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APPENDIX E
SUPPLEMENTAL EVALUATION OF FATE AND TRANSPORT PROCESSES

E.0 FATE AND TRANSPORT PROCESS

Contaminant fate and transport in the environment may be controlled by a number of factors such as the chemical and physical properties of the contaminants, the geologic formations encountered, the hydrogeologic conditions (vertical and horizontal groundwater gradients, conductivity of the aquifers, and seasonal fluctuations in the groundwater table), precipitation, tidal fluctuations, and topography of the study area. By evaluating the patterns of contaminant distribution and the transport pathways available, it is possible to identify key factors governing contaminant migration within the OU3 study area.

Chemical and biological processes may cause the transformation into other compounds, affecting the fate and transport of contamination. Chemical or biological degradation may be a significant factor for contaminant fate and transport within the OU3 study area; however; the results of the RI concentrations in various environmental media have been fairly constant over time for the contaminants within the OU3 study area. In addition, several of the contaminants are either difficult to biodegrade, or do not transform under normal environmental conditions (i.e. asbestos, PCBs, some metals). Therefore, no further evaluation of chemical or biological processes will be discussed in this RI.

Section E.1 summarizes the dominant transport mechanisms in the environment. Section E.2 discusses the properties of the chemical contaminant which influence their fate and transport. Section E.3 summarizes the contaminant sources and releases to the environment within the OU3 study area associated with historical disposal and operational practices associated with the Raymark Facility. Section E.4 provides a discussion of the physical states of contaminants in the various environmental media within the OU3 study area.

E.1 Major Fate and Transport Processes

Contaminants in natural systems are subject to a variety of physical and chemical interactions that influence their fate, and subsequent transport, in the environment. The basic processes governing contaminant transport include advection, diffusion and dispersion, decay, and retardation. Additional mechanisms support fate and transport of chemical contaminants on a smaller scale. The processes are described below.

E.1.1 Advection

Advection is the bulk movement of a dissolved-phase or particulate contaminant within a natural fluid flow (air or water) in response to a potential gradient such as pressure (hydraulic head), temperature, or concentration. In the environment, advection is the dominant transport mechanism controlling the physical transport of contaminants. Under advective transport, a contaminant present in air or water is passively carried at the same velocity as the fluid. Examples of advective transport include migration of: contaminant plumes in groundwater downgradient of unlined lagoons, contaminant plumes in surface water downstream of outbreaks to rivers and streams, dust clouds/air emissions downwind on an uncontrolled excavation, and bulk movement of contaminants as the result of tidal fluctuations.

E.1.2 Diffusion and Dispersion

In environmental systems, diffusion and dispersion are often considered concurrently in the transport of chemical contaminants through plume spreading and reduction in peak concentrations over time. However, the two terms represent distinct transport processes.

Diffusion is generally viewed as the slow migration of dissolved contaminants, in response to a concentration gradient, from areas of higher concentrations to areas of lower concentrations. Because this transport process occurs on the molecular scale, its affect is typically small in comparison to the forces driving the more rapid advective processes. Diffusion, however, may be significant in aquifers that have clayey sands and silts with low groundwater velocities; and it may be the dominant transport process for the movement of soil gas. Diffusion also plays a role in adsorption and other chemical properties discussed in Section 5.2.

Dispersion, on the other hand, is a mechanical process resulting from fluid-flow irregularities which cause contaminants to follow an indirect path from their point of origin. These tortuous and intertwining pathlines (caused by rough spots on or within the ground surface or a pipe wall) lead to mixing and spreading of the contaminants. The flow path irregularities may also arise at faster velocities and under conditions of turbulent flow. In groundwater systems, the contaminant pathway becomes more convoluted as the degree of subsurface heterogeneities

increases. Typical heterogeneities affecting groundwater flow include changes in porosity, hydraulic conductivity, and layering in the aquifer.

Examples of transport by diffusion and dispersion include movement of contaminants within: confined and unconfined aquifers, vadose zone groundwater, surface water, and the atmosphere.

E.1.3 Decay

Decay of organic chemical contaminants occurs by biological and non-biological means. In biological decay or biodegradation, chemical transformations are mediated by the extracellular enzymes synthesized by microorganisms residing in soil and aquatic media. These enzymes may be produced for the sole purpose of breaking down organic contaminants as a food source for the microorganisms (metabolism) to catalyze chemical decomposition for some other purpose (cometabolism). Mechanisms of non-biological decay include hydrolysis, photolysis, oxidation, reduction, and methylation. Photolysis, or photo-oxidation, is limited to situations where sunlight is present at the soil surface and in the upper few feet of most surface water.

Although various decay mechanisms may be important in specific environments, biodegradation often comprises a significant portion of the overall decay rate. Chemicals that were not originally present at the site may be produced. In some cases, these daughter products such as vinyl chloride may be more toxic than the original compounds released. Alternatively, biodegradation can significantly reduce the chemical hazards at a site by transforming chemical contaminants to harmless constituents, such as carbon dioxide and water.

Furthermore, depending on the microorganisms and contaminants present, biodegradation can occur under aerobic or anaerobic conditions. However, due to its slow rate in the absence of artificial stimulation, aerobic biodegradation is rarely observed at hazardous waste sites. Anaerobic biodegradation is a much more common occurrence.

E.1.4 Retardation

Adsorption-desorption reactions lead to the retardation of contaminant plume migration in groundwater flows, as well as of contaminant movement along the boundaries of surface water flows. Contaminants, moving by advective transport in the direction of the groundwater flow, are slowed down due to the presence of chemical interactions. The cause of this behavior is based on the concept that during some of the contaminant's travel time, a given contaminant may become adsorbed to stationary soil particles and, therefore, will not travel along with the bulk groundwater flow. Only upon desorption will a contaminant rejoin the groundwater flow. As a result, the overall travel time of a groundwater contaminant will increase due to the time spent stationary while adsorbed on soil particles. This retardation phenomenon can also occur in contaminant movement in surface water flows. Surface water contaminants that come into contact with sediment lining the flow path may also become adsorbed. As with groundwater contaminants, adsorption of organic compounds onto sediment particles in the surface water flow is influenced by the organic carbon content of the sediment; adsorption of metals is also influenced by the presence of metal oxide coatings on the soil/sediment particles.

E.1.5 Additional Mechanisms

Additional mechanisms, generally secondary in importance, affect fate and transport on a smaller scale. These mechanisms include partitioning, dissolution and precipitation, and biotic uptake.

Partitioning - Chemical contaminants are separated and distributed between various environmental media based on a variety of partitioning coefficients adopted from various engineering disciplines. These include an air-water partitioning coefficient based on the Henry's Law constant (K), an octanol-water partition coefficient (K_{OW}) depicting the ratio of solute concentration in octanol (an organic solvent) to that in water, and a soil-water partition coefficient (K_d) derived from the K_{OW} and the amount of carbon-containing material in the soil. These partition coefficients, based on the chemical properties of a particular contaminant, are described in Section 5.2.

Dissolution and Precipitation

In the environment, water naturally contains detectable quantities of a number of inorganic constituents (metals and salts). These constituents may be present in precipitation or may be the result of surface water runoff, or groundwater contact with, and dissolution of soil particles and rock surfaces. The amount of dissolved species present depends on the solubility of the individual constituent, as well as on the time and degree of contact between the water and soil/rock surfaces. Furthermore, once in solution, dissolved constituents may return to their solid form by precipitation onto soil/rock surfaces.

Under equilibrium conditions, the balance between precipitation and dissolution of an inorganic constituent in a natural water system depends on a number of factors, including:

Acid/Base Chemistry - The balance between H^+ and OH^-, expressed as pH, is a dominant control on aqueous solubility of many inorganics. Typically, the aqueous solubility of many metals increases as pH decreases and the water becomes more acidic. These effects are most notable in areas surrounding mine tailing dumps, as well as in areas where large quantities of acidic wastewater have been disposed.

Oxidation State - The presence of dissolved oxygen and other oxidants influences the ratio of stable states of various inorganics and, therefore, impacts their overall solubility. Reduction-oxidation or redox potentials can also be influenced by biological activity related to contaminant degradation. For example, the dissolution of iron in the environment is strongly influenced by redox reactions which are both biologically and non-biologically mediated.

Bulk Chemistry - The concentration of dissolved inorganics and other solutes determines the type of chemical compounds and complexes that can form, and potentially affects their overall stability. In addition, the total concentration of dissolved ions or ionic strength can affect the solubility of chemical contaminants.

Complexation - Certain soluble organics can form strong chemical bonds to metal ions in solution forming chelates and coordination complexes. These complexes tend to "tie

up" the metal species either in solution thereby preventing them from being adsorbed or precipitated onto soil/rock surfaces, or in an insoluble form that precipitates readily.

Biotic Uptake

A limited quantity of chemical contaminant fate and transport may also be the result of biotic uptake in plant and animal tissue. Typically, organic compounds are absorbed and retained by biotic materials depending on the individual compound's solubility in lipids (fats and oils) present in the plant and animal tissue. Because many of these lipid-soluble compounds have poor solubilities in water, the organic compounds that are easily adsorbed onto organic carbon in soil are also easily accumulated in plant tissue. Uptake of metals, on the other hand, generally increases with increased water solubility and decreased ability to adsorb onto soil particles.

Biotic uptake in plants primarily occurs through the root system. However, adsorption of aerially-deposited dusts and aerosols through plant leaves may also be significant. For most animals, contaminant uptake occurs through the food chain. However, benthic organisms (those living in the bottom sediments of a water body) appear to take up contaminants through direct ingestion and physical contact.

E.2 Chemical Properties that Influence Contaminant Fate and Transport

Several chemical properties strongly influence the fate and transport of contaminants in the environment. Each property, along with its relationship to the various fate and transport properties, is defined below.

E.2.1 Water Solubility

Water solubility is one of the primary chemical characteristics used to assess chemical fate and transport in the environment. The water solubility of a chemical contaminant provides considerable insight into its mobility, stability, tendency to adsorb to soil or sediment, and propensity to accumulate in the environment or bioaccumulate in the food chain.

Chemicals with high water solubilities, greater than 1000 mg/l or 0.1 percent (Ney, 1990), will have a tendency to remain dissolved in the water column and will not likely partition to soil/sediment particles or accumulate in the environment or bioaccumulate in aquatic organisms in the food chain. Highly soluble chemicals are less likely to volatilize from water and are generally more prone to biodegradation and metabolism. As these characteristics indicate, chemicals with higher water solubilities are more likely to be mobile, and therefore less likely to persist, in the environment.

Conversely, chemicals with low water solubilities, less than 10 mg/l or 0.001 percent (Ney, 1990), are generally less mobile and are more likely to adsorb to soil/sediment particles, accumulate and/or bioaccumulate, and persist in the environment. Low solubility chemicals tend to biodegrade or be metabolized less readily in plants and animals.

Many of the VOCs identified during the RI have moderate to high water solubilities. These included: the ketones with the highest solubilities (ranging from very high to miscible), most of the chlorinated compounds with high solubilities, and the aromatic compounds generally with moderate solubilities. The ketones would, therefore, more readily enter into an aqueous solution and migrate in groundwater and surface water than other VOCs. The remaining less soluble VOCs, the SVOCs, with pesticides/PCBs, the dioxins/furans, the metals, and asbestos detected in the study area are more likely to stay adsorbed to soil and sediment particles and be less mobile.

E.2.2 Octanol-Water Partition Coefficient (K_{ow})

The octanol-water partition coefficient (K_{ow}) is a measure of the tendency of an organic compound to partition between organic (in this case, octanol) and aqueous phases. The chemical-specific K_{ow} is an indicator of its water solubility, mobility, sorption, and bioaccumulation. It has also been shown to correlate well with bioconcentration factors in aquatic organisms and the adsorption to soil and sediment (Howard, 1990).

The higher the K_{ow} value of a specific chemical, the greater is the chemical's potential for sorption to soil/sediment particles, the lower its mobility, and the more likely it is to accumulate

in the environment and bioaccumulate in the food chain. A high K_{OW}, greater than 1000 (Ney, 1990), is indicative of low water solubility and greater persistence in the environment.

Conversely, the lower the K_{OW} value, the greater is the chemical's potential to biodegrade and be metabolized by plants and animals. A low K_{OW}, less than 500 (Ney, 1990), is indicative of high water solubility, high mobility, and little or no accumulation or bioaccumulation.

The VOCs identified in the study area have widely varied K_{OW} values. These included: the ketones with the lowest K_{OW} values; the chlorinated compounds with generally low K_{OW} values, with the exception of tetrachloroethene (PCE) with a high K_{OW}; and the aromatic compounds generally with low to moderate K_{OW} values, except for ethylbenzene with a high K_{OW}. The VOCs, as a group, have a stronger tendency to enter into an aqueous solution and migrate in groundwater and surface water than the other organic compounds. Most other organic compounds detected in the study area have high K_{OW} values, indicating a stronger preference to adsorb to soil/sediment particles and be less mobile. Metals and asbestos also preferentially adsorb to soil/sediment particles, due more to their low water solubilities rather than their ability to partitioning between organic and aqueous phases.

E.2.3 Adsorption Partition Coefficient (K_d & K_{OC})

The adsorption partition coefficients (K_d and K_{OC}) are measures of the tendency of an organic contaminant to bind to soil or sediment particles. Adsorption coefficients are useful in evaluating the mobility of contaminants in the subsurface media. K_d is an experimentally derived coefficient which measures the tendency of a chemical to sorb to a particular soil/ sediment media. The K_d is both a chemical- and a sorption media-specific coefficient related to the organic carbon content of the media. K_{OC}, the organic carbon partition coefficient, is a chemical-specific value derived by dividing K_d by the organic carbon content of the sorption media in order to normalize the value to the organic carbon content of the media. K_{OC} is defined as the ratio of the amount of chemical absorbed per unit weight of organic carbon in the media to the concentration of the chemical in solution at equilibrium.

Chemicals with high adsorption coefficients have a tendency to bind to soil/sediment particles containing organic carbon and are, therefore, relatively immobile in groundwater. A relationship developed between an organic compound's K_{OC} and its mobility is as follows (Dragun, 1988):

K_{OC} (ml/g)	Mobility Class
>2,000	Immobile
500-2,000	Low Mobility
150-500	Intermediate Mobility
50-150	Mobile
<50	Very Mobile

Most of the VOCs identified in the study area have low to moderate K_{OC} values. These included: the ketones with the lowest K_{OC} values; and the chlorinated and aromatic compounds with low to moderate K_{OC} values, with the exception of PCE with a high K_{OC}. The VOCs, as a group, have a low tendency to adsorb to soil/sediment particles and are, therefore, more mobile in the environment than the other organic compounds. Most other organic compounds detected in the study area have high K_{OC} values, indicating a tendency to sorb to soil/sediment particles and be more persistent in the study area. Metals and asbestos also preferentially adsorb to soil/sediment particles, due in large part to their low water solubilities.

E.2.4 Vapor Pressure

Vapor pressure is a measure of the ability of a compound volatilizing from the pure liquid phase into the vapor phase. It provides an indication of the rate at which a chemical will volatilize from soil, sediment, or water. This property is of primary significance at environmental interfaces, such as surficial soil/air, surficial sediment/air, and surface water/air.

Chemicals with higher vapor pressures are expected to enter into the vapor phase more readily than those with lower vapor pressures. If chemicals with low vapor pressures (less than 10^{-6} mm Hg) are present in the atmosphere, they are most likely associated with adherence to suspended particulate matter.

VOCs all have relatively high vapor pressures and will, therefore, tend to enter the vapor phase in the presence of air. Vapor pressures for the major groups of VOCs identified in the study area (ketones, chlorinated hydrocarbons, and aromatic hydrocarbons) are generally many orders of magnitude higher than vapor pressures for SVOCs, pesticides/PCBs, and dioxins/furans. The VOCs identified in the RI are likely to volatilize from the soil into the soil pore space in the vadose zone, and from surface water into the ambient air. Metals and asbestos, having very low or immeasurable vapor pressures, do not readily volatilize.

E.2.5 Henry's Law Constant (K)

Henry's Law Constant (K) is an air-water partition coefficient which serves to indicate the tendency of a chemical to volatilize or evaporate from water. K can be expressed as dimensionless (relating the concentration of a chemical in the vapor phase to its concentration in water at equilibrium conditions) or with units (representing the ratio of the vapor pressure of the chemical in atmospheres to its water solubility in moles/m^3).

In general, chemicals with low K values (less than 5×10^{-6} atm·m^3/mole) have a low tendency to volatilize from surface water into the ambient air or from groundwater into the soil pore spaces. For chemicals with higher K values, volatilization and diffusion into the ambient air and/or soil pore spaces could be a significant fate and transport mechanism (Dragun, 1988).

The VOCs identified in the study area all have moderate to high K values. These included: the ketones with moderate K values; and the chlorinated and aromatic compounds with high K values. The VOCs would, therefore, be likely to volatilize from the aqueous phase to the vapor phase. Most SVOCs, pesticides/PCBs, and dioxins/furans detected in the study area have low to moderate K values, indicating they are less likely to volatilize from the aqueous phase. Metals and asbestos, having very low or immeasurable K values, do not readily volatilize from the aqueous environment.

E2.6 Specific Gravity

Specific gravity is defined as the ratio of the weight of a given volume of a pure chemical at a specified temperature to the weight of the same volume of water at a given temperature.

Specific gravity indicates the tendency of a chemical to float or sink in water given that it is present in its pure form or at a very high concentration.

For contaminants that exist in a separate phase from the water, those with specific gravities less than 1 (such as aromatic hydrocarbons and ketones) will tend to rise or float to the top of the water column as a sheen or top layer. Contaminants with specific gravities greater than 1 (such as most chlorinated hydrocarbons, pesticides/PCBs, and dioxins/furans) tend to mix and/or sink in the water column. Since metals and asbestos generally have low water solubilities, and do not readily exist in the environment as a separate phase, they due not tend to either rise or sink in the water column based on their specific gravities. Instead, they may rise or sink along with particles to which they might adsorb.

E.3 Physical State of Contaminants in Environmental Media

The physical state in which contaminants exist in various environmental media dictate the manner in which they may migrate or be transported. The phases in which organic and inorganic contaminants may be present in the sediment/soil and surface water/pore water within the OU3 study area, as well as the potential to migrate from these phases, are discussed below. Issues related to groundwater contaminants are addressed in a qualitative fashion as it relates to the migration of contaminants to or from soil/sediment and surface water.

E.3.1 Soil/Sediment Contaminants

Organic and inorganic contaminants introduced at the ground surface through spills, discharges, or disposal may contaminate the underlying soil/sediment, migrate to downgradient groundwater and surface water/pore water sources, and/or be discharged into the atmosphere. These contaminants may be present in soils and sediment in three principal physical phases: solid, liquid, or vapor.

Solid Phase - Inorganic contaminants (metals and asbestos) are often present in the solid phase, as bulk solids or as suspended particulates in aqueous discharge, when disposed on the surface or into the subsurface. In the solid phase, inorganics are relatively immobile in a

soil or sediment matrix unless the particle sizes are sufficiently small that migration may occur as a suspended particle or colloid. Solid phase metal contaminants may also be broken down and/or leached by precipitation or subsequent liquid spills that solubilize the inorganic constituents, and may thereby become mobile.

Organic contaminants are rarely present in the environment in the solid phase.

Liquid Phase - Most of the organic contaminants related to industrial sites are present in the liquid phase (as a separate product or a mixture of liquid chemicals) or in the aqueous phase (dissolved in a water-based solution). Once these liquids enter unsaturated soil or sediment, several processes may occur. The organic contaminants may: (1) become adsorbed to the soil/sediment matrix because of low water solubilities, high soil/sediment organic carbon partition coefficients, and/or high soil/sediment organic content; (2) remain in a liquid phase in the soil/sediment pore water spaces as a result of pore size and interfacial tension; or (3) volatilize into soil/sediment pore spaces if the contaminants have high vapor pressures or high air-liquid partition coefficients. If present in sufficient quantity, a liquid contaminant may migrate downward under the influence of gravity and enter underlying groundwater.

Metals may also be present in the liquid phase, as dissolved ions. In low pH conditions, more metals are apt to be present as dissolved ions and are, therefore, more readily available to mobilize. For instance, aqueous acid solutions used for cleaning metal surfaces contain numerous dissolved metals. If the solution is discharged into soil/sediment, some of the metals may remain in the aqueous phase and/or additional metals present in the soil/sediment may dissolve, if the pH is sufficiently low. In addition, some metals may precipitate from solution in the presence of minerals in the soil/sediment matrix and become adsorbed onto soil/sediment particles.

Asbestos is not present in the environment in the liquid phase.

Vapor Phase - Organic contaminants, principally VOCs, present in an unsaturated soil or sediment matrix may volatilize into the pore spaces and migrate through the soil/sediment if the vapor pressure is sufficiently high. Once in the vapor phase, VOCs can migrate readily if no barriers impede their movement.

Other organic contaminants (with lower vapor pressures), as well as inorganic contaminants, are not typically present in the environment in the vapor phase.

E.3.2 Surface Water Contaminants

Organic and inorganic contaminants introduced at the ground surface through spills, discharges, or disposal may contaminate the surface water, migrate to underlying soil/sediment and groundwater sources, and/or be discharged into the atmosphere. These contaminants may be present in surface water in three principal physical phases: solid, liquid (aqueous or non-aqueous), or vapor.

Solid Phase - Metals, asbestos, and some organic compounds that are either insoluble or otherwise remain undissolved in water may migrate in the surface water as suspended particulates or colloids. Metal ions may also adsorb to the surface of colloidal particles, through surface attractions, and migrate through the surface water.

Aqueous Liquid Phase - Dissolved aqueous phase organic and inorganic contaminants present in surface water may be transported simultaneously by three processes: advection, mechanical dispersion, and molecular diffusion. During transport, contaminants may interact with other aqueous-phase contaminants and ions. A variety of chemical, physical, and biological interactions can significantly retard or accelerate the rate of contaminant transport, or transform the contaminants into other chemicals or phases.

Undissolved organic and inorganic contaminants, as well as asbestos, are not present in the environment in the aqueous liquid phase. In surface water or groundwater aquifers, they are generally present as solid particulates or colloids.

Non-Aqueous Liquid Phase - Non-aqueous phase liquids (NAPLs), such as organic solvents or fuels containing little or no water, may exist in surface water as a separate/immiscible liquid. Contaminants present in this phase behave differently than those dissolved in the aqueous phase. NAPLs are a continuing source of dissolved-phase organics to surface water and groundwater. Because NAPLs have limited surface areas relative to their volume, dissolution may extend over an indefinite amount of time.

Dense NAPLs (DNAPLs), such as TCE which has a higher density than water, tend to migrate vertically downward under the influence of gravity in response to both the physical properties of the contaminant and the characteristics of the surface water (or underlying groundwater aquifer). Contaminant properties influencing transport include density, viscosity, and interfacial tension. Groundwater aquifer characteristics influencing transport include pore size, permeability, general stratigraphy (location and topography of low-permeability units), and micro-structures (such as small fractures in subsurface soil media or bedrock) (EPA, 1992).

Light NAPLs (LNAPLs), such as toluene which has a lower density than water, are generally present near the surface of surface water sources (or at the water table surface of groundwater aquifers). LNAPLs tend to migrate laterally along the top of the water surface in response to the organic properties and groundwater aquifer characteristics described above for DNAPLs.

Metals and asbestos are not typically present in the environment in the non-aqueous liquid phase. If present in surface water or groundwater aquifers, they are generally found as solid particulates or colloids.

Vapor Phase - Organic contaminants, principally VOCs, present in surface water may volatilize into the atmosphere if the vapor pressure is sufficiently high. Once in the vapor phase, VOCs can migrate readily if no barriers impede their movement.

Other organic contaminants with lower vapor pressure, as well as inorganic contaminants, are not typically present in the environment in the vapor phase.

E.4.1 Contaminant Fate and Transport in Sediment and Surface Water – Ferry Creek and Adjacent Wetlands

Various chemical contaminants are present in the sediment and surface water in the Ferry Creek channel, and in sediment in the wetlands adjacent to the channel, the western reaches of the ditch extending from Ferry Creek westward between properties located at 250 and 230 Ferry Boulevard, and in the single location sampled in the triangular-shaped property between East Broadway and Ferry Boulevard. Several pathways are available for contaminants to have

entered these media, and for them to subsequently be transported downstream and/or to adjacent media.

The chemical and physical properties of the chemical contaminants affects their ability to migrate into the sediment and surface water in the Ferry Creek Area, and to subsequently be transported to adjacent media. Contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend adsorb to the sediment particles. These contaminants are apt to remain localized in undisturbed sediment, or to migrate on sediment particulates transported by surface water flows, rainwater runoff, tidal fluctuations, or groundwater discharge. Contaminants adsorbed to sediment particles may later become desorbed and/or dissolved following contact with solvents or acids, if present. Contaminants with low soil/sediment adsorption coefficients, high water partition coefficients, or high water solubilities would tend to remain in solution and be free to migrate with naturally occurring waters.

Groundwater discharge to the creek, tidal fluctuations, and seep areas along the Ferry Creek channel may also cause contaminants to be transported into and/or pass through the sediment. Again, those contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend to adsorb to the sediment particles; while those with low soil/sediment adsorption coefficients, high water partition coefficients, and high water solubilities would tend to remain in solution and be free to migrate with natural water sources. Groundwater discharges and seeps containing organic solvents or acids may also cause leaching of chemical contaminants from the surface of sediment particles, and subsequent migration into naturally occurring waters.

The fate and transport of contamination is, therefore, dependent on the type of chemical contaminant present. A discussion of the fate and transport of the various categories of chemical contaminants in sediment and surface water throughout the Ferry Creek Area is presented below. Since no elevated levels of SVOCs or PCBs were present in surface water samples throughout Ferry Creek, and since no samples were collected for analysis of dioxins/furans and asbestos (since these contaminants are virtually insoluble in water), the fate and transport discussion related to surface water is limited to VOCs and metals.

VOCs - Due to their high water solubilities, low soil/sediment partition coefficients, and low octanol-water partition coefficients, VOCs in a sediment/surface water environment tend to remain dissolved in, and free to be transported by, the aqueous media; they do not readily adsorb to sediment particles. Furthermore, VOCs present in surface sediment located in relatively dry locations have more of a tendency to volatilize into the atmosphere than other organic contaminants due to their high vapor pressures. VOCs present in surface water (especially in regions of high turbulence or aeration) also have a tendency to volatilize into the atmosphere due to their high vapor pressures and high air-water partition coefficients.

These chemical properties support the infrequent detection of elevated levels of VOCs in both surface and subsurface sediment throughout the Ferry Creek channel and the adjacent wetland areas, and the corresponding frequent detection of elevated levels of VOCs, primarily chlorinated hydrocarbons, in surface water throughout the length of Ferry Creek.

In the sediment, the highest concentration of an individual VOCs (3,400 ug/kg 1,1-DCA; detected more than an order of magnitude greater than any other VOC) was detected in surface sediment in the Ferry Creek channel just upgradient of the culvert under East Broadway in Area A-1. At this location, the surface water flow was slow moving and the channel was deep, factors may have resulted in deposition of sediment, higher organic-content silts, and/or DNAPLs that could encourage adsorption of VOCs onto sediment/silt particles.

In the surface water, the higher concentrations included: 1,1-DCE, 1,2-DCE, and 1,1,1-TCA in the northern reaches of Ferry Creek near the first major bend in the channel and in the channel extending into the western arm of the wetlands both adjacent to the Morgan Francis property in Area A-1; and 1,1,1-TCA south of the culvert under East Broadway and in the vicinity of an observed seep in the south-central region of Area A-3. These results may have been caused by migration from a nearby source area due to surface runoff or groundwater discharge.

SVOCs (primarily PAHs) - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, SVOCs in a sediment/surface water environment are more readily adsorbed to sediment particles than are VOC contaminants. Furthermore, SVOCs present in surface sediment located in relatively dry locations have a

tendency to volatilize into the atmosphere to some degree. Their ability to volatilize, however, is less than that of VOCs (with higher vapor pressures) but greater than that of PCBs and dioxins/furans (with much lower vapor pressures).

These chemical properties support the frequent detection of elevated levels of SVOCs, primarily PAHs, in surface sediment throughout the Ferry Creek channel and the adjacent wetland areas. The higher frequency of PAH detection in surficial samples, especially in higher deposition areas in the Ferry Creek channel, suggests that the PAHs were adsorbed onto sediment particles that may have migrated to these areas with surface water flows, rainwater runoff, or tidal fluctuations. Less frequent detections in subsurface sediment suggest that the contaminant source is relatively recent (resulting in surficial deposition of contamination) and/or the particles to which the PAHs adsorb have relatively low densities (resulting in frequent resuspension and surficial redeposition).

The highest concentrations of PAHs were detected in surface sediment in the northern reaches of Ferry Creek near the first major bend in the channel adjacent to the Morgan Francis property in Area A-1, and south of the culvert under East Broadway and in the vicinity of an observed seep in south-central region of Area A-3. These results may have been caused by migration from a nearby source due to surface water runoff or groundwater discharge, and subsequent adsorption to sediment particles.

PCBs - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, PCBs in a sediment/surface water environment are more readily adsorbed to sediment particles than are either VOC or SVOC contaminants. Furthermore, PCBs present in surface sediment located in relatively dry locations have little or no tendency to volatilize into the atmosphere due to their low vapor pressures, compared to the highly volatile VOCs and somewhat volatile SVOCs.

These chemical properties support the frequent detection of elevated levels of PCBs, particularly Aroclor 1262 and Aroclor 1268 (with less frequent detection of Aroclor 1248, Aroclor 1254, and Aroclor 1260), in both surface and subsurface sediment throughout the Ferry Creek channel and the adjacent wetland areas. The high frequency of PCB detection in the sediment suggests that the PCBs were adsorbed onto sediment particles that were placed

there as fill material from the Raymark Facility or may have migrated to these areas with surface water flows, rainwater runoff, or tidal fluctuations. The relatively similar frequency of detection in both surface and subsurface sediment in the Ferry Creek channel suggests that deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth) and/or the particles to which the PCBs adsorb have relatively high densities (resulting in infrequent resuspension and redeposition of previously deposited sediment).

The levels of PCBs were relatively consistent in sediment throughout the Ferry Creek channel and adjacent wetlands, with the highest levels detected in both surface and subsurface samples immediately upgradient of the culvert under East Broadway in Area A-1 and immediately downgradient of the culvert in Area A-3.

Dioxins and Furans (as TEF) - As with PCBs, dioxins and furans have low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, resulting in a tendency for the contaminants to adsorb to sediment particles in a sediment/surface water environment. Furthermore, dioxins and furans present in surface sediment located in relatively dry locations have little or no tendency to volatilize into the atmosphere due to their low vapor pressures, again similar to PCBs.

These chemical properties support the frequent detection of elevated TEF levels in surface sediment throughout the Ferry Creek channel, and the somewhat less frequent detection in subsurface sediment from the northern and southern reaches of the Ferry Creek channel. The high frequency of detection suggests that the dioxins and/or furans were absorbed onto sediment particles that migrated to these areas with surface water flows, rainwater runoff, or tidal fluctuations. The relatively similar frequency of detections in surface and subsurface sediment suggests that deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth) and/or the particles to which the dioxins and/or furans adsorb have relatively high densities (resulting in infrequent resuspension and redeposition of previously deposited sediment).

The highest TEF levels were detected in both surface and subsurface sediment samples immediately upgradient of the culvert under East Broadway in Area A-1, and immediately downgradient of the culvert in Area A-3.

Metals (primarily Copper and Lead) - Metals tend to be less mobile in the environment than organic contaminants. Under natural conditions, dissolution of metals may occur in the presence of water (due to surface water flows, rainwater runoff, or tidal fluctuations) and some metal ions may migrate. However, many of these dissolved metals can readily precipitate out of solution and adsorb to sediment particles. Copper and lead will be more soluble and remain in an aqueous state if the pH is sufficiently low.

These properties support the frequent detection of elevated levels of copper and lead in both surface and subsurface sediment throughout the Ferry Creek channel and adjacent wetlands, and their corresponding infrequent detection in surface water.

In the sediment, the similar frequency of detections in surface and subsurface samples suggests that deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth) and/or the metals migrated in the dissolved state and precipitated on sediment particles upon contact. The highest levels detected in both surface and subsurface samples immediately upgradient of the culvert under East Broadway in Area A-1, and immediately downgradient of the culvert in Area A-3. Elevated concentrations of barium were detected at similar frequencies, with the highest concentrations at the same locations, as copper and lead.

The fact that copper and lead are not apt to dissolve in an aqueous environment under natural conditions (neutral pHs) is supported by their low frequency of detection in surface water from Ferry Creek. In particular, copper and lead were not detected above background concentrations in surface water from north of the culvert under East Broadway, and elevated levels were detected infrequently in surface water from south of the culvert.

Elevated concentrations of barium (being much more water soluble) were detected in surface water throughout the entire length of Ferry Creek.

The highest concentration of these three metals were detected in the high deposition area at the confluence of the Ferry Creek channel with the ditch extended westward between 250 and 230 Ferry Boulevard in Area A-3. These metals may have been present in suspended particulate in this area, or they may have been leached out of contaminated sediment or soils.

It is important to note that elevated levels of lead and/or copper were detected in sediment and soil samples submitted for SPLP analysis from regions north of the culvert under East Broadway (including: five soil samples throughout Area A-1) and south of the culvert (including: three soil samples from the commercial/industrial properties in the northern region of Area A-2, one sediment sample from the northeastern region of the wetland area in Area A-3, and two soil samples in the region north of the Ferry Creek channel in Area A-3). This suggests that these materials may result in a continual release of copper and lead into the surrounding media.

Asbestos - Asbestos is relatively immobile in the environment, except through bulk advective movement or dispersion in aqueous or airborne environments.

Elevated levels of asbestos were detected frequently in both surface and subsurface sediment in the Ferry Creek channel north of the culvert under East Broadway and in the limit number of subsurface sediment samples collected in the triangular-shaped property located between East Broadway and Ferry Boulevard in Area A-1. Less frequent detections were in both surface and subsurface sediment throughout that section of the Ferry Creek channel and adjacent wetlands south of the culvert in Area A-3. The similar frequency of detection in both surface and subsurface sediment in the northern section of the Ferry Creek channel suggests that deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth). The findings further suggest that asbestos may have been transported in discharge from Lagoon No. 4, as well as by transport in rainwater runoff from asbestos-laden fill materials placed in close proximity to the northern section of the Ferry Creek channel.

The highest concentrations of asbestos were detected in surface and subsurface samples north of the culvert under East Broadway along the central portion of the Ferry Creek channel in Area A-1, in subsurface samples from the triangular-shaped property between East

Broadway and Ferry Boulevard in Area A-1, and in surface samples south of the culvert from the Ferry Creek channel and adjacent wetlands in the northern and north-central regions of Area A-3.

E.4.2 Contaminant Fate and Transport in Soil – Ferry Creek and Adjacent Wetlands

Various chemical contaminants are also present in the soil located at commercial and industrial properties adjacent to Ferry Creek and the wetland areas. Several pathways are available for contaminants to have entered the soil in these regions, and for them to subsequently be transported to adjacent media.

As with the sediment and surface water, the chemical and physical properties of the chemical contaminants in soil affects their ability to migrate in the Ferry Creek Area, and to subsequently be transported to adjacent media. Contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend to adsorb to the soil particles or remain in the soil pore spaces. These contaminants are apt to remain localized in undisturbed soil. Contaminants in soil pore spaces or adsorbed to soil particles may later become mobilized through contact with solvents or acids, precipitation, or groundwater. Contaminants with low soil adsorption coefficients, high water partition coefficients, and high water solubilities would tend to remain in solution and be free to migrate with naturally occurring waters either downward to the water table or laterally to a surface water source.

The fate and transport of contamination is, therefore, dependent on the type of chemical contaminant present. A discussion of the fate and transport of the various categories of chemical contaminants in soil throughout the Ferry Creek Area is presented below.

VOCs - Due to their high water solubilities, low soil partition coefficients, and low octanol-water partition coefficients, VOCs are readily leached from soil and transported into an aqueous media. Furthermore, VOCs present in surface soil have more of a tendency to volatilize into the atmosphere, and VOCs absorbed to soil particles or present in soil pore spaces are more apt to volatilize into unsaturated soil pore spaces or voids and may potentially migrate to the

surface or follow some other preferential flow paths (subsurface drains, utility conduits, etc.), than other organic compounds due to their high vapor pressures.

These chemical properties support the infrequent detection of elevated levels of VOCs in surface soil and the somewhat higher frequency in subsurface soil throughout the Ferry Creek Area. The higher concentrations of VOCs, primarily aromatic hydrocarbons (benzene, toluene, ethylbenzene, and/or xylenes (total)), were detected in subsurface soils located in a few of commercial and industrial properties between Ferry Boulevard and the Ferry Creek channel in Area A-2. The presence of these contaminants may have been the result of localized releases at the properties.

SVOCs (primarily PAHs) - Due to their low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, SVOCs are more readily adsorbed to soil particles than are VOC contaminants. Furthermore, SVOCs present in surface soil have a tendency to volatilize into the atmosphere to some degree, and SVOCs adsorbed to soil particles or present in soil pore spaces have a tendency to volatilize into unsaturated soil pore spaces or voids and may potentially migrate to the surface or follow some other preferential flow paths to some degree. Their ability to volatilize, however, is less than that of VOCs (with higher vapor pressures) but greater than that of PCBs and dioxins/furans (with much lower vapor pressures).

These chemical properties support the frequent detection of elevated levels of SVOCs, primarily PAHs, in surface soil and the somewhat lower frequency in subsurface soil throughout the Ferry Creek Area. The high frequency of detections suggests that the PAHs were sorbed onto soil particles placed in the area as fill material. The somewhat higher frequency of detections in the surface samples suggests a more recent source of contamination, such as residual from paving of nearby roads and parking lots.

The highest concentrations of PAHs were detected in surface soils collected in the vicinity of paved roadways and/or parking lots in Areas A-1, A-2, and A-3, and may have been a result of asphalt paving activities. High levels were also detected in subsurface samples from a few locations throughout the commercial/industrial properties in Areas A-1 and A-2.

PCBs - Due to their low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, PCBs are more readily adsorbed to soil particles than are either VOC or SVOC contaminants. Furthermore, PCBs present in surface soil have less of a tendency to volatilize into the atmosphere, and PCBs adsorbed to soil particles or present in soil pore spaces have less of a tendency to volatilize into unsaturated soil pore spaces or voids and to potentially migrate to the surface or follow some other preferential flow paths due to their low vapor pressures, compared to the highly volatile VOCs and somewhat volatile SVOCs.

These chemical properties support the frequent detection of elevated levels of PCBs, particularly Aroclor 1262 and Aroclor 1268 (with less frequent detection of Aroclor 1242, Aroclor 1248, Aroclor 1254, and Aroclor 1260), in both surface and subsurface soil throughout the Ferry Creek Area. The high frequency of PCB detection in both surface and subsurface soil suggests that the PCBs were sorbed onto soil particles placed in the area as fill material from the Raymark Facility. Due to the lack of mobility of PCBs in the environment, the PCBs are likely to have remained where they were deposited.

The levels of PCBs were relatively consistent in soil samples throughout the Ferry Creek Area, with the highest levels detected in both surface and subsurface samples north of the culvert under East Broadway in the central and southern regions of Area A-1, south of the culvert/west of the Ferry Creek channel in the northern commercial/industrial properties of Area A-2, and south of the culvert/east of the Ferry Creek channel in the northern region of Area A-3.

Dioxins and Furans (as TEF) - As with PCBs, dioxins and furans have low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, resulting in a tendency for the contaminants to adsorb to soil particles. Furthermore, dioxins and furans present in surface soil have less of a tendency to volatilize into the atmosphere, and those contaminants adsorbed to soil particles or present in soil pore spaces have less of a tendency to volatilize into unsaturated soil pore spaces or voids and to potentially migrate to the surface or follow some other preferential flow paths due to their low vapor pressures, again similar to PCBs.

These chemical properties support the frequent detection of elevated TEF levels in surface soil throughout the Ferry Creek Area, and the somewhat less frequent detection in subsurface soil.

The higher frequency of detections in the surface soils is due to the lack of elevated TEF values in the deeper samples collected. Due to the low likelihood of dioxin/furan mobility in the environment, they are likely to have remained where they were deposited.

The TEF levels were relatively consistent in soil samples throughout the Ferry Creek Area, with the highest levels detected in surface samples north of the culvert under East Broadway in the central region of Area A-1, and south of the culvert and north of the Ferry Creek channel along the eastern border adjacent to wetland area in Area A-3; and subsurface soil north of the culvert in the southern and southwestern regions of Area A-1, south of the culvert and west of the Ferry Creek channel at one of the properties in the northern region of Area A-2, and south of the culvert and north of the Ferry Creek channel along the eastern border adjacent to wetland area in Area A-3.

Metals (primarily Copper and Lead) - Metals tend to be less mobile in the environment than organic contaminants. Under natural conditions, dissolution of metals may occur in the presence of water (due to rainwater runoff or groundwater infiltration) and some metal ions may migrate. However, these dissolved metals can readily precipitate out of solution and adsorb to soil particles. Metals will be more soluble and remain in an aqueous state if the pH is sufficiently low.

These properties support the frequent detection of elevated levels of copper and lead in both surface and subsurface soil throughout the Ferry Creek Area. The somewhat higher frequency of detections in the surface soils is due to the lack of elevated values in the deeper samples collected. Due to the low likelihood of metals mobility in the environment, they are likely to have remained where deposited in the fill material from the Raymark Facility.

The highest levels of both copper and lead were detected in both surface and subsurface samples north of the culvert under East Broadway in region south and west of the Ferry Creek channel in Area A-1, south of the culvert and west of the Ferry Creek channel in the northern properties in Area A-2, and south of the culvert both north and east of the Ferry Creek channel in Area A-3. Elevated concentrations of barium were detected at similar frequencies, with the highest concentrations at the same locations as copper and lead.

It is important to note that elevated levels of lead and/or copper were detected in soil samples submitted for SPLP analysis from regions north of the culvert under East Broadway (including: five soil samples throughout Area A-1) and south of the culvert (including: three soil samples from the commercial/industrial properties in the northern region of Area A-2, and two soil samples in the region north of the Ferry Creek channel in Area A-3). This suggests that these materials may result in a continual release of low levels of copper and lead into the surrounding media.

Asbestos - Asbestos is relatively immobile in the environment, except through bulk advective movement or dispersion in aqueous or airborne environments.

Elevated levels of asbestos were detected relatively frequently in both surface and subsurface soil through the Ferry Creek Area, in similar regions as the presence of elevated levels of copper and lead. Due to the low likelihood of asbestos mobility in the environment, it is likely to have remained where deposited in the fill material from the Raymark Facility.

E.4.3 Contaminant Fate and Transport in Sediment and Surface Water – Housatonic River Area

Various chemical contaminants are present in the sediment and surface water in the Housatonic River Area. Several pathways are available for contaminants to have entered these media, and for them to subsequently be transported to adjacent media.

The chemical and physical properties of the chemical contaminants affects their ability to migrate into the sediment and surface water, and to subsequently be transported to adjacent media. Contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend adsorb to the sediment particles. These contaminants are apt to remain localized in undisturbed sediment, or to migrate on sediment particulates transported by surface water flows, rainwater runoff, or tidal fluctuations. Contaminants adsorbed to sediment particles may later become desorbed and/or dissolved following contact with solvents or acids, if present. Contaminants with low soil/sediment adsorption coefficients, high water partition coefficients, or high water solubilities would tend to remain in solution and be free to migrate with naturally occurring waters.

Tidal fluctuations may also cause contaminants to be transported into and/or pass through the sediment. Again, those contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend to adsorb to the sediment particles; while those with low soil/sediment adsorption coefficients, high water partition coefficients, and high water solubilities would tend to remain in solution and be free to migrate with natural water sources.

The fate and transport of contamination is, therefore, dependent on the type of chemical contaminant present. A discussion of the fate and transport of the various categories of chemical contaminants in sediment and surface water throughout the Housatonic River Area is presented below. Since no elevated levels of SVOCs (except low levels of phthalates in two samples from Area B) or PCBs were present in surface water samples, and since no samples were collected for analysis of dioxins/furans and asbestos (since these contaminants are virtually insoluble in water), the fate and transport discussion related to surface water is limited to VOCs and metals.

VOCs - Due to their high water solubilities, low soil/sediment partition coefficients, and low octanol-water partition coefficients, VOCs in a sediment/surface water environment tend to remain dissolved in, and free to be transported by, the aqueous media; they do not readily adsorb to sediment particles. Furthermore, VOCs present in surface sediment located in relatively dry locations have more of a tendency to volatilize into the atmosphere than other organic contaminants due to their high vapor pressures. VOCs present in surface water (especially in regions of high turbulence or aeration) also have a tendency to volatilize into the atmosphere due to their high vapor pressures and high air-water partition coefficients.

These chemical properties support the infrequent detection of elevated levels of VOCs (primarily 2-butanone, acetone, and carbon disulfide) in surface sediment, and even less frequent detection in subsurface sediment throughout the Housatonic River Area. VOCs were also detected infrequently in surface water, including: acetone and chlorinated hydrocarbons in a limited number of samples from Area B, and acetone in one sample from Area D; elevated levels of VOCs were not detected in Area C.

The highest concentrations of VOCs were detected in surface sediment from the Ferry Creek channel immediately south of bridge under Ferry Boulevard in the western region, and in the

mouth of the Ferry Creek channel in the northeastern region of the Area B. In both of these areas, factors may have resulted in deposition of sediment, higher-organic content silts, and/or DNAPLs that could encourage adsorption of VOCs onto sediment/silt particles.

SVOCs (primarily PAHs) - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, SVOCs in a sediment/surface water environment are more readily adsorbed to sediment particles than are VOC contaminants. Furthermore, SVOCs present in surface sediment located in relatively dry locations have a tendency to volatilize into the atmosphere to some degree. Their ability to volatilize, however, is less than that of VOCs (with higher vapor pressures) but greater than that of PCBs and dioxins/furans (with much lower vapor pressures).

These chemical properties support the infrequent detection of elevated levels of SVOCs, primarily PAHs, in surface sediment samples and the less frequent detection in subsurface sediment in the Housatonic River Area. The higher frequency of PAH detection in surficial samples suggests that the PAHs were adsorbed onto sediment particles that may have migrated to the areas with surface water flows, rainwater runoff, or tidal fluctuations. Less frequent detections in subsurface sediment suggests that the contaminant source is relatively recent (resulting in surficial deposition of contamination) and/or the particles to which the PAHs adsorb have relatively low densities (resulting in frequent resuspension and surficial redeposition).

The highest concentrations of PAHs were detected in the northwestern region of the Delbuono wetlands adjacent to the lower Ferry Creek channel and downgradient in the channel opposite the wetlands in Area B, along the eastern border adjacent to Shore Road in Area C, and north of the dry dock near the southern portion of the paved parking lot in Area D. These results may have been caused by migration from a nearby source from surface water flows, rainwater runoff, or tidal fluctuations, and subsequent adsorption to sediment particles.

PCBs - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, PCBs in a sediment/surface water environment are more readily adsorbed to sediment particles than are either VOC or SVOC contaminants. Furthermore, PCBs present in surface sediment located in relatively dry locations have little or

no tendency to volatilize into the atmosphere due to their low vapor pressures, compared to the highly volatile VOCs and somewhat volatile SVOCs.

These chemical properties support the relatively frequent detection of elevated levels of PCBs, particularly Aroclor 1262 and Aroclor 1268 (with less frequent detection of Aroclor 016, Aroclor 1242, Aroclor 1248, Aroclor 1254, and Aroclor 1260), in the surface sediment and less frequent detection in subsurface sediment samples collected in the Housatonic River Area. The higher frequency of PCB detection in surficial samples suggests that the PCBs were adsorbed onto sediment particles that may have migrated to the areas with surface water flows, rainwater runoff, or tidal fluctuations. Less frequent detections in subsurface sediment suggests that the contaminant source is relatively recent (resulting in surficial deposition of contamination) and/or the particles to which the PCBs adsorb have relatively low densities (resulting in frequent resuspension and surficial redeposition).

PCBs were detected more frequently in the surface sediment from Ferry Creek channel north of the Delbuono wetlands in Area B, than the two areas further down stream along the Housatonic River. This is believed to be due to the proximity of this area to, and potential contaminant migration from, contaminants present in the Ferry Creek Area. The detection of PCBs in all three areas, however, may also be attributed to the placement of contaminated fill materials from the Raymark Facility in or adjacent to the wetland areas.

Dioxins and Furans (as TEF) - As with PCBs, dioxins and furans have low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, resulting in a tendency for the contaminants to adsorb to sediment particles in a sediment/surface water environment. Furthermore, dioxins and furans present in surface sediment located in relatively dry locations have little or no tendency to volatilize into the atmosphere due to their low vapor pressures, again similar to PCBs.

These chemical properties support the frequent detection of elevated TEF levels in surface sediment and the less frequent detection in subsurface samples throughout the Housatonic River Area. The higher frequency of detection in surface samples suggests that the dioxins and/or furans were adsorbed onto sediment particles that migrated to these areas with surface water flows, rainwater runoff, or tidal fluctuations. Less frequent detections in subsurface

sediment suggests that the contaminant source is relatively recent and/or the particles to which the dioxins and/or furans adsorb have relatively low densities (resulting in frequent resuspension and surficial redeposition).

The highest TEF levels were detected surface sediment in the narrow wetland area in the mid-western region of Area B, both surface and subsurface sediment in the southwestern region and in the wetlands east of Shore Road in Area C, and both surface and subsurface sediment near the dry dock in the southern region of Area D. It is important to note that elevated TEF levels were detected more frequently in the wetland area than in the Ferry Creek channel. These results suggest that the source may be based on surface disposal of contaminated fill materials and/or the migration of dioxins/furans on suspended in surface water flows that tend to accumulate in the wetlands were the sediment/silt media may be higher in organic carbon.

Metals (primarily Copper and Lead) - Metals tend to be less mobile in the environment than organic contaminants. Under natural conditions, dissolution of metals may occur in the presence of water (due to surface water flows, rainwater runoff, or tidal fluctuations) and some metal ions may migrate. However, many of these dissolved metals can readily precipitate out of solution and adsorb to sediment particles. Metals will be more soluble and remain in an aqueous state if the pH is sufficiently low.

These properties support the frequent detection of elevated levels of copper and lead in both surface and subsurface sediment in Area B, the frequent detection in surface sediment and less frequent detection in subsurface sediment in Areas C and D, and a corresponding infrequent detection in surface water (except in the wetlands of Area C).

In the sediment, the similar frequency of detections in surface and subsurface sediment samples in the Ferry Creek channel suggests that deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth) and/or the metals migrated in the dissolved state and precipitated on sediment particles upon contact. Similar detections with depth in the wetland areas adjacent to the lower Ferry Creek channel may be attributable to the placement of contaminated sediments dredged from the mouth of Ferry Creek. In the additional wetland areas further downstream along the Housatonic River, a higher frequency of copper and lead detections in the surface sediment

suggests that the contaminant source is relatively recent (resulting in surficial deposition of contamination) and/or the metals migrated in the dissolved state and precipitated on surface sediment particles upon contact. The distribution of the contaminants suggest the primary source in the placement of contaminated fill materials from the Raymark Facility in or adjacent to these area. Elevated levels of barium were also detected in the same regions, as the copper and lead.

The fact that copper and lead are not apt to dissolve in an aqueous environment under natural conditions (neutral pHs) is supported by their low frequency of detection in surface water throughout Areas B and D. The more frequent detection in surface water from the Area C suggests that these metals may have been present in suspended particulate in this area or were leached out of contaminated sediment or soils. Elevated concentrations of barium (being more water soluble) were detected at slightly higher frequencies in surface water throughout the Housatonic River Area.

It is important to note that elevated levels of lead and/or copper were detected in three sediment samples submitted for SPLP analysis from Area B; no samples were collected for SPLP analysis from the other two areas. This suggests that these materials may result in a continual release of copper and lead into the surrounding media.

Asbestos - Asbestos is relatively immobile in the environment, except through bulk advective movement or dispersion in aqueous or airborne environments.

Elevated levels of asbestos were detected sediment in relatively the same locations as were copper and lead, thereby supporting the conclusions stated previously regarding the placement of contaminated fill material in or adjacent to the wetlands in Areas B, C, and D, as well as the placement of contaminated sediment dredged from the mouth of Ferry Creek in the wetlands adjacent to the lower Ferry Creek channel in Area B.

E.4.4 Contaminant Fate and Transport in Soil – Housatonic River Area

Various chemical contaminants are also present in the soil located adjacent to the wetlands in the Housatonic River Area. Several pathways are available for contaminants to have entered the soil in these regions, and for them to subsequently be transported to adjacent media.

As with the sediment and surface water, the chemical and physical properties of the chemical contaminants in soil affects their ability to migrate in the Housatonic River Area, and to subsequently be transported to adjacent media. Contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend to adsorb to the soil particles or remain in the soil pore spaces. These contaminants are apt to remain localized in undisturbed soil. Contaminants in soil pore spaces or adsorbed to soil particles may later become mobilized through contact with solvents or acids, precipitation, or groundwater. Contaminants with low soil adsorption coefficients, high water partition coefficients, and high water solubilities would tend to remain in solution and be free to migrate with naturally occurring waters either downward to the water table or laterally to a surface water source.

The fate and transport of contamination is, therefore, dependent on the type of chemical contaminant present. A discussion of the fate and transport of the various categories of chemical contaminants in soil throughout the Housatonic River Area is presented below.

VOCs - Due to their high water solubilities, low soil partition coefficients, and low octanol-water partition coefficients, VOCs are readily leached from soil and transported into an aqueous media. Furthermore, VOCs present in surface soil have more of a tendency to volatilize into the atmosphere, and VOCs absorbed to soil particles or present in soil pore spaces are more apt to volatilize into unsaturated soil pore spaces or voids and may potentially migrate to the surface or follow some other preferential flow paths, than other organic compounds due to their high vapor pressures.

These chemical properties support the infrequent detection of elevated levels of VOCs in surface soil and the somewhat higher frequency in subsurface soil throughout the Housatonic River Area. The higher concentrations of VOCs, primarily carbon disulfide, ketones (2-butanone and acetone), and aromatic hydrocarbons (toluene and xylenes (total)), were

detected in subsurface soils located in a few of locations adjacent to the wetland areas, including: southeast of the Delbuono wetlands in Area B, north and east of the wetlands adjacent to the Housatonic Boat Club in Area C, and in the dry dock area in the southern region of Area D. The presence of these contaminants may have been the result of localized releases at the properties.

SVOCs (primarily PAHs) - Due to their low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, SVOCs are more readily adsorbed to soil particles than are VOC contaminants. Furthermore, SVOCs present in surface soil have a tendency to volatilize into the atmosphere to some degree, and SVOCs adsorbed to soil particles or present in soil pore spaces have a tendency to volatilize into unsaturated soil pore spaces or voids and may potentially migrate to the surface or follow some other preferential flow paths to some degree. Their ability to volatilize, however, is less than that of VOCs (with higher vapor pressures) but greater than that of PCBs and dioxins/furans (with much lower vapor pressures).

These chemical properties support the frequent detection of elevated levels of SVOCs, primarily PAHs, in surface soil and the somewhat lower frequency in subsurface soil throughout the Housatonic River Area. The high frequency of detections suggests that the PAHs were adsorbed onto soil particles placed in the area as fill material. The somewhat higher frequency of detections in the surface samples suggests a more recent source of contamination, such as residual from paving of nearby roads and parking lots.

The highest concentrations of PAHs were detected in surface soils collected in the vicinity of paved roadways and/or parking lots in Areas B, C, and D, and may have been a result of asphalt paving activities.

PCBs - Due to their low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, PCBs are more readily adsorbed to soil particles than are either VOC or SVOC contaminants. Furthermore, PCBs present in surface soil have less of a tendency to volatilize into the atmosphere, and PCBs adsorbed to soil particles or present in soil pore spaces have less of a tendency to volatilize into unsaturated soil pore spaces or voids and to

potentially migrate to the surface or follow some other preferential flow paths due to their low vapor pressures, compared to the highly volatile VOCs and somewhat volatile SVOCs.

These chemical properties support the frequent detection of elevated levels of PCBs, particularly Aroclor 1262 and Aroclor 1268 (with less frequent detection of Aroclor 1254), in both surface and subsurface soil throughout the Ferry Creek Area. The high frequency of PCB detection in both surface and subsurface soil suggests that the PCBs were adsorbed onto soil particles placed in the area as fill material from the Raymark Facility. Due to the lack of mobility of PCBs in the environment, the PCBs are likely to have remained where they were deposited.

The levels of PCBs were relatively consistent in soil samples throughout the Housatonic River Area, with the highest levels detected in subsurface soils west of lowermost extent of the Ferry Creek channel in Area b, and in both surface and subsurface soils both north and east of the wetlands adjacent to the Housatonic Boat Club in Area C, and in the dry dock area in the southern region of Area D.

Dioxins and Furans (as TEF) - As with PCBs, dioxins and furans have low water solubilities, high soil partition coefficients, and high octanol-water partition coefficients, resulting in a tendency for the contaminants to sorb to soil particles. Furthermore, dioxins and furans present in surface soil have less of a tendency to volatilize into the atmosphere, and those contaminants adsorbed to soil particles or present in soil pore spaces have less of a tendency to volatilize into unsaturated soil pore spaces or voids and to potentially migrate to the surface or follow some other preferential flow paths due to their low vapor pressures, again similar to PCBs.

These chemical properties support the frequent detection of elevated TEF levels in the limited number of surface and subsurface soil samples collected throughout the Housatonic River. These contaminants were detected in the same regions as the PCBs and are believed to have been transported to these regions in a similar manner.

Metals (primarily Copper and Lead) - Metals tend to be less mobile in the environment than organic contaminants. Under natural conditions, dissolution of metals may occur in the presence of water (due to rainwater runoff or groundwater infiltration) and some metal ions

may migrate. However, these dissolved metals can readily precipitate out of solution and adsorb to soil particles. Metals will be more soluble and remain in an aqueous state if the pH is sufficiently low.

These properties support the frequent detection of elevated levels of copper and lead in both surface and subsurface soil throughout the Housatonic River Area. The somewhat higher frequency of detections in the surface soils is due to the lack of elevated values in the deeper samples collected. Due to the low likelihood of metals mobility in the environment, they are likely to have remained where deposited in the fill material from the Raymark Facility.

The highest levels of both copper and lead were detected in both surface and subsurface samples located in the southwest of the Delbuono wetlands in Area B, north and east of the wetlands adjacent to the Housatonic Boat Club in Area C, and central and southern regions of Area D. Elevated concentrations of barium were detected at similar frequencies, with the highest concentrations at the same locations as copper and lead.

Asbestos - Asbestos is relatively immobile in the environment, except through bulk advective movement or dispersion in aqueous or airborne environments.

Elevated levels of asbestos were detected infrequently frequently in both surface and subsurface soil throughout the Housatonic River Area, in similar regions as the presence of elevated levels of copper and lead. Due to the low likelihood of asbestos mobility in the environment, it is likely to have remained where deposited in the fill material from the Raymark Facility.

E.4.5 Contaminant Fate and Transport in Sediment and Surface Water – Elm Street Wetland and Selby Pond Areas

Various chemical contaminants are present in the sediment and surface water in the Elm Street Wetland and Selby Pond Areas. Several pathways are available for contaminants to have entered these media, and for them to subsequently be transported to adjacent media.

The chemical and physical properties of the chemical contaminants affects their ability to migrate into the sediment and surface water, and to subsequently be transported to adjacent media. Contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend adsorb to the sediment particles. These contaminants are apt to remain localized in undisturbed sediment, or to migrate on sediment particulates transported by surface water flows, rainwater runoff, or tidal fluctuations. Contaminants adsorbed to sediment particles may later become desorbed and/or dissolved following contact with solvents or acids, if present. Contaminants with low soil/sediment adsorption coefficients, high water partition coefficients, or high water solubilities would tend to remain in solution and be free to migrate with naturally occurring waters.

Tidal fluctuations may also cause contaminants to be transported into and/or pass through the sediment. Again, those contaminants with high soil/sediment adsorption coefficients and low water partition coefficients would tend to adsorb to the sediment particles; while those with low soil/sediment adsorption coefficients, high water partition coefficients, and high water solubilities would tend to remain in solution and be free to migrate with natural water sources.

The fate and transport of contamination is, therefore, dependent on the type of chemical contaminant present. A discussion of the fate and transport of the various categories of chemical contaminants in sediment and surface water throughout the Elm Street Wetland and Selby Pond Areas is presented below. Since no elevated levels of SVOCs were present in surface water samples, and since no samples were collected for analysis of dioxins/furans and asbestos (since these contaminants are virtually insoluble in water), the fate and transport discussion related to surface water is limited to VOCs, PCBs, and metals.

<u>VOCs</u> - Due to their high water solubilities, low soil/sediment partition coefficients, and low octanol-water partition coefficients, VOCs in a sediment/surface water environment tend to remain dissolved in, and free to be transported by, the aqueous media; they do not readily adsorb to sediment particles. Furthermore, VOCs present in surface sediment located in relatively dry locations have more of a tendency to volatilize into the atmosphere than other organic contaminants due to their high vapor pressures. VOCs present in surface water (especially in regions of high turbulence or aeration) also have a tendency to volatilize into the atmosphere due to their high vapor pressures and high air-water partition coefficients.

These chemical properties support the infrequent detection of elevated levels of VOCs (primarily 2-butanone, acetone, and carbon disulfide) in both surface and subsurface sediment throughout the Elm Street Wetland Area and surface sediment throughout the Selby Pond Area; no subsurface sediment samples were collected for VOC analysis from the Selby Pond Area. In surface water, low levels of acetone and styrene were each detected in a single sample collected in the Elm Street Wetland Area; while, elevated levels of VOCs were not detected in surface water from the Selby Pond Area.

In the sediment, the higher concentrations of VOCs was detected in surface sediment in the wetlands both in the eastern region of the Elm Street Wetland Area and along the eastern side of Selby Pond. This phenomenon may be due to the fact that that these samples were collected close to the outer boundary of the designated wetland areas where surface water was less apt to desorb the contaminants from the sediment.

SVOCs (primarily PAHs) - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, SVOCs in a sediment/surface water environment are more readily adsorbed to sediment particles than are VOC contaminants. Furthermore, SVOCs present in surface sediment located in relatively dry locations have a tendency to volatilize into the atmosphere to some degree. Their ability to volatilize, however, is less than that of VOCs (with higher vapor pressures) but greater than that of PCBs and dioxins/furans (with much lower vapor pressures).

These chemical properties support the detection of elevated levels of SVOCs, primarily PAHs, in sediment samples and the lack thereof in the surface water in the two areas. In the Elm Street Wetland Area, elevated levels of PAHs were detected in only two samples (surface sediment in the eastern region). Infrequent detection of PAHs in the Selby Pond Area were present primarily in surface sediment. The higher frequency of PAH detection in surficial samples, suggests that the PAHs were adsorbed onto sediment particles that may have migrated to these areas with surface water flows, rainwater runoff, or tidal fluctuations. Less frequent detections in subsurface sediment suggest that the contaminant source is relatively recent (resulting in surficial deposition of contamination).

The highest concentrations of PAHs were detected in the northeastern portion of Selby Pond and at two locations in the wetlands along the northeastern and southeastern borders of Selby Pond.

PCBs - Due to their low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, PCBs in a sediment/surface water environment are more readily adsorbed to sediment particles than are either VOC or SVOC contaminants. Furthermore, PCBs present in surface sediment located in relatively dry locations have little or no tendency to volatilize into the atmosphere due to their low vapor pressures, compared to the highly volatile VOCs and somewhat volatile SVOCs.

These chemical properties support the frequent detection of elevated levels of PCBs, particularly Aroclor 1254 (with less frequent detection of Aroclor 1242, Aroclor 1262, and Aroclor 1268), in both the surface and subsurface sediment samples collected in the Elm Street Wetland Area; and the infrequent detection of PCBs, particularly Aroclor 1262 and Aroclor 1268, in the surface sediment and lack of detection in the subsurface sediment in the Selby Pond Area.

The high frequency of PCB detection in the sediment in the Elm Street Wetland Area, localized in the eastern region, suggests that the PCBs were adsorbed onto sediment particles that were placed there as fill material from the Raymark Facility or that may have migrated to this area with surface water flows, rainwater runoff, or through the nearby culvert. The relatively similar frequency of detection in both surface and subsurface sediment deposition of contaminated sediment has occurred over an extended period of time (resulting in similar deposition of contamination with depth) and/or the particles to which the PCBs adsorb have relatively high densities (resulting in infrequent resuspension and redeposition). The highest levels were detected in surface and subsurface sediment in the eastern region of the delineated wetlands and in surface sediment in the northeastern region of the area just beyond the wetland boundary. Moderate levels of Aroclor-1254 were also present in surface water from these areas.

The low frequency of PCB detection in the Selby Pond Area were localized in the surface sediment in the northern region of the pond and in the vicinity of the mouth of the channel

connecting the pond tidally to the Ferry Creek channel. No PCBs were detected in subsurface sediment or surface water collected in the area.

Dioxins and Furans (as TEF) - As with PCBs, dioxins and furans have low water solubilities, high soil/sediment partition coefficients, and high octanol-water partition coefficients, resulting in a tendency for the contaminants to adsorb to sediment particles in a sediment/surface water environment. Furthermore, dioxins and furans present in surface sediment located in relatively dry locations have little or no tendency to volatilize into the atmosphere due to their low vapor pressures, again similar to PCBs.

These chemical properties support the infrequent detection of elevated TEF levels in surface sediment and the lack of detection in subsurface samples throughout the Elm Street Wetland and Selby Pond Areas.

The TEF levels were fairly consistent in surface samples collected throughout the Selby Pond Area. In the Elm Street Wetland Area, the highest levels were detected in surface sediment from the eastern region of the delineated wetlands. The potential migration pathways are the same as those for PCBs.

Metals (primarily Copper and Lead) - Metals tend to be less mobile in the environment than organic contaminants. Under natural conditions, dissolution of metals may occur in the presence of water (due to surface water flows, rainwater runoff, or tidal fluctuations) and some metal ions may migrate. However, many of these dissolved metals can readily precipitate out of solution and adsorb to sediment particles. Metals will be more soluble and remain in an aqueous state if the pH is sufficiently low.

These properties support the frequent detection of elevated levels of copper and lead in surface sediment and the detection in a single subsurface sediment in the Elm Street Wetland and Selby Pond Areas, the frequent detection in surface water in the eastern region of the Elm Street Wetland, and the detection of a single elevated level of lead in surface water collected in the Selby Pond Area in the vicinity of the mouth of the channel connecting the pond tidally to the Ferry Creek channel.

In the sediment, the higher frequency of detections in surface samples suggests that the contaminant source is relatively recent (resulting in surficial deposition of contamination) and/or the metals migrated in the dissolved state and precipitated on surface sediment particles upon contact. The levels were fairly consistent throughout the Selby Pond Area, with the highest levels detected in the vicinity of the mouth of the channel connecting the pond tidally to the Ferry Creek channel. In the Elm Street Wetland Area, the highest levels were detected in surface sediment from the northern and eastern regions of the delineated wetlands in the vicinity of the culvert; surface water samples from these locations also contained elevated levels of copper and lead.

The fact that copper and lead are not apt to dissolve in an aqueous environment under natural conditions (neutral pHs) is supported by their low frequency of detection in surface water from the Selby Pond Area. The more frequent detection in surface water from the eastern region of the Elm Street Wetlands suggests that these metals may have been present in suspended particulate in this area, leached out of contaminated sediment or soils, or transported to the wetlands through the culvert.

Elevated concentrations of barium were detected at slightly higher frequencies in surface and subsurface sediment, as well as in surface water, in the Elm Street Wetland Area. Barium was also detected at slightly higher frequencies in surface sediment in the Selby Pond Area, but it was not detected in the surface water. The highest concentrations of barium were detected in the same general areas, as copper and lead.

Asbestos - Asbestos is relatively immobile in the environment, except through bulk advective movement or dispersion in aqueous or airborne environments.

Elevated levels of asbestos were detected infrequently in surface sediment from the Selby Pond Area. The highest levels were detected in the northeastern region of the pond in the vicinity of the mouth of the channel connecting the pond tidally to the Ferry Creek channel. The findings suggest that asbestos may have been transported tidally from Ferry Creek, as well as by transport in rainwater runoff from asbestos-laden fill materials placed in close proximity to the north eastern region of Selby Pond.

Asbestos was not detected in surface sediment from the Elm Street Wetland Area. No subsurface samples were collected for asbestos analysis from either area.

E.4.6 Contaminant Fate and Transport in Soil – Elm Street Wetland

Low levels of PAHs, copper, and lead were present in the single surface soil sample collected from the western border of the delineated wetlands in the Elm Street Wetland Area. PCBs and dioxins/furans were not detected above background concentrations, and no sample was collected for analysis of VOCs. These results suggest that the soil sample may have been contaminated to a small degree by the placement of fill material from the Raymark Facility, or perhaps more likely to have been the result of rainwater runoff due to the close proximity to Elm Street.