 state. Soluble chemical constituents will be transported in the direction of groundwater flow.
28 At Parcel 66(7), however, the direction of groundwater flow is influenced by a localized ground
29 water divide. Little difference in groundwater elevation exists across the site, but enough of a
30 variation appears to be present to give weak north and south components to flow. Groundwater
31 flow direction is similar in the residuum and bedrock water-bearing zones. Calculations of the
32 vertical hydraulic gradients between residuum and bedrock are presented on Table 3-2. Head
33 differences between residuum and bedrock well clusters indicate that both upward and downward
34 weak gradients are present.

1 Soluble chemical constituents entering the groundwater system in either residuum or bedrock
2 would flow in the direction of groundwater movement. The rate of transport of these chemical
3 constituents in the residuum is determined, in part, by equilibrium partitioning between the
4 mobile aqueous phase and the soil particles of the residuum. The degree of partitioning in the
5 residuum is governed mainly by the organic matter content. Because organic matter content in
6 bedrock is naturally low, the degree of partitioning in bedrock is substantially less. At Parcel
7 66(7), release and transport to the groundwater system is the principal migration pathway and
8 mechanism of on-site contamination migration and potential off-site contaminant transport.
9

10 **5.2.6 Discharge of Groundwater to the Surface**

11 There are no groundwater discharges in the form of seeps, springs, or wetlands at Parcel 66(7).
12 No standing bodies of water, such as ponds, are present. Therefore, the fate of contaminant
13 discharge of groundwater to the surface is not considered.
14

15 **5.2.7 Bioaccumulation**

16 Many organic and inorganic chemicals have the potential to bioconcentrate and bioaccumulate in
17 plants and/or animals. This may occur through direct bioconcentration from an aqueous
18 medium, root uptake from soils to plants, ingestion of water, incidental ingestion of soils and
19 sediments, or ingestion of contaminated plants or animal prey as food sources. Discussion of
20 these pathways is presented in detail in Chapter 7.0.
21

22 **5.3 Contaminant Persistence**

23 Factors affecting environmental persistence and mobility processes are defined in this section.
24 These factors deal with the chemical and physical reactions that take place in the environment
25 and their effect on contaminant transport. Physical and chemical parameters affecting the
26 environmental fate and transport of site-related chemicals at Parcel 66(7) are presented in Table
27 5-1. The environmental fate and transport data for the chemicals detected at Parcel 66(7) are
28 discussed. The chemicals are divided into two groups: organic and inorganic. Organic
29 constituents are further divided where possible into groups that share similar characteristics.
30

31 **5.3.1 Chemical and Physical Processes Affecting Fate and Transport**

32 The most important fate and transport process for organic constituents detected at Parcel 66(7) is
33 likely to be aqueous solubility. The greater the solubility of an organic constituent, the greater
34 the potential for migration via groundwater transport. For inorganic constituents, the ability to

1 enter the groundwater transport system is largely determined by the distribution coefficient of the
2 chemical.

3
4 A number of measurable chemical parameters are used to determine the rate and extent of a
5 chemical process. The parameters include: aqueous solubility, Henry's Law constants, diffusion
6 coefficients, vapor pressures, adsorption/partitioning coefficients, and degradation rates. These
7 parameters can be used to estimate the quantity of contaminants that will go into solution, rates
8 of volatilization, rates of diffusion, quantity of contaminant adsorbed onto or desorbed from soil
9 particles, and rates of degradation.

10

11 **5.3.1.1 Aqueous Solubility**

12 Aqueous solubility is the maximum amount of a chemical that will dissolve in pure water at a
13 specified temperature. Solubilities of most organic compounds range from approximately 1 to
14 100,000 mg/L at ambient temperatures. As the solubility of a compound increases, so does the
15 likelihood the compound will go into the dissolved phase. Aqueous solubility is an important
16 determinant of chemical concentration and residence time in water. Highly soluble chemicals
17 readily dissolve in water and remain in solution; chemicals with low solubility tend to adsorb to
18 solids or form nonpolar phases.

19

20 **5.3.1.2 Volatilization**

21 Volatilization is the movement of a chemical from the surface of a liquid or solid matrix to a gas
22 or vapor phase. Volatilization losses to the air are related to the chemical concentration,
23 molecular weight, solubility, vapor pressure, and ambient temperature. The tendency for a
24 chemical to volatilize from water can be estimated from its Henry's Law constant, H (cubic
25 meters per mole per atmosphere [atm-m³/mol]). This measure relates the equilibrium
26 concentrations of a compound in the dissolved and vapor phases and is a constant at a given
27 temperature. H relates the partial pressure of a gas above a liquid and a mole fraction of the gas
28 dissolved in the liquid and affects the rate and extent of volatilization. Lyman et al. (1982)
29 classified compounds based on their H value as "readily" ($>10^{-3}$ atm-m³/mol), "significantly" (10^{-3}
30 to 10^{-5} atm-m³/mol), or "limitedly" ($< 10^{-5}$ atm-m³/mol) tending to volatilize from water.

31

32 **5.3.1.3 Diffusion**

33 Diffusion is the movement of contaminants as a consequence of a concentration gradient.
34 Contaminants diffuse from an area of higher concentration to an area of lower concentration;
35 diffusion will occur until equilibrium in concentration exists. The rate of diffusion increases

1 with temperature and decreases as the porosity of the medium increases. The chemical parameter
governing diffusion is the diffusion coefficient; as the diffusion coefficient increases, so does the
3 extent of contamination movement by diffusion.

5 5.3.1.4 Adsorption/Desorption

6 Adsorption/desorption is the binding to (adsorption) or release from (desorption) of a chemical to
7 a solid matrix (e.g., soils, sediments, and suspended solids). Partition coefficients are important
8 measures of sorptive characteristics and help define the relative concentrations of a given
9 chemical in two phases or matrices. Partition coefficients are expressed as concentration ratios
10 between two phases and include:

- 11
12 • Organic partitioning or adsorption coefficient, K_{oc} – Provides a measure of the
13 extent of chemical partitioning between organic carbon and water at equilibrium.
14 The greater the K_{oc} of a chemical, the more likely that chemical is to adsorb to soil
15 or sediment rather than remain dissolved in water.
- 16
17 • Soil adsorption or distribution coefficient, K_d – Provides a measure of the extent of
18 chemical partitioning between soil or sediment and water, unadjusted for
19 dependence on organic carbon. Adsorption coefficients are site specific and
20 specific to soil types. K_d can be normalized for organic carbon content by the soil
21 adsorption coefficient, K_{oc} , times the soil organic carbon content, f_{oc} , (mg of organic
22 carbon/mg soil). If site-specific values cannot be obtained, values can be estimated
23 from the organic carbon content, carbon content, and the octanol-water coefficient.
24 The higher the K_d value, the more likely a chemical is to bind to soil or sediment
25 rather than remain dissolved in water.
- 26
27 • The octanol-water partition coefficient, K_{ow} – Provides a measure of the extent of
28 chemical partitioning between water and octanol at equilibrium. The greater the
29 K_{ow} value, the more likely a chemical is to partition to octanol rather than remain in
30 water. K_{ow} can be used to estimate K_{oc} and to predict bioconcentration in living
31 organisms. Chemicals with a $\log K_{ow} < 2.5$ rarely bioaccumulate significantly in
32 plants or animals and have a high water solubility.

34 5.3.1.5 Degradation Rate

35 Degradation rate is a measure of the rate at which contaminants breakdown into other, simpler
36 compounds. Types of degradation rates can be broken into four categories: hydrolysis rates,
37 photolysis rates, oxidation/reduction rates, and biodegradation rates.

- 38
39 • Hydrolysis is the reaction of a chemical with hydrogen ions or the hydroxyl
radicals, resulting in the degradation or structural modification of the chemical.

1 The extent of a chemical's hydrolytic reaction is a function of the molecular
2 structure of the chemical and the pH of the environment.

- 3
- 4 • Photolysis is a chemical degradation process caused by sunlight. The rate of
5 degradation from photochemical reactions depends on the chemical's molecular
6 structure, the proximity and character of the radiant energy (light source), and the
7 presence of other reactive compounds.
- 8
- 9 • Oxidation/reduction is a chemical reaction in which a chemical either loses an
10 electron (oxidation) or gains an electron (reduction). Oxidation/reduction rates of
11 chemicals are significant, in that they influence both the environmental mobility
12 and fate of a chemical.
- 13
- 14 • Biodegradation is the biological transformation of organic compounds through
15 various reactions. The chemical processes that remove or transform compounds
16 can involve oxidation or reduction, depending on whether aerobic or anaerobic
17 conditions exist. The rate of biodegradation is influenced by numerous parameters
18 including, but not limited to, groundwater temperature, pH, dissolved oxygen,
19 organic matter content, and phosphate, sulfate, and nitrate concentrations.
- 20

21 **5.3.2 Contaminant Fate and Transport**

22 Contaminant fate and transport of VOCs, SVOCs, pesticides, and inorganic compounds are
23 discussed in the following sections.

24 **5.3.2.1 Volatile Organic Compounds**

25 VOCs were detected in all media sampled at Parcel 66(7), as summarized in Chapter 4.0. Six
26 VOCs were detected in surface soil samples, and six VOCs were detected in subsurface soil
27 samples. The VOC concentrations were below SSSLs and ESVs in surface soil and below
28 SSSLs in subsurface soil.

29

30

31 Twelve VOCs were detected in groundwater samples at the site. Of the VOCs detected, five
32 were detected at concentrations exceeding SSSLs: 1,1-DCE, 1,2-DCA, cis-1,2-DCE, TCE, and
33 vinyl chloride. Based on the physical and chemical characteristics of the compounds, they are all
34 grouped as chlorinated aliphatic hydrocarbons. Five additional chlorinated hydrocarbons were
35 detected in groundwater but at concentrations below SSSLs.

36

37 **Chlorinated Aliphatic Hydrocarbons.** The dominant fate process for chlorinated aliphatic
38 hydrocarbons in surface soil is volatilization to the atmosphere; however, these compounds were

1 not detected in this medium. These constituents, however, were detected in groundwater in both
2 residuum and bedrock monitoring wells.

3
4 Chlorinated hydrocarbons tend to have high solubility in water. The high solubilities are, in part,
5 due to their relatively low molecular weights and high polarity. The constituents tend to have a
6 low affinity for soils and are generally highly mobile. The log K_{oc} values are relatively low,
7 indicating that these chemicals have a low affinity for adsorption to organic matter or soil.
8 Transport in groundwater would thus be expected to be the dominant transport pathway. This
9 does not imply that there would not be soil-adsorbed VOCs but rather that, if associated with
10 soils at the site, they would be miscible and would have the potential to be a source for
11 groundwater contamination.

12
13 Chlorinated hydrocarbons are synthetic solvents used in many industrial activities (e.g.,
14 degreasers, dry-cleaning processes). Chlorinated solvents can occur in the environment directly
15 through product usage or as a by-product from the degradation of other solvents. It is reported
16 that small weapons were degreased in Building 335 using either 1,1,1-TCA or TCE. The main
17 portion of the building was reportedly used for tank repair, which may have also involved the use
18 of chlorinated solvents for degreasing parts.

19
20 The presence of cis-1,2-DCE and vinyl chloride in groundwater at the site likely indicates that
21 reductive dechlorination of a precursor solvent by microbial degradation under anaerobic
22 conditions has occurred. cis-1,2-DCE and vinyl chloride are among the common daughter
23 products of TCE. TCE in the groundwater is present through product usage. 1,2-DCA and 1,1-
24 DCA are likely degradation products of 1,1,1-TCA, which was detected but at concentrations
25 below its SSSL. The attenuation of 1,1,1-TCA is often an abiotic transformation through
26 hydrolysis. The presence of 1,1-DCE at concentrations exceeding its SSSL may be attributed to
27 degradation of either TCE or 1,1,1-TCA.

28 29 **5.3.2.2 Semivolatile Organic Compounds**

30 Twelve SVOCs, all of which are PAH compounds, were detected in surface soil samples at
31 Parcel 66(7). The PAH compounds identified as exceeding ESVs are: benzo(a)pyrene,
32 fluoranthene, phenanthrene, and pyrene. In addition, three other PAHs exceeded SSSLs:
33 dibenz(a,h)anthracene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene. Only one SVOC was
34 detected in subsurface soils, but at a concentration below its SSSL.

35

1 **Polynuclear Aromatic Hydrocarbons.** PAHs have high organic carbon partition
2 coefficient (K_{oc}) values and, thus, tend to readily adsorb to soil. High-molecular-weight PAHs
3 have higher K_{oc} values, indicating a stronger tendency to adsorb to organic carbon. Transport of
4 particle-associated PAHs would be controlled by the slow leaching of PAHs to percolating water
5 and any gross particle movements such as surface soil runoff. This may constitute the dominant
6 fate process for these compounds at the site. The solubility of PAHs is variable but in general is
7 low compared to other organic groups; runoff and groundwater transport would not be
8 considered a significant transport process. PAHs were not detected in groundwater at the site.
9 Their presence is believed to be directly related to the asphalt pavement at Parcel 66(7), as no
10 industrial discharges or wastewater treatment plants or other potential sources are present.

11
12 The potential for bioaccumulation is important because PAH compounds have high K_{ow} values
13 and generally tend to bioaccumulate (Table 5-1).

14

15 **5.3.2.3 Pesticides**

16 Three pesticides were detected in surface soils; only one compound (endrin) was detected at a
17 concentration above its ESV. Pesticides were not detected in subsurface soil or groundwater.
18 Pesticides are strongly adsorbed to soils and are not likely to leach to the groundwater. The K_{oc}
19 value for endrin is of the same order of magnitude as that of several PAHs shown in Table 5-1.

20

21 **5.3.2.4 Inorganic Compounds**

22 Many of the chemical and physical processes governing fate and transport discussed in Section
23 5.3.1 also influence inorganic compounds. In addition to those processes, complexation,
24 precipitation/co-precipitation, and cationic exchange are significant factors unique in influencing
25 the persistence and movement of inorganic chemicals (Alloway, 1990). A brief discussion of
26 these is presented in this section. The distribution coefficient (K_d) values for inorganic
27 constituents is also discussed for metals. For inorganic chemicals, the simple relationship
28 between soil organic carbon content and sorption observed for organic chemicals does not apply;
29 K_d is essentially independent of K_{oc} or K_{ow} . Following this section, a discussion of the
30 environmental fate of the inorganic constituents detected at Parcel 66(7) is presented.

31

- 32 • Complexation – Complexation is the ability of metals to form numerous organic
33 and inorganic complexes with inorganic ligands such as carbonate, chloride,
34 hydroxide, and sulfate in the natural environment. Complexation is influenced by
35 many factors, of which pH and the availability of complexing compounds are
36 significant.

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- Precipitation/co-precipitation – Precipitation and co-precipitation are important removal mechanisms of dissolved aqueous species. Precipitation depends upon the ionic concentration/aqueous solubility, pH, and other physical/chemical considerations of the aqueous medium.
 - Cationic Exchange – Many metals are capable of undergoing substitution with cations present in the crystal lattice of minerals within soils and sediments. The type of clay minerals present in the media and factors such as pH and organic content commonly influences this process.

12 The potential for inorganic constituents to migrate in groundwater is related to their distribution coefficient, K_d . The soil-water distribution coefficient for metals is affected by many

13 geochemical parameters, including but not restricted to pH, adsorption to clays,

14 oxidation/reduction conditions, ion chemistry of the water, and chemical form of the metal. K_d

15 values for commonly evaluated metals range from less than 1 to over 10,000 milliliters per gram

16 (mL/g).

17

18

19 Inorganic solutes in groundwater with K_d values exceeding 100 mL/g are considered essentially

20 immobile. K_d values between 0.1 and 50 mL/g suggest moderate mobility, and K_d values below

21 0.1 mL/g suggest high mobility (Dragun, 1988). Trace metals in general have a very high

22 immobility. Cations are moderately mobile in groundwater, and anions are the most mobile.

23 Because of the number of varying geochemical parameters in the field influencing organic

24 distribution coefficients and differences in experimental methods, a wide range of K_d values are

25 obtained. K_d values are presented in Table 5-2.

26

27 Unlike organic compounds discussed in Section 5.3.2.1, metals are not degradable through

28 biological or chemical actions and are typically considered to be persistent in the environment.

29 The fate of metals depends primarily on partitioning between soluble and particulate solid

30 phases. Some metals can be oxidized or reduced through the actions of microorganisms that can

31 change their chemical and physical properties. Among the mechanisms discussed in the

32 preceding sections, solubility/aqueous chemical speciation, adsorption/desorption, complexation,

33 precipitation/co-precipitation, and cationic exchange have the potential to significantly influence

34 fate and transport of the metals detected.

35

36 Eleven metals were detected at concentrations exceeding ESVs in surface media at Parcel 66(7).

37 Two of the eleven metals also exceeded their respective SSSLs. Arsenic was also detected above

1 its SSSL. Four metals were detected at concentrations above their SSSLs in subsurface soil
2 samples and two, iron and manganese, in groundwater samples.

3
4 Subsequent to the establishment of background values discussed in Chapter 4.0 and used in the
5 above screening process, an integrated statistical and geochemical evaluation (Appendix K) was
6 performed for metals in soil and groundwater. In soils, the elevated concentrations could be
7 explained by preferential enrichment of samples with clays, iron oxides, or manganese oxides
8 that naturally concentrate specific trace elements. Based on this screening process, the available
9 data do not indicate metals contamination in soils at Parcel 66(7). Using the same screening
10 process for groundwater, most metals detected were determined to be within the range of
11 background or were determined to be naturally occurring. The concentration of manganese in
12 one sample (from monitoring well PPMP-75-GP01) may be elevated due to reductive
13 dissolution. The sample from PPMP 75-GP01 was also slightly turbid and the manganese
14 concentration could reflect its adsorption to particulates. This is a secondary effect of VOC
15 contamination in groundwater at that location and suggests that naturally occurring manganese is
16 being mobilized in the locally reducing environment caused by the degradation of VOCs.

17 18 **5.4 Contaminant Migration**

19 Chemical and physical processes involved in the solute transport of contaminants at Parcel 66(7)
20 include advection, dispersion, diffusion, and retardation. The response of these factors to the
21 local hydrogeologic conditions will control the horizontal and vertical migration of volatile
22 organic compounds. These processes are briefly discussed in Section 5.4.1. In Section 5.4.2, the
23 horizontal, vertical, and downgradient migration of contaminants is discussed.

24 25 **5.4.1 Processes Involved in Solute Transport**

26 The mechanisms that govern contaminant transport in the groundwater flow system include
27 various physical and chemical processes. These transport processes include advection,
28 dispersion, diffusion, and retardation.

29 30 **5.4.1.1 Advection**

31 Advection is the process of contaminant (solute) migration due to the average linear velocity of
32 groundwater and is typically the most important factor governing solute movement.
33 Contaminants that are moving under advection are travelling at the same rate as the average
34 linear flow velocity of the groundwater. The advective transport term is computed using

1 velocities determined from Darcy's law. The governing chemical parameter in advection is
2 solubility; the effect of advection increases with increasing solubility.

3 4 **5.4.1.2 Dispersion**

5 Hydrodynamic dispersion is the spread or mixing of contaminants around an average
6 groundwater flow path. Dispersion can occur both longitudinally and transversely. The mixing
7 that occurs along or parallel to the flow path in the horizontal plane is called longitudinal
8 dispersion, and that occurring perpendicular to the flow path is called transverse dispersion.

9 10 **5.4.1.3 Diffusion**

11 Diffusion is the movement of contaminants as a consequence of a concentration gradient.
12 Contaminants diffuse from an area of higher concentration to an area of lower concentration;
13 diffusion will occur until an equilibrium in concentration exists. The rate of diffusion increases
14 with increasing temperature and decreases as the porosity of the medium increases. The
15 chemical parameter governing diffusion is the diffusion coefficient. As the diffusion coefficient
16 increases, so does the extent of contamination movement by diffusion.

17 18 **5.4.1.4 Retardation**

19 Dissolved contaminants moving through an aquifer may interact with solid constituents
20 encountered along its flow path. This interaction may include adsorption, partitioning, ion-
21 exchange reactions, and other chemical and physical processes that remove the dissolved
22 constituent(s) from groundwater. The greater the fraction of contaminant sorbed, the more its
23 transport is retarded. Because of these various processes (primarily adsorption), a solute may
24 move at a slower velocity than the groundwater mass itself. One of several accepted and utilized
25 equations for estimating the migration rate of a chemical in a soil-groundwater system is the
26 retardation equation (Fetter, 1988):

$$27 \quad V_c = V [1 + K_d(D_b/n)]^{-1} = Rd$$

28
29 where:

30
31 V_c = velocity of the chemical at the point where the solute concentration is one-
32 half the original value

33 V = average linear velocity of groundwater

34 K_d = adsorption coefficient

35 D_b = soil bulk density

36 n = total porosity

37 Rd = retardation factor.
38

1
2 The adsorption or distribution coefficient is a function of the soil's and solute's chemistry and
3 therefore can be compound-specific. For VOCs, the amount of organic carbon present in the
4 aquifer matrix is an important factor. Generally, the larger the K_d value, the greater the
5 compound's affinity for the solid matrix (Dragun, 1988). For compounds with very low K_d
6 values, the contaminant's mass moves at virtually the same rate as the average linear
7 groundwater velocity. The distribution coefficient is defined by:

8
9
$$K_d = C_s / C_w = f_{oc} K_{oc}$$

10
11 where:

- 12
13 C_s = concentration by weight in soil
14 C_w = concentration by volume in water
15 f_{oc} = fraction of organic carbon
16 K_{oc} = organic partitioning coefficient
17

18 **5.4.2 Migration of Contaminants**

19 Based on the soil and groundwater data collected at the site, the most significant fate and
20 transport pathway is the leaching of organic contaminants in subsurface soils and movement
21 through the residuum into the groundwater system. The general absence of VOCs in surface and
22 subsurface soils suggests that significant removal and/or subsequent leaching of organic
23 contaminants to groundwater has occurred. Although PAHs are present, they are considered
24 relatively immobile because of their propensity to adsorb to soils. The site is effectively capped
25 by asphalt. It is considered that additional significant leaching of near-surface sources to
26 groundwater is not likely.

27
28 The mobility of inorganic constituents is primarily related to their retardation factor (Table 5-2).
29 Depending upon how the metals enter site media, some may persist near the source area longer
30 than others. Metals detected at the site, however, are believed to be within the background range
31 or naturally occurring.

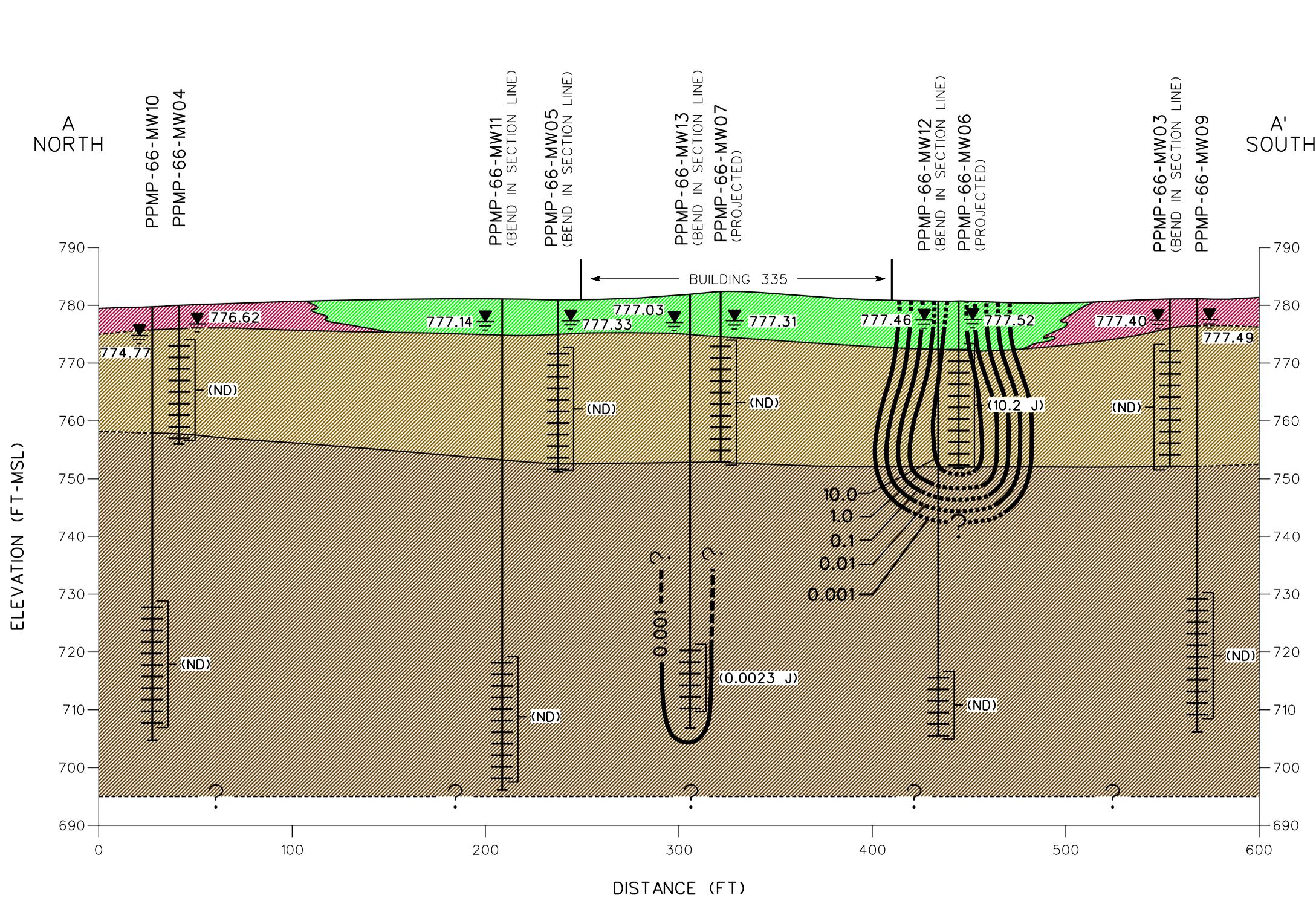
32
33 Vertical hydraulic gradients for five well clusters are presented in Table 3-2. The gradients were
34 calculated for hydraulic head differences from groundwater elevations taken in January 2002.
35 The gradients calculated for the well clusters exhibit either a weak upward flow (- values) or
36 downward flow (+ values). The gradient obtained for the monitoring well cluster where

1 maximum VOC contamination was detected in the residuum well (PPMP-66-MW06) indicated a
2 weak (0.00147 ft/ft) downward gradient. However, no contamination was detected in its paired
3 bedrock well (PPMP-66-MW12). The vertical gradient at the other well cluster
4 (PPMP-66-MW02 and PPMP-66-MW08) where VOC contamination was present in the
5 residuum indicated a moderate (-0.01288 ft/ft) upward hydraulic gradient. VOC contamination
6 was not detected in the bedrock well.

7
8 Figures 5-1 and 5-2 present cross-sectional views of the distribution of total chlorinated VOCs in
9 relation to the subsurface geology. The vertical extent and distribution of contamination shown
10 at the residuum/bedrock interface on the figures is conceptual. It is not documented by analytical
11 data because chlorinated VOCs were not detected in bedrock wells adjacent to contaminated
12 residuum wells. The only bedrock well with chlorinated VOC contamination was PPMP-66-
13 MW13, where TCE was detected at an estimated concentration below its SSSL.

14
15 The rate and distance of contaminant migration in groundwater were estimated for both residuum
16 and bedrock. The parameters used and the results are shown in Table 5-3. Solute transport rates
17 in residuum ranged from 0.25 feet per year (ft/yr) for TCE to 0.56 ft/yr for vinyl chloride.
18 Contaminant velocities in the bedrock were also low and ranged from 0.16 ft/yr for TCE to 0.65
19 ft/yr for vinyl chloride. The minimum and maximum contaminant transport rates calculated for
20 both residuum and bedrock suggest that, over a 50-year period, movement of contaminants
21 beyond the parcel boundary is not likely to occur.

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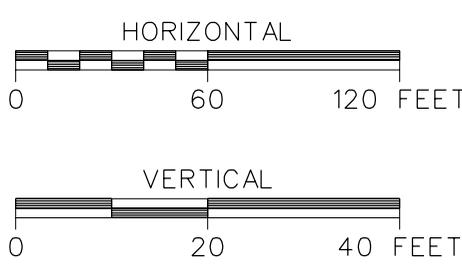
- SCREEN INTERVAL
- WATER TABLE (JANUARY 2002)
- 774.77 GROUNDWATER ELEVATION (FT MSL)
- ? --- CONTACT DASHED WHERE INFERRED
- TOTAL CHLORINATED VOCs CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- (10.2) CONCENTRATION IN MILLIGRAMS PER LITER (mg/L)
- (ND) NOT DETECTED
- J ESTIMATED CONCENTRATION
- CLAY
- SILTY CLAY
- WEATHERED SHALE
- SHALE

NOTES:

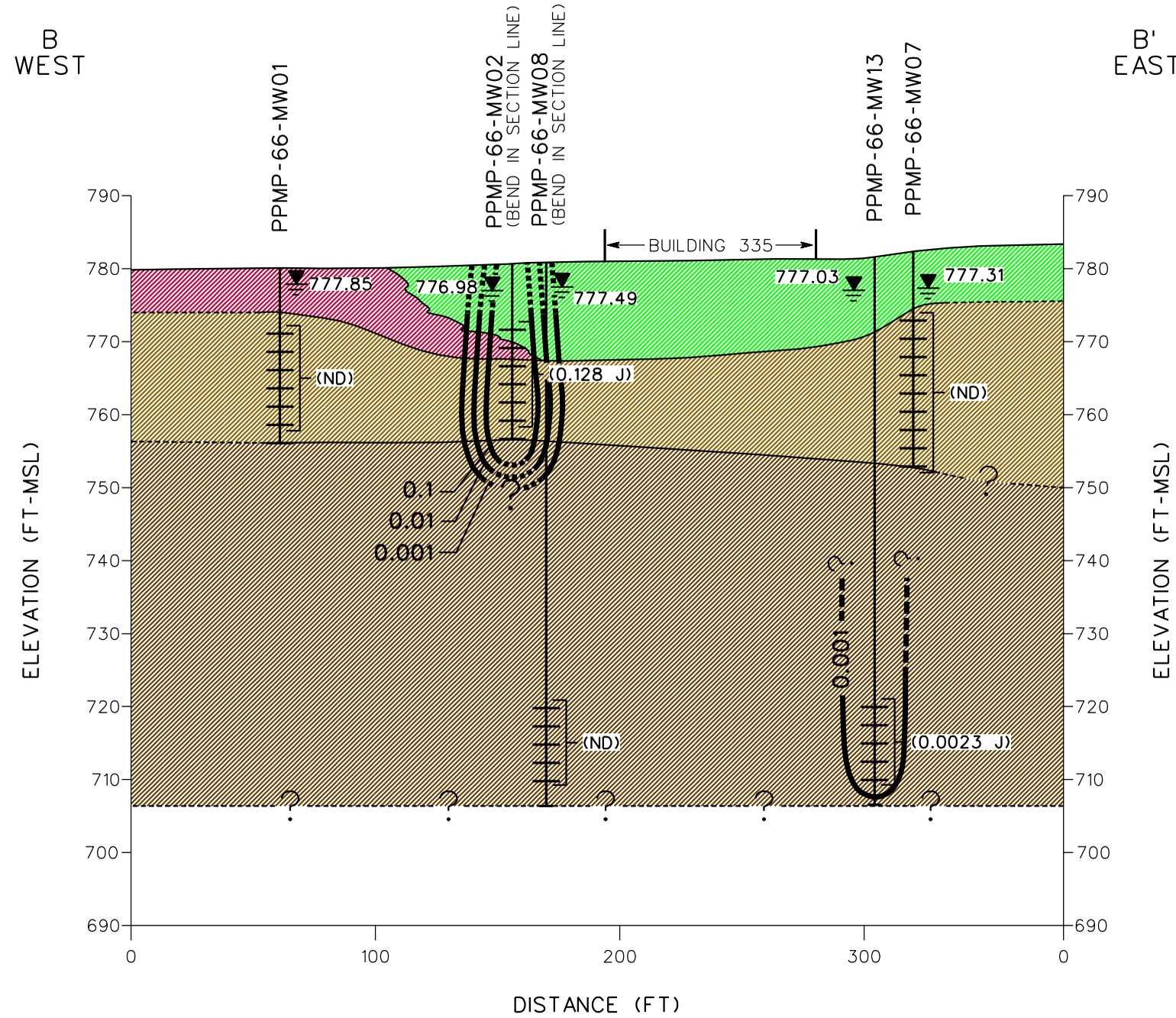
- ELEVATIONS ARE REFERENCED TO THE NORTH AMERICAN VERTICAL DATUM OF 1988.
- DASHED WHERE INFERRED.
- TOTAL CHLORINATED VOC CONCENTRATION EXCLUDES COMMON LABORATORY CONTAMINANTS CHLOROFORM AND METHYLENE CHLORIDE.

FIGURE 5-1
 TOTAL CHLORINATED VOCs
 GEOLOGIC CROSS SECTION A-A'
 SMALL WEAPONS REPAIR SHOP
 PARCEL 66(7)

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- SCREEN INTERVAL
- WATER TABLE (JANUARY 2002)
- 776.98 GROUNDWATER ELEVATION (FT MSL)
- ? --- CONTACT DASHED WHERE INFERRED
- TOTAL CHLORINATED VOCs CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- (0.128 J) CONCENTRATION IN MILLIGRAMS PER LITER (mg/L)
- (ND) NOT DETECTED
- J ESTIMATED CONCENTRATION
- CLAY
- SILTY CLAY
- WEATHERED SHALE
- SHALE

NOTES:

1. ELEVATIONS ARE REFERENCED TO THE NORTH AMERICAN VERTICAL DATUM OF 1988.
2. DASHED WHERE INFERRED.
3. TOTAL CHLORINATED VOC CONCENTRATION EXCLUDES COMMON LABORATORY CONTAMINANTS CHLOROFORM AND METHYLENE CHLORIDE.

FIGURE 5-2
TOTAL CHLORINATED VOCs
GEOLOGIC CROSS SECTION B-B'
SMALL WEAPONS REPAIR SHOP
PARCEL 66(7)

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