

matter. The extent to which the entrained chemical is transported by air depends on the chemical's persistence in air and the rate at which the particulate matter settles out and is deposited.

Daily ambient air temperatures at Fort Ord typically range from 40 to 70 degrees Fahrenheit, but temperatures in the low 100s have been measured in the past. Thick fog is common in the mornings throughout the year. Winds are generally from the west in the spring and summer, but are variable during the fall and winter. Wind speed is typically low and variable in the mornings until the fog dissipates, strengthening in the afternoon. Average wind speed documented at the Fritzche Army Airfield (FAAF) between 1960 and 1970 was 5 to 10 knots (Weston, 1990). The average annual rainfall is 14 inches and occurs almost entirely between November and April.

Based on climatic and physical conditions at Fort Ord, particulate entrainment in air is an unlikely transport pathway for the contaminants detected at the Fort Ord RI sites. The daily fog leaves abundant moisture on the ground and ground cover, making entrainment of particles into the air difficult. The average wind speed of 5 to 10 knots is too slow to easily entrain the surface soil particles, which are predominantly fine-to medium-grained sand. In addition, the vegetation (e.g., ice plant on dunes) helps prevent erosion and entrainment of particles in air.

Volatilization of chemicals from soil, surface water, and groundwater to air is considered a potential contaminant pathway; however, VOC concentrations in soil are low (generally less than 10  $\mu\text{g/l}$ ), VOCs have not been detected in surface water, and the depth to groundwater is generally greater than 80 feet which would minimize volatilization from groundwater to air. Thus, volatilization of chemicals to air is an unlikely contaminant transport pathway for the chemicals detected at the Fort Ord RI sites.

#### 3.1.2 Surface Water

For the purposes of this report, surface water at Fort Ord refers to surface water runoff and water flowing in or from the storm drains and sanitary sewers. Chemicals may enter the storm drains by

erosion, dissolution of chemicals in soil into surface water, or suspension of soil particles that contain adsorbed chemicals into surface water runoff. Chemicals may also enter surface water runoff by erosion of soil particles that contain adsorbed chemicals and be transported into ephemeral streams and or surface depressions.

Surface water runoff and/or sewage may leak from storm drain and sanitary sewer lines into unsaturated zone soil; however, based on the study conducted on the storm drain and sanitary sewer lines at Fort Ord (Basewide Storm and Sanitary Sewer Investigation, Volume II), the potential for current or past leakage from these lines to the unsaturated zone is low.

Contaminated soil (in suspension) or chemicals dissolved in water flowing within the storm drain lines may be: (1) carried to either inland or ocean storm drain outfalls and discharged, or (2) in the case of sanitary sewers, carried to the Monterey Pollution Control District facility where it is treated to waste discharge requirements. The extent to which a chemical is transported depends on the mobility and persistence of the chemical and the degree to which suspended particles are retained in storm drain sediment traps. Following discharge from storm drains, volatilization and transport in the unsaturated zone of the chemical may occur. As discussed above, volatilization is an unlikely transport mechanism at Fort Ord. Based on the results of the Basewide Storm Water Outfall Investigation (presented as part of Volume II, and discussed below in Section 3.1.3), transport in the unsaturated zone appears to be limited in both vertical and lateral extent for chemicals detected.

#### 3.1.3 Unsaturated Zone

Several mechanisms and processes control transport of chemicals in the unsaturated zone, resulting in a complex multiphase (air and water) flow and transport regime. These processes can affect both organic and inorganic chemicals. The major processes include:

- Chemical Partitioning - In the unsaturated zone, air-water, water-solid, and, to a lesser extent, air-solid partitioning of chemicals occurs within soil pores. At the water table, volatilization from the water phase to the

vapor phase or dissolution from the vapor phase to groundwater can occur, depending on air-water partitioning coefficients of the chemical, adsorption to soil particles, and the chemical concentrations in each phase relative to the equilibrium concentrations.

- Concentration-Driven Gas Diffusion - Concentration-driven gas diffusion occurs as the result of concentration gradients in the unsaturated zone. VOCs can be transported rapidly by gas diffusion from areas of higher to lower concentration. The movement of chemical mass via gas diffusion is greatest when large differences in gas concentration exist. As concentrations reach equilibrium and gradients decrease, gas diffusion slows.
- Vapor (gas-phase) Advection - Gas-phase advection in the unsaturated zone occurs via vapor pressure and temperature gradients resulting from vapor density differences, barometric pressure changes, and unsaturated zone pumping caused by changes in the water table.
- Water (liquid-phase) Advection - Liquid-phase advection of porewater in the unsaturated zone occurs via capillary pressure (matric potential) gradients. The downward advective movement of water occurs as the result of infiltrating precipitation that creates downward matric potential gradients. During dry weather periods, these matric potentials are reversed by evaporation and plant transpiration, resulting in the upward advective movement of porewater.

As an effect of the above processes, unsaturated zone advection and dispersion/diffusion results in the transport of chemicals in vapor-phase and water-phase. The extent of migration of the chemical or its degradation products depends on the spatial and phase distribution of the chemical, the relative states of equilibrium between the phases, and its mobility and persistence.

#### 3.1.4 Groundwater

The predominant mechanisms for chemical transport in groundwater include:

- Advection - Advection is the movement of fluids (i.e., groundwater or non-aqueous phase liquid [NAPL]) and/or the associated transport of chemicals dissolved in the fluids
- Hydrodynamic Dispersion - Hydrodynamic dispersion describes the spreading of the dissolved chemical in groundwater due to mechanical mixing during fluid advection and molecular diffusion
- Molecular Diffusion - Molecular diffusion transports the chemical from areas of high concentration to areas of low concentration due to the thermal-kinetic energy of the chemical particles (*Freeze and Cherry, 1977*)
- Dissolution - Dissolution is the primary mechanism by which NAPLs sustain high dissolved concentrations of a chemical in groundwater. Removal of contaminant mass by groundwater flow with dissolution requires very long times.

The extent of migration of a contaminant or its degradation products in groundwater depends on the mobility and persistence of the chemical and the direction and rate of groundwater flow.

### 3.2 Contaminant Mobility and Persistence

This section describes the factors governing the mobility and persistence of the chemicals detected at Fort Ord RI sites. Mobility and persistence of a chemical released into the environment depends on key physical, chemical, and degradation properties of the chemical and on the physical and chemical properties of the environment into which it is released. Tables 2a through 2c present selected physical and chemical properties of the organic chemicals detected at the RI sites and during the Basewide Surface Water Outfall Investigation. The following sections discuss the general factors that affect the mobility and persistence of organic and inorganic chemicals. The organic chemicals include volatile organic compounds (VOCs), semivolatile organic compounds (SOCs), total petroleum hydrocarbons (TPH), pesticides, PCBs, conventional weapons explosive compounds, (including primary explosives such as tetrazene, secondary explosives such as

cyclotetramethylene tetranitramine [HMX] and cyclotrimethylenetrinitramine [RDX], and propellant compounds such as nitrocellulose, nitroglycerin, and black powder), and dioxins and furans. Inorganic chemicals include metals, nitrates, and chloride. Not all factors are applicable at any given site. The factors and chemicals applicable to each site are described in the fate and transport section of the site-specific RIs.

### 3.2.1 Organic Chemicals

Factors that affect the mobility and persistence of organic chemicals include the transport factors already discussed and the following:

- **Sorption/Desorption** - Sorption includes the processes by which a chemical will be held to the surface of the soil particles. These processes include: (1) the attraction of polar compounds to ion exchange sites, (2) the chemical bonding of reactive organic chemicals to natural soil organic material, (3) Van der Waals bonding, and (4) other mechanisms that depend on the specific characteristics of the released chemical and on soil properties such as mineralogy, specific surface area, and fraction of organic carbon content ( $f_{oc}$ ).
- **Photolysis** - Photolysis is the transformation of a chemical into other chemical entities due to absorption of light energy by the chemical
- **Oxidation/Reduction Reactions** - Oxidation and reduction (redox) reactions refer to the loss (oxidation) or the gain (reduction) of electrons, and they occur together, that is, electrons lost by one compound must be gained by another (Knox, *et al.*, 1993)
- **Hydrolysis** - Hydrolysis is the process in which a chemical reacts with water or a hydroxide ion. Factors affecting hydrolysis in soil include: pH of the soil particle surfaces, the presence of metals in the soil, the adsorption of the organic chemical in the soil, and the water content of the soil (Dragun, 1988).

The mobility and persistence of organic chemicals is generally evaluated by comparing

the chemical properties to published chemical criteria. Ney (1990) proposed a chemical property ranking for low, medium, and high mobility in groundwater based on water solubility and the log of the octanol-water partition coefficient,  $K_{ow}$ . Dragun (1988) proposed a similar ranking scheme based on the organic carbon partition coefficient,  $K_{oc}$ . Table 3 presents a summary of these criteria. These criteria were used to rank the mobility and persistence of organic chemicals detected above MCLs in samples collected from groundwater monitoring wells at the Fort Ord RI sites.

Table 3 also presents the chemical property criteria for evaluating the volatilization potential from water (e.g., from groundwater to the unsaturated zone, from soil porewater to soil vapor, or from storm drain/sanitary sewer line to air or soil vapor). Volatilization potentials were evaluated using vapor pressure criteria from Dragun (1988) and Henry's Law constant ( $K_h$ ) criteria from Lyman (1982). Vapor pressure is the pressure at which equilibrium exists between a pure liquid chemical and air.  $K_h$  is the ratio of the chemical vapor pressure to aqueous solubility and is a measure of the vaporization of dissolved organic chemicals from water.

As Table 3 indicates, solubility, vapor pressure, and  $K_h$  are proportional to the mobility of the organic chemical (i.e., the higher the value of the property, the more mobile the chemical tends to be).  $K_{ow}$  and  $K_{oc}$  are inversely proportional to the mobility of the organic chemical (i.e., the higher the value of the property, the less mobile the chemical tends to be).

Table 3 also includes the persistence criterion for groundwater, the water half-life (Ney, 1990). This is the number of days it takes a chemical to be degraded by abiotic (e.g., hydrolysis) and/or biotic processes to one-half its original concentration.

The chemical property rankings described by Ney (1990) and Dragun (1988) are also used in the site-specific RI fate and transport sections to rank the mobility and persistence of organic chemicals detected in soil. The rankings of organic chemicals in soil are not provided in this general section but are provided in the site-specific fate and transport sections.

The solubility of a chemical in water is compared to its maximum concentration in groundwater to evaluate the presence or absence of NAPLs. If the concentration of the chemical in groundwater exceeds 1 percent of its solubility in water, a NAPL phase of the chemical may be present (EPA, 1993 DNAPL Site Evaluation, published by C.K. Smoley). If the specific gravity of the contaminant is less than water, the NAPL phase will tend to float (i.e., light NAPL; LNAPL) on the water and capillary fringe. Conversely, if the specific gravity of the contaminant is greater than water, the NAPL phase will tend to sink (i.e., dense NAPL: DNAPL) to a zone with a relatively lower hydraulic conductivity. Dissolved-phase contaminants tend to move in the direction of groundwater flow, regardless of specific gravity. Table 4 presents this comparison for organic chemicals detected above the MCLs in groundwater monitoring wells at the Fort Ord RI sites. Based on this comparison, only bis(2-ethylhexyl)phthalate, a common laboratory contaminant, has a potential (albeit slight) to exist as a NAPL.

Dissolved-phase contaminants that are transported by groundwater flow do not typically move at the same rate as the groundwater and generally move slower relative to the average groundwater velocity. This is primarily due to sorption of the chemical to the aquifer solids. The retardation factor, R, expresses the velocity of the sorbed species relative to the average velocity of the groundwater and is calculated by the following equation:

$$R = 1 + \frac{\rho_d K_d}{n_e}$$

where:

$\rho_d$  = dry bulk density (g/cm<sup>3</sup>)

$K_d$  = distribution coefficient (ml/g)

$n_e$  = effective porosity (dimensionless)

The distribution coefficient,  $K_d$ , describes the partitioning of a chemical between water and organic material and is calculated by the following equation:

$$K_d = K_{oc} f_{oc}$$

where:

$K_{oc}$  = organic carbon partition coefficient (ml/g)

$f_{oc}$  = fraction of organic carbon content in the soil (dimensionless)

The range for  $f_{oc}$  values detected at Fort Ord RI sites is 0.0001 to 0.0683. The range for  $f_{oc}$  values detected during the BWSOI is 0.00007 to 0.0755.

As discussed above, the greater the  $K_{oc}$ , the lower the mobility. That is, the greater the R value, the greater the chemical is retarded and the slower the rate of contaminant mass transfer. Tables 5 and 6 present calculated  $K_d$  and R values for the organic compounds detected in groundwater above MCLs at Sites 2 and 12 and Sites 16 and 17, respectively. Organic compounds were not detected in groundwater above MCLs at the other RI sites.

Biological processes that affect the mobility and persistence of organic compounds are the degradation or breakdown of compounds by the subsurface microorganisms. Degradation can be complete, resulting in the removal of the contaminant mass, although the intermediate breakdown products produced can be more toxic than the initial chemical. For example, trichloroethene (TCE) can degrade to CO<sub>2</sub> and H<sub>2</sub>O; however the intermediate breakdown products include 1,1-dichloroethene and vinyl chloride, which have lower permissible exposure limits and action levels than the parent compound. Analytical results for groundwater samples at Sites 2 and 12 show a decrease in TCE concentrations and an increase in 1,2-dichloroethene concentrations (an additional breakdown product) in the down gradient portion of the plume indicating that degradation of TCE is occurring at the site.

Conditions that affect microorganism population and activity include: available nutrient, pH, temperature, osmotic pressure, toxics, substrate concentration, moisture content, missing members of a microbial consortia, and substrate structure (Knox, et al., 1993).

### 3.2.2 Inorganic Chemicals

The mobility and persistence of inorganic chemicals (metals) in the environment are influenced by the amount, chemical form, and oxidation state of the chemical, the composition and physiochemical properties of the soil, and the porewater or groundwater chemistry. Soil properties that may affect the fate and transport of metals include: bulk density, surface area, particle-size distribution, pH, oxidation/reduction (redox) potential, cation exchange capacity (CEC), salinity, and the type and concentration of organic matter, clay minerals, and colloidal hydrous iron, manganese, and aluminum oxides (*Kotuby-Amacher and Gambrell, 1988; Salomons and Forstner, 1984; Oak Ridge National Laboratory, 1989*).

The total concentration of a metal in soil is generally defined as (*Dragun, 1988*):

$$C_{\text{total}} = C_{\text{fixed}} + C_{\text{adsorbed}} + C_{\text{water}}$$

where:

$C_{\text{fixed}}$  = concentration of fixed element comprising part of the structure of clay and soil minerals (mg/kg)

$C_{\text{adsorbed}}$  = concentration of element adsorbed onto soil mineral surfaces and organic matter exchange sites (mg/kg)

$C_{\text{water}}$  = concentration of element in porewater in equilibrium with  $C_{\text{adsorbed}}$  (mg/kg)

$C_{\text{fixed}}$  includes: (1) chemisorption - covalent bonding between adsorbed element and mineral surface resulting in element immobilization; (2) solid-state diffusion - irreversible penetration of an element into the pore spaces of a mineral structure; and (3) precipitation - formation of an insoluble solid composed of an element previously dissolved in water.

For background concentrations, the majority of  $C_{\text{total}}$  (for cations) may be present as  $C_{\text{fixed}}$  (*Dragun, 1988*). As  $C_{\text{total}}$  increases, the relationship (relative concentrations) between

$C_{\text{fixed}}$ ,  $C_{\text{adsorbed}}$ , and  $C_{\text{water}}$  may or may not change. That is, the majority of  $C_{\text{total}}$  may become  $C_{\text{adsorbed}}$  or  $C_{\text{water}}$ , or remain  $C_{\text{fixed}}$ . Therefore, the element-loading capacity of the soil, which is the concentration of the element that can be retained by the soil, cannot be assumed to be the background concentration, which is the concentration of the element present in the soil following soil formation.

The oxidation state of certain elements can determine their relative mobility, bioavailability, and toxicity (*McLean and Bledsoe, 1992*). These elements include arsenic (AsV and AsIII), chromium (CrVI and CrIII), mercury (HgI and HgII), and selenium (SeVI and SeIV). As presented earlier, oxidation and reduction (redox) reactions are the loss (oxidation) or the gain (reduction) of electrons and occur together; that is, electrons lost by one compound must be gained by another (*Knox, et al., 1993*).

The effect of pH, redox potential, and cation exchange capacity (CEC) on the adsorptive capacity of a soil, and hence on the mobility of a metal, can be significant. These factors will generally affect anions (negatively charged ions) and cations (positively charged ions) differently. The CEC is a measure of the negatively charged sites for cation adsorption (*McLean and Bledsoe, 1992*). As the pH is lowered, the number of negatively charged sites decreases, allowing additional anion adsorption as the cations are exchanged for anions. Cationic species will tend to be more mobile in lower pH environments. Oxide surfaces can generate a significant quantity of positive charges as the pH is lowered, creating abundant adsorption sites for anions.

Metals can form soluble complexes with inorganic and organic ligands that may enhance mobility. Generally, cation complexation with inorganic ligands will reduce mobility. A complex is defined as a unit in which a central metal ion is bonded to a number of associated atoms or molecules in a defined geometric pattern, where the associated atoms or molecules are called ligands (*McLean and Bledsoe, 1992*). Common inorganic ligands include sulfate, hydroxide, phosphate, carbonate, and chloride.

The following information is taken from McLean and Bledsoe (1992) and describes general mobility and persistence of the most frequently detected metals above background in soil samples collected at Fort Ord. Because information in the literature regarding antimony, beryllium, and thallium is very limited and were not available in the information from McLean and Bledsoe (1992), these elements are discussed in general terms at the end of this section. The expected mobility of the metals detected at the specific RI sites is discussed in the fate and transport section for each RI site in relationship to site-specific soil property data, where available.

### Cations

- Lead** - Soluble lead added to soil reacts with clays, phosphates [to form  $Pb_3(PO_4)_2$ ], sulfates (to form  $PbSO_4$ ), carbonates (to form  $PbCO_3$ ), and hydroxides [to form  $Pb(OH)_2$ ], greatly reducing the solubility, hence mobility. At pH values greater than 6, lead is either adsorbed onto clay surfaces or forms lead carbonate ( $PbCO_3$ ). Puls et al. (1991) and Kotuby-Amacher and Gambrell (1988) have demonstrated decreased sorption of lead in the presence of complexing ligands and competing cations. Lead has a strong affinity for organic ligands and the formation of these complexes may increase the mobility of lead in the soil.
- Copper** - Generally, the mobility of copper is decreased in soil by exchange and adsorption mechanisms. Copper is adsorbed to a greater extent by soil and soil constituents than most metals, with the exception of lead. However, as with lead, copper has a high affinity for organic ligands and the formation of these complexes may increase the mobility of copper in the soil.
- Zinc** - Zinc is readily adsorbed by clays, carbonates (to form  $ZnCO_3$ ), and hydrous oxides (to form  $ZnO$ ). Because of the relatively high solubility of zinc compounds, precipitation is not a major mobility mechanism for zinc in soil. Zinc adsorption increases with pH (similar to other cations) and hydrolyzes at  $pH > 7.7$ . These hydrolyzed species are strongly adsorbed to soil surfaces.
- Cadmium** - Cadmium can be adsorbed by clay minerals, carbonates, or hydrous oxides of iron and manganese or precipitated as cadmium carbonate ( $CdCO_3$ ), hydroxide [ $Cd(OH)_2$ ], and phosphate [ $Cd_3(PO_4)_2$ ]. Dudley et al., (1988, 1991) suggest that adsorption mechanisms may be the primary mechanism of removal of cadmium from the soil. In acidic conditions, the solubility of cadmium increases, which increases its mobility in soil. At  $pH > 6$ , cadmium is adsorbed or precipitated, greatly reducing its mobility. The formation of soluble complexes with inorganic and organic ligands (particularly chloride) will increase the mobility of cadmium in soil. The formation of soluble chloride complexes could be important below the water table near Monterey Bay where limited saltwater intrusion has occurred; however, saltwater intrusion is generally limited to a maximum of 1,000 feet inland and should not impact pore water in the vadose zone.
- Chromium** - As discussed above, chromium can exist as CrIII and CrVI, CrVI being the more toxic. CrIII reportedly forms hydroxyl complexes in natural water, including  $Cr(OH)_2^-$ ,  $Cr(OH)^{2+}$ ,  $Cr(OH)_3$ , and  $Cr(OH)_4^-$  (anionic form). It is readily adsorbed by soils. These hydroxyl species precipitate at pH 4.5, with complete precipitation occurring at pH 5.5. Although CrVI was not detected in any soil samples collected at the RI sites, it is discussed here because the data were not validated (see Appendix F discussion). The mobility of CrVI species may decrease at low pH by transformation to insoluble CrIII species. Ferrous iron and organic matter can also transform CrVI to CrIII, but manganese oxides can cause the rapid oxidation of CrIII to CrVI. The soil present at Fort Ord is not expected to support the existence of CrVI, based on the results of matrix spike analyses performed during analyses for CrVI which showed recoveries of less than 30 percent suggesting that the spiked CrVI is rapidly converted to CrIII. Rapid reduction of CrVI to CrIII is influenced by organic matter content, bioactivity, and oxygen status (Losi, et al, 1994).

- **Mercury** - Mercury can exist in three oxidation states: elemental mercury (Hg) and the mercurous ( $\text{Hg}_2^{2-}$ ) and mercuric ( $\text{Hg}^{2+}$ ) ions. The form present is dependant on pH and redox potential conditions. Generally, mercuric mercury will precipitate in alkaline conditions. Elemental mercury can be converted into the more toxic forms of methyl and ethyl mercury, both of which are volatile and soluble in water, hence very mobile.
- **Nickel** - Nickel will adsorb to clays, iron, manganese oxides, and organic matter, removing it from the soil solution. Because nickel is a cation, its mobility would tend to be reduced with higher pH. The formation of complexes with inorganic and organic ligands will increase the mobility of nickel in soil.
- **Silver** - Limited studies have been performed on the mobility of silver. Because silver is a cation, its mobility would tend to be reduced with higher pH. Lindsay (1979) suggests that silver is very strongly adsorbed by clay and organic matter, and precipitates of silver are highly insoluble, making it very immobile in the soil.
- **Selenium** - Selenium can exist in four oxidation states: elemental selenium (Se), selenide ( $\text{Se}^{2-}$ ), selenite ( $\text{SeO}_3^{2-}$ )(SeIV), and selenate ( $\text{SeO}_4^{2-}$ )(SeVI). The concentration and form of selenium is governed by pH, redox potential, and soil composition. As with other anionic metalloids, increasing pH tends to increase the mobility. In addition, high concentrations of other anions that strongly adsorb to soil and compete for adsorbing sites, can also increase selenium mobility.

#### Antimony, Beryllium, and Thallium

- Antimony is expected to exhibit behavior similar to arsenic and should be absorbed by the same soil constituents that bind phosphate and arsenate (Adriano, 1986)
- Beryllium is expected to be strongly bound by montmorillentic clays and readily complexes with organic compounds; however, the inorganic complexes  $\text{BeCl}_2$  and  $\text{BeSO}_4$  can be relatively mobile (Adriano, 1986)
- Thallium is most often fixed by clay and gels of manganese and iron oxides. It is also adsorbed by organic matter under reducing conditions. Minimal soil data are available, however (Adriano, 1986).

#### Metalloids

- **Arsenic** - As described above, arsenic can exist as  $\text{AsV}(\text{AsO}_4^{3-})$  and  $\text{AsIII}(\text{AsO}_2^-)$ , AsIII being more toxic. AsV forms insoluble precipitates with iron, aluminum, and calcium, with iron being the most effective in controlling mobility. AsIII compounds are reported to be up to an order-of-magnitude more mobile than AsV compounds. The adsorption of both forms is pH dependant. Maximum adsorption of AsV was found to occur at pH 5 and maximum adsorption of AsIII at pH 7 (Griffin and Shrimp, 1978). Because these species are anionic and their charge is pH-dependant, increasing pH tends to decrease sorption, which increases solubility and mobility. At high redox levels, AsV predominates and mobility is limited. With decreasing redox or increasing pH, AsIII is the dominant form, increasing mobility because of its higher solubility.

#### 3.3 Contaminant Migration

This section discusses the transport pathways of the chemicals detected at Fort Ord RI sites. The significance of a pathway is based on: (1) the presence of the chemical at a concentration greater than background in media samples (air, surface water, soil gas, soil matrix, and/or groundwater) and (2) whether the chemical/physical properties of the chemical indicate a preference for the pathway. This discussion is a general overview of chemical transport: chemical transport for each site is discussed in the site-specific sections of this report.

**3.3.1 Air**

As discussed above, contaminants may enter the air by volatilizing or by particulate entrainment. In general, VOCs have higher vapor pressures and would be expected to volatilize to the air and be transported and diluted in the prevailing wind direction by advection and diffusion. SOCs, TPH components, pesticides, PCBs, explosive compounds, and dioxins and furans have relatively low vapor pressures and would not be readily volatilized to the air at ambient temperature conditions. These compounds and inorganic chemicals (i.e., metals, metalloids) can be transported by particulate entrainment and transported in the prevailing wind direction by advection and diffusion; however, as discussed in Section 3.1.1 particulate entrainment in air is an unlikely transport pathway for chemicals detected at Fort Ord.

**3.3.2 Surface Water**

As discussed in Section 3.1.2, contaminants may enter surface water by dissolution or suspension. The contaminant is then transported to a discharge point (outfalls for storm drain lines and the Monterey Pollution Control District Facility for the sanitary sewers). Surface water runoff may also accumulate in inland depressions and ephemeral streams which flow short distances prior to infiltrating the sandy soil. The streams do not discharge into larger streams or rivers. These depressions and streams are generally in areas that are not developed and therefore not connected to the storm drain system. Some volatilization of VOCs can occur during transport, thus decreasing the concentrations of the VOCs.

Based on stormwater sampling results conducted as part of the Baseline Ecological Risk Assessment, seven metals (cadmium, copper, lead, silver, mercury, nickel, and zinc) and two phthalates were detected in stormwater samples. These data indicate that these chemicals are being transported by stormwater runoff either in the dissolved phase or adsorbed to soil particles. Following deposition at the outfalls, volatilization is highly unlikely; however entrainment into the air is a possible but unlikely migration pathway. Because of the high total organic carbon (TOC) values detected in soil and sediment samples

(discussed below) and slightly acidic to slightly alkaline pH of the soil at Fort Ord, these chemicals would not be expected to readily migrate through the unsaturated zone.

No liquid samples were collected from the sanitary sewer because the liquid is transported to the Monterey Pollution Control District Facility where it is treated prior to discharge.

As discussed in Section 3.1, the Salinas River is not considered a viable transport pathway because of its distance from any of the RI sites and the lack of elevated concentrations of chemicals along that portion of the Fort Ord boundary. The Pacific Ocean is also not considered a significant transport pathway because chemicals that may be discharged to the ocean are rapidly diluted.

**3.3.3 Unsaturated Zone**

Contaminants can enter the unsaturated zone from surface releases, by infiltration at storm drain outfall locations, or by volatilization from groundwater. Once the contaminant enters the unsaturated zone, it is transported by the various mechanisms and processes described in Section 3.2.3.

The leaching potential of organic chemicals detected in soil matrix samples collected in the unsaturated zone has been addressed utilizing the EPA's one-dimensional vadose zone transport model, VLEACH (EPA, 1990h). In general, model results indicate that very low concentrations (below target detection limits) of some organic chemicals may reach groundwater over the 100-year period modeled. The modeling results are presented in an appendix for each individual site where use of this model was applicable. The distribution of organic compounds, particularly semivolatile organics, also indicates limited leaching potential because most of these chemicals are present at only 5 to 10 feet bgs.

Organic compounds detected in soil and sediment samples collected during the basewide storm drain and sanitary sewer investigations and RI investigations included: VOCs (e.g., TCE, PCE, and acetone) pesticides (e.g., 4,4-DDE, 4,4-DDT, and 4,4-DDD), various SOCs (including PAHs), dioxins and furans, explosive compounds,

and TPH as unknown hydrocarbons in the gas and diesel range. Because TOC concentrations are generally high, up to 7.5 percent, and most of these chemicals readily adsorb to organic matter, the organic chemicals detected, with the exception of the VOCs, are not expected to be very mobile. In general, concentrations rapidly decrease with depth, indicating that limited migration of these chemicals has occurred. Organic compounds are rarely detected below 10 feet.

Priority pollutant metals detected above the established Fort Ord background values during the basewide storm drain and sanitary sewer investigations and the individual RI site investigations included: copper, zinc, lead, cadmium, chromium, mercury, arsenic, silver, beryllium, antimony, nickel, thallium, and selenium. In general, concentrations decrease with depth, indicating that very limited migration of these metals has occurred. Soil pH values range from mildly acidic to mildly alkaline, favoring adsorption of these metals. Site-specific soil CEC and TOC values also favor adsorption. Metals detected above background values in soil are not expected to migrate significantly beyond their present distribution because: (1) the above site-specific conditions favor adsorption, (2) reproducible concentrations of metals have not been identified in groundwater, and (3) groundwater pH ranges from 6.0 to 9.0 favoring adsorption to soil particles.

#### 3.3.4 Groundwater

Contaminants can enter groundwater by dissolution from the vapor phase in the unsaturated zone and downward advective movement of contaminated porewater. Once the contaminant enters the saturated zone, it is transported by the various mechanisms and processes described in Section 3.2.4.

Based on analytical results of samples collected from the monitoring wells at the RI sites, only nine organic compounds at only two of the RI sites have been detected above MCLs in the groundwater. Tables 5 and 6 present the mobility, persistence, and volatilization potential ranking for these compounds, as well as the calculated  $K_d$  and R values based on site-specific soil properties, for Sites 2 and 12 and Sites 16

and 17, respectively. The reader is referred to the site-specific portion of this report for a discussion of the contaminants associated with each site.

Transport of VOCs in groundwater appears to be a significant pathway at sites where VOCs have been detected in groundwater. Transport of other chemicals detected in groundwater at Fort Ord does not appear to be significant due to the low frequency of detection of other organics and inorganics in groundwater.

VOCs in groundwater may be discharged to the ocean both within and just below the surf zone. Following discharge to the surf zone, VOCs would expect to be volatilized to air. Concentrations of VOCs which discharge below the surf zone would be expected to be rapidly diluted within the ocean.