

Section 5

Fate and Transport

The analysis of the fate and transport of site-related contaminants is critical to the evaluation of risk and the development of potential remedial alternatives. PCE is the most widespread contaminant detected at the GWP site, occurring in both soil vapor and ground water, in both monitor wells and municipal supply wells. This section has been prepared, therefore, to focus on the factors affecting the migration and fate of PCE, the potential routes of migration, the likelihood for natural attenuation of the contamination, and an evaluation of potential routes of exposure. This information is used along with the site characterization to finalize the CSM in [Section 6](#). The potential routes of exposure are discussed in more detail in the BHHRA in [Section 7](#).

5.1 Chemical and Physical Nature of PCE

The fate of a contaminant in the environment, and the ability of that contaminant to migrate in the environment, depends in part on the chemical and physical properties of the contaminant. For example, the properties that can affect an organic contaminant's fate and transport are water solubility, vapor pressure, molecular weight, organic carbon partition coefficient, Henry's Law constant, and specific gravity. These properties can determine how constituents behave under certain conditions and can be useful while evaluating the fate and transport of contaminants associated with a site, and for evaluating applicable remedial technologies.

For example, the potential for movement of contaminants from one environmental medium, such as air, to another, such as ground water, is defined by partitioning coefficients. Partition coefficients estimate a contaminant's propensity toward accumulating in one medium over another. The more water-soluble a compound is, the more it is likely reside in the aqueous phase and move with percolating water through the soil column to the saturated zone and continue to migrate as a solute in ground water flow. Water-soluble compounds are generally considered mobile in the subsurface environment. A compound with a high organic carbon partitioning coefficient (K_{oc}) value will tend to remain attached to the soil organic matter or reside principally in non-aqueous phases. These contaminants are generally considered immobile in the subsurface environment.

Henry's Law defines the partitioning of a contaminant between the gaseous and aqueous phase. A compound that has a high Henry's Law constant will prefer the gaseous phase to either the solid,

liquid, or the aqueous phase. Contaminants with this characteristic will be more mobile within the soil vapor phase, depending on the pneumatic permeability of the soil and vapor phase density of the compound.

The applicable physical and chemical properties for PCE, as the primary contaminant at the GWP site, are discussed in the following paragraphs.

PCE is a chlorinated VOC commonly used in the dry cleaning industry or as a degreasing agent in metal cleaning operations. It is characterized by relatively high vapor pressure, high Henry's Law constant, and high solubility in water compared to the concentration required to exceed its MCL. The chemical and physical characteristics of PCE are identified in [Table 5-1](#). As a free product, PCE is denser than water, and therefore, will tend to settle to the bottom of the water column. For this reason, the pure phase of this compound is referred to as a dense non-aqueous phase liquid (DNAPL).

The relatively high Henry's Law constant indicates that PCE will tend to partition to the vapor phase from either sorbed (soil) or dissolved (aqueous) phases, provided there is adequate interaction between the two partitioning mediums (i.e., mixing). PCE is released through volatilization from either contaminated soil or surface water. The rate of loss through volatilization depends on the chemical-specific vapor pressure, the ambient temperature, and the unsaturated zone permeability.

Vapor phase PCE, which has a half-life of about 96 days, is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals. PCE is also degraded in the atmosphere by reaction with ozone, but the rate of this reaction is too slow to be environmentally important. Direct photolysis is not expected to be significant because PCE only weakly absorbs light in the UV spectrum. All of the PCE contamination at the GWP site resides below land surface and therefore cannot be degraded by photolysis. Volatilization from the surface of water and soil is also possible based upon the relatively high Henry's Law constant ([Table 5-1](#)). Based upon the range of K_{oc} values ([Table 5-1](#)), PCE is expected to have moderate mobility in soil. PCE is not expected to adsorb significantly to solids and sediment in water.

5.2 Potential Routes of PCE Migration

Understanding how PCE may have migrated in the subsurface is instrumental to understanding how PCE is currently affecting potential receptors and/or how it may potentially affect such receptors in the future.

5.2.1 Overview of Potential Migration Pathways

Following release at the surface or shallow subsurface, migration of contamination within the subsurface occurs via three primary mechanisms: infiltration of water containing dissolved contaminants through the unsaturated zone, migration of vapor-phase contamination through the unsaturated zone, and free-phase DNAPL migration through the unsaturated zone, or in the saturated zone.

5.2.1.1 Infiltration

Leachate containing the PCE may have been generated at each of the potential source areas discussed in [Section 2.2.1](#). While precipitation in the area of the site is very low (See [Section 3.3.1](#)), it is possible that dissolved PCE occurring in leachate from precipitation or storm water in the former arroyo located north of the DACTD maintenance facility could have migrated to the water table over a period of many years. Although infiltration of precipitation through contaminated parts of the unsaturated zone can transport contamination to the water table, infiltration of impacted water or fluids could have originated from, or been accelerated by, leaking underground pipes (e.g. sanitary sewers or storm sewers), unlined discharge structures (sumps, etc), or irrigation within the parks area. Improperly disposed fluids containing PCE, driven by further disposal of everyday fluids or process water, could have enhanced or induced infiltration of PCE into the soil and possibly to the water table. Such conditions are difficult to assess and might go unnoticed for long periods of time. In a similar manner, irrigation water, infiltrating through areas of PCE contamination, could have enhanced or induced infiltration of PCE into the soil and possibly to the water table. Such conditions are also difficult to assess and might go unnoticed for long periods of time.

5.2.1.2 Soil Vapor

Soil vapor migration via air diffusion is a significant transport mechanism that may explain the distribution of PCE under broad areas of the site in unsaturated soils. Diffusion occurs as a result of a concentration difference between the source and the surrounding area. It can result in the upward, lateral and downward migration of vapors in the unsaturated zone. Site characteristics such as soil porosity, soil moisture content, soil temperature, presence or absence of an impermeable surface cover (such as pavement or a building) and age of the release could affect the distance traveled by soil vapor contaminants. For example, a relatively impermeable surface cover above a vapor source might increase the distance a vapor plume would travel laterally if it significantly impedes vapors from escaping to the atmosphere. Also, disturbance of the soil through reworking during development activities could increase volatilization and reduce near surface vapor concentrations. Infiltration of water from the surface, through precipitation or irrigation, could also decrease near-surface vapor

concentrations. PCE in the soil vapor could also transfer to the atmosphere through advective flow and pressure gradients, decreasing near surface vapor concentrations. Chemical properties that influence diffusion are the diffusion coefficients in air and liquid, and Henry's Law coefficient of the chemical. These mechanisms are described in more detail in the following sections.

5.2.1.3 DNAPL

The specific method(s) of contamination at the site are unknown but are likely to include releases of PCE dissolved in waste water or other products or, releases of free-phase PCE or DNAPL. The behavior of DNAPL in the subsurface is strongly affected by the nature and heterogeneity of the subsurface media. When DNAPL is released to the unsaturated zone, it can migrate downward, and capillary forces will immobilize some of the liquid in the pore spaces as residual phase product. In lower permeability media (such as clays), DNAPL may enter through micro-fracture networks where dissolution and subsequent diffusive losses into the bulk matrix can occur. Pools of DNAPL may also form on layers of lower-permeability media and at the top of the capillary zone. This DNAPL can then begin to vaporize into the gaseous phase and migrate by diffusion away from the source. Pressure or density gradients can result in advective flow of the gases, which can sometimes play a role in the overall transport process. As they migrate, the vapors will partition into the aqueous-phase (or dissolved-phase) and solid phases, tending to retard the rate of vapor migration. Gaseous partitioning into the soil-water phase will also make contaminants more readily available for aqueous-phase transport. Depending on the volume and extent of the DNAPL release and the sorptive capacity of the unsaturated media, contaminants may eventually reach the capillary fringe, and dissolved constituents will be transported to the ground water system by diffusion across the water table by infiltrating water and water table fluctuations.

Soil vapor in direct contact with a DNAPL source would demonstrate concentrations based on the vapor pressure of the compound composing the DNAPL. For PCE, the concentration expected in soil vapor in direct contact with a PCE DNAPL, under ideal conditions, can be calculated using the vapor pressure of PCE and the Ideal Gas Law. The Ideal Gas Law states:

$$PV=nRT \text{ or } P/RT =n/V$$

Where: P is the vapor pressure of PCE (atmospheres [atm]), R is the ideal gas constant (8.20×10^{-5} atm-meter³/moles-Kelvins), T is the temperature (Kelvins), n is the number of moles of PCE, and V is the volume (meters³).

Under ideal conditions, the PCE concentration in soil vapor next to a DNAPL source would be approximately 165,000 µg/L (or 23,900,000 ppbv). Concentrations of 1,650 µg/L (239,000 ppbv)

(1% of the ideal concentration) or greater would be expected in samples that were collected close to an existing PCE DNAPL. The highest concentration of PCE detected in soil vapor at the site range is 25 µg/L (3,620 ppbv).

Ground water in direct contact with a DNAPL source, under ideal conditions, would demonstrate concentrations near the solubility of the compound composing the DNAPL (**Cohen and Mercer, 1993**). However, DNAPLs are generally difficult to locate based on ground water concentrations. Generally, the potential presence of DNAPL in or near the saturated zone is indicated if concentrations in ground water exceed approximately 1 to 10 percent of chemical solubility limits for the specific dissolved contaminants. The chemical solubility of PCE in water is 150,000 µg/L (**Table 5-1**). The highest PCE concentration detected in ground water at the site is 53 µg/L. Because the highest detected levels of PCE in ground water at the site are much lower than 1 to 10 percent of the solubility (1,500 µg/L to 15,000 µg/L), it is unlikely that DNAPL is currently present and in direct contact with the ground water.

Although PCE concentrations in soil vapor and ground water do not indicate that a DNAPL source is present at the site, this does not preclude the potential presence of DNAPL in the unsaturated zone as small, isolated pockets of DNAPL and/or residual phase PCE liquid that may occur in areas lying between monitoring points and/or directly below structures. The absence of elevated PCE concentrations in soil vapor and ground water indicates that if such areas are present, they are not likely to be significant contributors to the current distribution of contamination.

5.2.2 Transport of PCE to Ground Water

Each of the three mechanisms mentioned have the potential to transport PCE to ground water. The absence of elevated detections of PCE in ground water and soil suggest that DNAPL is not present at the site. If present, it is likely that the DNAPL or residual phase liquids are bound up within the soil matrix of the unsaturated zone with some limited potential to provide low levels of PCE to infiltrating liquids/soil moisture and soil vapor. Migration of PCE to ground water is more likely related to infiltration; migration via soil vapor diffusion is also possible.

PCE that is released as dissolved phase product is unlikely to bind tightly to soil, based on its low soil organic carbon partition coefficient (k_{oc}). PCE in soil will largely be found either dissolved in pore water or as vapor in soil voids. PCE could migrate through soil either by leaching in pore water, or diffusion through air-filled voids between soil particles. Contaminants dissolved in pore water would enter ground water directly.

PCE in soil vapor that diffuses downward to the water table can partition into ground water. However, the contaminant transport between soil gas and ground water is slow and significantly limited by the liquid diffusion coefficient. Likewise, the reverse condition is also true. The volatilization of PCE from ground water to soil vapor is very slow and is not considered to be a significant transport mechanism for PCE in ground water.

There are limited available comparisons of soil vapor and ground water concentrations where the soil vapor concentrations are measured very close to the water table because of the depth to ground water at the GWP site. The limited data available (from SVMP03 and SVMP16) suggest that PCE in soil vapor and ground water are at or near equilibrium, although there are many uncertainties involved in such an evaluation. The general decrease in PCE concentrations observed in ground water from water table monitor wells provides a more definitive indication that soil vapor is not an ongoing significant source of PCE to the ground water (refer to the water table well trend graph in [Appendix K-8](#)).

5.2.3 Transport of PCE Vapors into Buildings

Volatile contaminants that migrate close to building foundations might intrude into the building via advective/convective transport, in a process referred to as vapor intrusion. Indoor spaces can have negative pressures at various times relative to the outdoors and the surrounding soil vapor. The pressure difference can be from operation of heating, ventilating, and air conditioning systems with unbalanced air supplies and inadequate makeup air; use of fireplaces or heaters that vent exhaust gases to the exterior; use of fans in bathrooms or kitchens; the “stack effect” in which higher indoor temperatures slightly decrease; the density of air relative to the colder underlying soil, producing a pressure difference; or the pressure exerted by wind on the walls of building. The combination of these conditions results in advective flow of soil vapor to indoor spaces through floor cracks, floor-wall seams, utility penetrations or other conduits into the closed space. A conceptual model of this pathway is depicted in [Figure 2-5](#). In Las Cruces, the stack effect would be somewhat reduced because houses are not closed up as tightly as in other parts of the county (such as the northeastern United States), and slab-on-grade construction reduces transport through the stack effect relative to homes constructed with basements. Simulation of indoor vapor intrusion from PCE concentrations in shallow soil vapor using the Johnson and Ettinger model ([Johnson, P. C., and R. A. Ettinger, 1991; EPA, 2004](#)) are presented in the BHHRA ([Section 7](#)).

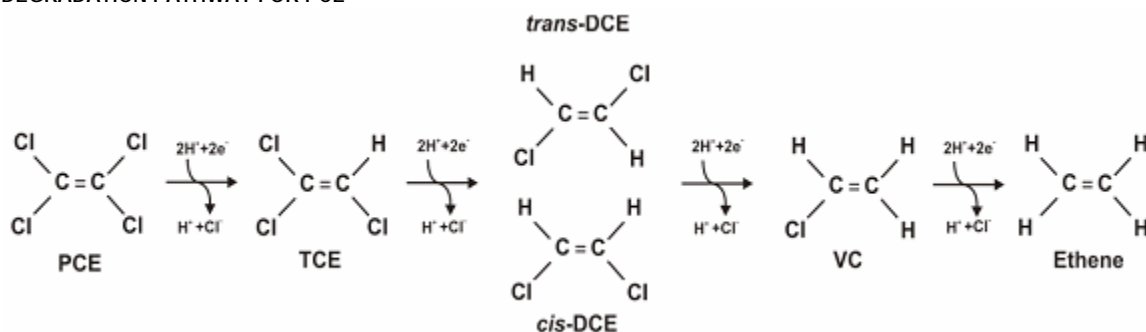
5.3 Potential Degradation of PCE

Degradation of contaminants is an important factor in evaluating the fate and transport. The potential degradation pathways of the primary contaminant, PCE, are described in the following paragraphs.

The degradation of PCE is known to occur through biological and physical processes. The primary biological method is reductive dechlorination. Reductive dechlorination of PCE results in the release of one chloride ion while accepting two electrons from an electron carrier. The degradation pathway for PCE is shown in [Figure 5-1](#) along with daughter compounds.

FIGURE 5-1

DEGRADATION PATHWAY FOR PCE



Although *trans*-1,2-DCE and *cis*-1,2-DCE could be formed, *cis*-1,2-DCE tends to be the preferred intermediate between TCE and vinyl chloride (VC) (NRC, 2000). Of the potential daughter products resulting from degradation of PCE, all were detected in at least one ground water sample collected from the GWP site with the exception of VC. None of the daughter compounds from degradation of PCE were detected at concentrations above their respective MCL.

Overall, the aquifer at the GWP site appears to exhibit a range of geochemical conditions. Conditions are generally aerobic and therefore not capable of reductive dechlorination of PCE. This can be from a lack of organic carbon, inadequate populations of bacteria necessary for the process to occur, or a significant presence of DO in the ground water. Further, the extremely low number of detections and concentrations of daughter products (i.e. TCE, and *cis*-1,2-DCE) in ground water indicate that biodegradation is not a significant method of attenuation at the GWP site. A comprehensive evaluation regarding the potential for natural attenuation of PCE at the GWP site is included in [Appendix I](#).

Physical processes such as dilution and volatilization can also attenuate concentrations of PCE at the GWP site. Dilution is probably the most significant attenuation process in deep aquifers, or in

aquifers without reducing conditions nor significant populations of bacteria necessary for biodegradation to take place. Physical processes that can comprise natural attenuation of PCE at the GWP site include diffusion, dispersion, sorption, and volatilization.

Diffusion and dispersion rely on concentration differences and the mixing effect of ground water flowing through porous media, respectively, to reduce concentrations. This occurs to some extent in most contaminated systems but can vary in effect, depending upon aquifer characteristics, chemical concentrations, and chemical properties.

Sorption processes result in reduction of contaminant concentrations and transport attenuation from contaminant sorption to soil particles. PCE present in the dissolved phase in the ground water is unlikely to bind tightly to soil, based on its low soil K_{oc} ; therefore, sorptive attenuation processes are likely small at the GWP site. The PCE concentration trends, discussed in [Section 4.2.2.5](#), indicate that the PCE concentrations are decreasing in most portions of the plume. The decreasing concentrations are most likely the result of dispersion and dilution of the PCE in ground water and possibly the decreasing amounts of PCE entering ground water from the release areas.

Volatilization can also be a mode for attenuation of PCE from its relatively high vapor pressure (18.5 millimeters of Mercury [mmHg]) and Henry's Law constant (0.765). Most volatilization of PCE in ground water would occur near the ground water-soil vapor interface. The loss of PCE from ground water through volatilization to soil vapor could be possible in localized areas, but it is not likely to be a significant throughout the plume at the GWP site.

5.4 Potential Exposure Pathways

PCE has been detected in both ground water and soil vapor at the GWP site. Previous reports ([EPA, 2003a](#); [ATSDR, 2005](#)) identified that the following potential exposure pathways are present at the GWP site:

- Ingestion, dermal contact, or inhalation of PCE from indoor ground water use from CLC municipal supply wells and/or private wells.
- Inhalation of PCE from ground water used in evaporative coolers (i.e. swamp coolers).
- Inhalation of PCE from soil vapor intrusion into buildings.
- Ingestion of plants irrigated with ground water.

5.4.1 Ground Water Use

Individuals might be exposed to contaminants in ground water through ingestion, dermal contact, and ingestion of water provided through the CLC municipal water supply network. Pathways could include exposure from direct consumption, or, PCE transferred from tap water to the air from showers, baths, toilets, dishwashers, washing machines, and cooking. Testing of the water supply provided by the CLC indicates that four city wells (Nos. 18, 19, 21, and 27) are impacted by PCE and serve as the only identified link to possible receptors. Two of the wells (Nos. 18 and 27) have been shut down because of elevated concentrations of PCE. CLC Well No. 19 has been shut down since July 2005 because of mechanical failure. Although CLC Well No. 21 contains low levels of PCE, CLC has implemented a blending program by mixing water from CLC Well No. 21 with non-PCE impacted ground water to meet the MCL of 5 µg/L for PCE prior to distribution to the public water supply. The concentrations of PCE in the CLC's water supply distribution system have been documented to be below the drinking water MCL.

The private wells that have been identified in the vicinity of the plume are upgradient or cross-gradient to the direction of ground water flow and to the plume (See [Section 2.2.2.1](#)). Therefore, it is unlikely that PCE detections in these private wells exceed the MCL. The uses of ground water and the potential pathways for exposure from those uses are addressed in [Section 7](#).

5.4.2 Evaporative Coolers

The use of ground water with evaporative coolers has also been cited ([EPA, 2003a](#); [ATSDR, 2005](#)) as a potential exposure pathway for PCE via inhalation of vapors. Evaporative coolers use a fan to move hot dry air through screens or filters saturated with water. This evaporates water into the air, absorbing heat and in turn creating a cooling effect that lowers indoor temperature. An evaluation of evaporative coolers as a potential pathway for contaminant vapors is provided in [Section 7](#).

5.4.3 Soil Vapor Intrusion

Soil vapor data indicate that a potential pathway for exposure to soil vapor from inside potentially affected buildings exists. Concentrations of PCE in the shallow soil vapor were significant enough in the vicinity of Hadley Avenue and Walnut Street to warrant further evaluation to determine if soil vapors are presenting a risk to human health or not. The soil vapor intrusion is further evaluated in the BHHRA taking into account additional data collected during the second field mobilization.

5.4.4 Irrigation Water

Ingestion of home-grown produce irrigated with ground water impacted by PCE could be a potential pathway for ingestion of PCE above health based standards if the irrigation water is obtained directly from the shallow aquifer, is measured to be above the MCLs, and is not part of the municipal water supply system. However, PCE does not bioaccumulate in plants or produce (**ATSDR, 2005**). Therefore, this potential exposure pathway might not be complete.