RCRA Facility Investigation – Remedial Investigation/ Corrective Measures Study – Feasibility Study Report for the Rocky Flats Environmental Technology Site

Section 8.0

Contaminant Fate and Transport

This Report was prepared by Kaiser-Hill Company, L.L.C.
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8.0 CONTAMINANT FATE AND TRANSPORT

8.1 Introduction

The purpose of this section is to describe the fate and transport[1] of contaminants in the environment at the Rocky Flats Environmental Technology Site (RFETS). To assess contaminant fate and transport, information is used about the site physical characteristics, contaminant source characteristics, and contaminant distribution to develop a conceptual understanding of the dominant transport processes that affect the migration of different contaminants in various RFETS environmental media. For reference, the text also provides general background information on physical, chemical, and biological processes that influence contaminant migration. While this evaluation addresses contaminant fate and transport in surface soil, subsurface soil, groundwater, surface water, sediment, and air, the primary focus, consistent with the Rocky Flats Cleanup Agreement (RFCA) objectives, is evaluating the potential for contaminants to impact surface water quality.

Evaluation of a contaminant's fate and transport is based upon the following two questions:

1. Does a complete migration pathway to surface water exist based on an evaluation of contaminant transport in each environmental medium?
2. Is there a potential impact to surface water quality based on an evaluation of data at representative groundwater and surface water monitoring locations in the creek drainages?[2]

This fate and transport analysis focuses on contaminants that were identified as analytes of interest (AOIs) for each medium identified through the nature and extent evaluation process; in this Section 8.0, all of these contaminants (for surface soil, sediment, subsurface soil, groundwater, surface water, and air) will be referred to as AOIs (this nomenclature is not followed in the other sections of the RI/FS), contaminants of concern (COCs) that contribute risk greater than 1×10^{-6} to a wildlife refuge worker (WRW) or a hazard index (HI) greater than or equal to 1, and ecological chemicals of concern (ECOCs) that present significant risk of adverse ecological effects.

The chemistry of each AOI is unique. As a result, each AOI interacts differently with the geochemical environment surrounding it, making the transport mechanism (particulate, dissolved, or both) and rate of migration highly variable for each AOI. In addition, the

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[1] "Fate" refers to measurement of a compound's persistence in the environment and the chemical transformation or degradation it may undergo; "transport" refers to the migration of a contaminant through the environment as a result of environmental mechanisms, such as soil erosion or groundwater movement, that are affected by physical and chemical processes that affect the contaminant's migration.

[2] Representative surface water and groundwater monitoring locations are consistent with those identified in the Fiscal Year (FY) 2005 Integrated Monitoring Plan (IMP), Revision 1, dated September 2005.

persistence in the environment varies greatly from one AOI to another, ranging from certain organic compounds that biodegrade in a period of weeks, to stable metals that persist indefinitely.

In addition to chemical and physical processes, the location of the AOI, particularly in relation to surface water drainages, plays an important role in its fate and transport. For example, an AOI located in surface soil is subject to different transport mechanisms, such as wind and water erosion, than a contaminant located several feet below the ground surface. An AOI that is primarily transported by surface transport mechanisms, but is located in subsurface soil (such as waste deposited into a trench during historic operations), may not be mobile and available for transport via subsurface mechanisms. The AOI's geochemistry, persistence, and location, coupled with the results of predictive numerical transport modeling and process knowledge, were considered when the potential migration pathway(s) to surface water was evaluated.

8.2 Process to Evaluate Analyte of Interest Fate and Transport

The process used to systematically determine whether an AOI in surface soil, sediment, subsurface soil, or groundwater has a complete pathway to surface water (via surface or subsurface transport mechanisms) is diagrammed in Flowchart 8.1. The evaluation process involves six major steps, described below.

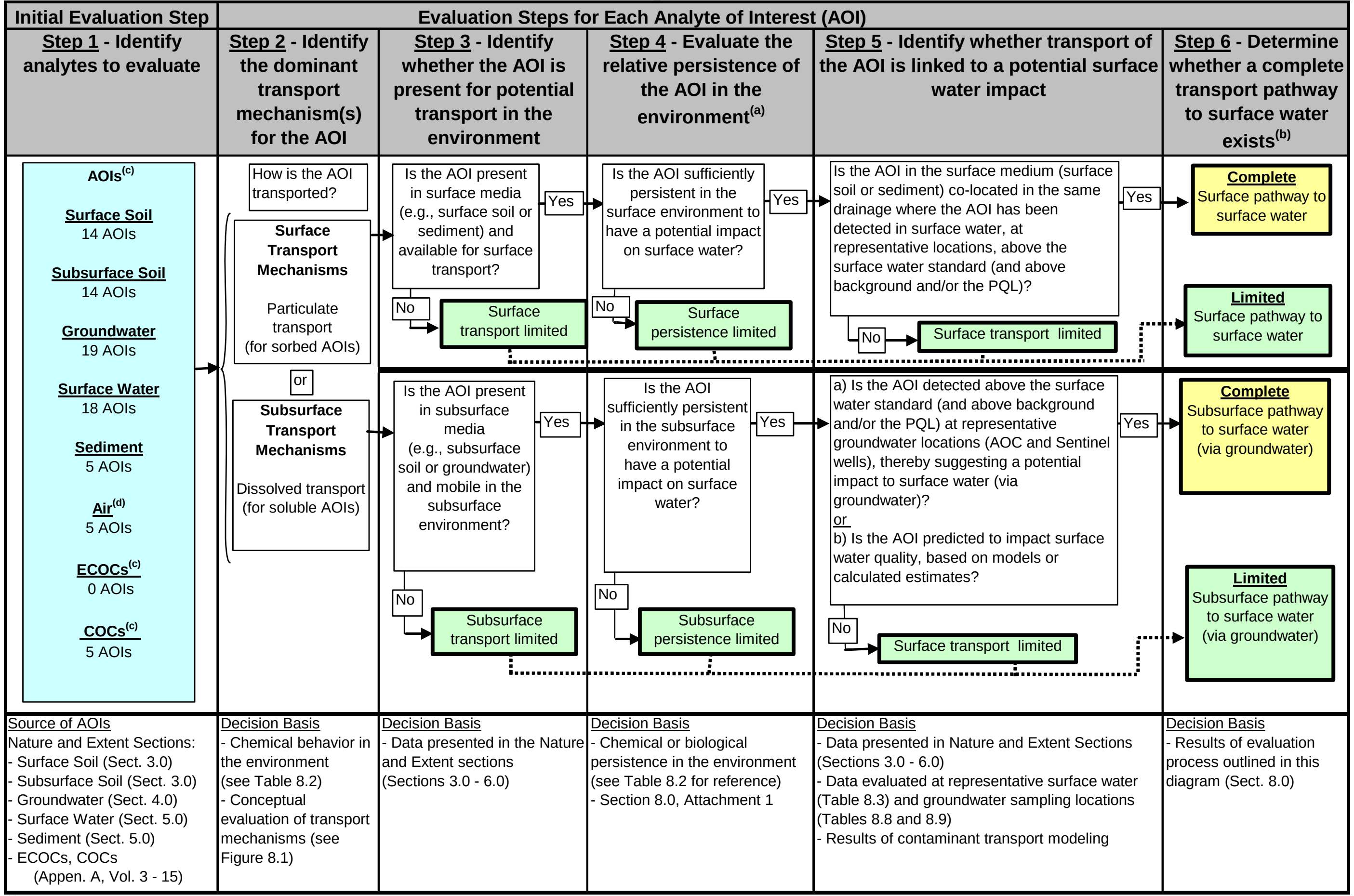
Step 1: Identify analytes to evaluate, based on the AOIs identified in the nature and extent of contamination for each environmental medium, as well as analytes identified in the Comprehensive Risk Assessment (CRA).

Step 2: Identify the dominant transport mechanism for each analyte, whether it involves a surface transport mechanism (via particulate transport) or a subsurface transport mechanism (via dissolved transport). The dominant transport mechanism is dependent on the physical, chemical, and biological processes that affect its fate and transport in the environment.

Step 3: Identify whether the AOI is available for transport in the environment. Analytes that are not mobile by a specific mechanism are considered to not be available for transport via that mechanism.

Step 4: Evaluate whether the AOI persists in the environment. For the purposes of this fate and transport analysis, environmental persistence is defined herein as being sufficiently long-lived to impact surface water quality above the surface water standards at representative surface water monitoring locations.

Flowchart 8.1
AOI Fate and Transport Evaluation Process



[a] Persistence is defined herein as being sufficiently long-lived to potentially cause an exceedance of surface water standards at representative surface water monitoring locations.

[b] A "complete pathway" is defined herein for "surface pathways" and "subsurface pathways" as follows:

- Complete surface pathway - Migrating in the environment from surface soil or sediment to surface water, and being detected above the surface water standard at representative surface water monitoring locations.
- Complete subsurface pathway - Migrating in the environment in subsurface soil or groundwater, and being detected above the surface water standard at representative groundwater locations (AOC or Sentinel wells).

[c] "AOIs" are collectively defined herein as AOIs from the Nature and Extent of Contamination sections (Sections 3.0 - 6.0), ECOCs, and COCs (with increased cancer risk $\geq 1 \times 10^{-6}$ or HQ $\geq$ 1.0).

[d] Air AOIs are not addressed in this evaluation process because impacts to surface water are attributed primarily to AOIs in surface soil, sediment, subsurface soil, and groundwater. Air AOI modeling is discussed in Section 8.5.

Step 5: Evaluate whether transport of the AOI is linked to a potential surface water impact. This is determined based on answers to the following questions:

a) Are surface soil and sediment AOIs co-located in the same drainage as the AOI observed in surface water at representative surface water monitoring locations above the surface water standard, background (defined as 99 percent of background concentrations with 99 percent confidence, that is, the 99/99 upper tolerance limit [99/99 UTL]), and/or the practical quantitation limit (PQL)?[3]

b) Is the subsurface soil and/or groundwater AOI detected above a surface water standard at representative groundwater monitoring locations, thereby suggesting a potential impact to surface water quality, or is the subsurface soil and/or groundwater AOI predicted to impact surface water quality based upon modeling or estimate results?

Step 6: The final step of the evaluation process involves assimilating information from the prior evaluation steps to determine whether an analyte, for each specific environmental medium, has a “complete” or “limited” pathway to surface water. As shown on Flowchart 8.1, a “no” answer to Step 3, 4, or 5 results in the analyte being considered to have a “limited” pathway to surface water. For the purposes of this evaluation, a “complete” pathway is defined as follows:

- A complete surface pathway exists when a contaminant migrates in the environment from surface soil or sediment, and is detected in surface water above the respective surface water standard, background, and/or the PQL at a representative surface water monitoring location.

- A complete subsurface pathway exists when a contaminant migrates in the environment from subsurface soil or groundwater, and is detected in groundwater above the respective surface water standard, background, and/or the PQL at a representative groundwater monitoring location (Area of Concern [AOC] or Sentinel well).

An AOI that has not been identified as having a complete pathway is deemed to have a “limited pathway” for one of the following three reasons:

- It is not available for transport (either by its location or dominant transport mechanism).

- It is not persistent in the environment.

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[3] The nature and extent of groundwater contamination (Section 4.0) provides comparisons of groundwater AOIs to Maximum Contaminant Levels (MCLs). MCLs are not discussed in this section because the objective is to evaluate the potential impacts of AOIs on surface water quality. Therefore, comparisons are made with the surface water standard, background, or laboratory PQL instead of with MCLs.

- There is a low potential for the AOI to impact surface water quality above the surface water standard, background, and/or PQL.

As described in Step 5, representative surface water and groundwater monitoring locations are a key component of the evaluation process. Figure 8.1 denotes the representative surface water and groundwater monitoring locations, which are based upon monitoring locations in the FY2005 Integrated Monitoring Plan (IMP) Summary Document, Revision 1 (K-H 2005a). The representative surface water monitoring locations represent sitewide surface water quality in segments 4a, 4b, 5, and upstream of the terminal ponds in the North Walnut Creek watershed (SW018, SW093, and GS11), South Walnut Creek watershed (GS08), Walnut Creek watershed (GS03), South Interceptor Ditch (SID) watershed (GS51 and SW027), and Woman Creek watershed (GS05, GS31, and GS01). POM2 and POM3 are also IMP performance locations in South Walnut Creek, but do not have data prior to August 1, 2005, and consequently are not used in the Remedial Investigation/Feasibility Study (RI/FS) evaluation.

Representative groundwater monitoring locations assess potential impacts to surface water quality as measured at AOC and Sentinel wells. The AOC and Sentinel well classifications, consistent with the FY2005 IMP, are as follows:

- AOC wells – Wells that are within a drainage and downgradient of a contaminant plume or group of contaminant plumes. These wells will be monitored to determine whether the plume(s) may be discharging to surface water.

- Sentinel wells – Wells that are typically located near downgradient contaminant plume edges, in drainages, and downgradient of existing groundwater treatment systems. These wells will be monitored to identify changes in groundwater quality.

Using the evaluation process described above, the environmental media evaluated first are surface soil and sediment because they represent the surface transport mechanisms. Subsurface soil and groundwater are evaluated second as part of the subsurface transport mechanism evaluation process.

The evaluation process does not take into consideration the effect of air fate and transport on surface water quality, because air is based on the potential contaminant exposure received by a human receptor via the airborne pathway, as measured against annual U.S. Environmental Protection Agency (EPA) dose limits (see Section 8.5 for more details).

8.2.1 Analytes of Interest - General Environmental Transport Mechanisms

The AOIs vary for each environmental medium. They are identified as:

- Analytes specifically identified as AOIs from the respective nature and extent sections for each medium;

- COCs that contribute risk greater than or equal to 1×10^{-6} to a WRW or an HI greater than or equal to 1; and

- ECOCs that present significant risk of adverse ecological effects.

Note that all three types of analyte categories are referred to herein as AOIs. Certain AOIs are identified in all media (surface soil, subsurface soil, groundwater, surface water, sediment, and air), while other AOIs are identified in one medium only. The major AOI groups, as well as specific AOIs, are described in Section 8.2.1.1.

In the RFETS environment, movement of AOIs from different environmental media to surface water can generally be characterized as transport of the constituent via either: 1) surface transport mechanisms (surface soil or sediment to surface water), or 2) subsurface transport mechanisms (subsurface soil [via groundwater] or groundwater to surface water). These general transport pathways are embodied in the evaluation process depicted in Flowchart 8.1.

8.2.1.1 AOI Groups

AOIs evaluated for fate and transport fall into one of the following analyte groups:

- Radionuclides;
- Volatile organic compounds (VOCs);
- Metals;
- Semivolatile organic compounds (SVOCs);
- Polychlorinated biphenyls (PCBs);
- Dioxins; and
- Water quality parameters, including inorganic compounds.

Table 8.1 presents a listing of all AOIs, and identifies the environmental medium, or media, associated with each. For each of the contaminants identified as an AOI, a description of the fate and transport characteristics for that analyte is provided in Table 8.2. In addition to general fate and transport characteristics, Table 8.2 provides fate and transport information specific to RFETS, such as data from RFETS-specific studies related to the chemical form or mobility of specific contaminants.

8.2.1.2 Dominant Environmental Transport Mechanisms at RFETS

Contaminant transport at RFETS is the result of varied environmental mechanisms and is largely a function of:

- The chemical properties and corresponding environmental transport characteristics of each contaminant;

- The nature of the AOI contamination. Contaminants distributed in surface soil are subject to different transport mechanisms than AOI contamination in subsurface soil; and
- The physical, chemical, and biological characteristics of the environment where the AOI is present.

Each AOI has unique characteristics regarding its mobility and persistence in the environment. These characteristics are the result of the chemical characteristics of each AOI, in conjunction with the major physical, chemical, and biological mechanisms listed below. These mechanisms are depicted on Figure 8.2, described in Table 8.2, and described in further detail in Attachment 1 to this section.

Physical Transport Mechanisms

- Erosion – Surface water and wind;
- Sediment transport – Surface water (and air, if sediments are exposed);
- Advection – Surface water and groundwater;
- Dispersion – Surface water and groundwater;
- Particle transport – Air, surface water, sediment, and groundwater (as colloids);
- Recharge and dilution – Groundwater;
- Discharge – Groundwater to surface water;
- Volatilization – Soil, surface water, and groundwater to air; and
- Burrowing animals – Surface and subsurface soil.

Chemical Transport Mechanisms

- Sorption, desorption, and ion exchange – Soil and groundwater;
- Hydrolysis – Surface water and groundwater;
- Oxidation-reduction – Surface water, groundwater, and sediment;
- Solubility, precipitation, and dissolution – Soil, surface water, groundwater, and sediment;
- Complexation and speciation – Surface water, groundwater, and sediment; and
- Radioactive decay – Soil, surface water, groundwater, and sediment.

<u>Biological Transport Mechanisms</u>

- Biodegradation – Surface water and groundwater;
- Denitrification and ammonification – Surface water;
- Assimilation and bioconcentration – Surface water, groundwater, and sediment; and
- Evapotranspiration (ET) – Groundwater to plants.

In the RFETS environment, dominant transport mechanisms identified for the AOIs are (K-H 2002a, 2004a; DOE 2005a):

- Erosion of contaminated surface soil by wind;
- Erosion of contaminated surface soil and sediment by surface water; and
- Subsurface transport of contaminants by groundwater.

Surface water fate and transport mechanisms are depicted on Figure 8.3. Surface water and wind erosion of contaminated surface soil is particularly important for low-solubility contaminants (such as plutonium-239/240 and americium-241) bound to soil particles.

Sediment is also subject to surface water erosion processes. Erosion of contaminated surface soil, with subsequent deposition into drainage channels, redistributes the contaminants from surface soil into the drainages. Deposition of contaminated sediments is particularly important for low-solubility (sorptive) contaminants bound to soil particles. Detection of these contaminants in surface water corresponds with elevated concentrations of suspended solids and resulting sediment contamination.

The migrations of certain AOIs that occur naturally (such as chromium, arsenic, and uranium) are difficult to ascertain because of their high natural background levels which is also variable across RFETS. In addition, manmade interferences, such as AOIs introduced into wells from stainless-steel well construction, can cause contamination in samples that are not reflective of actual groundwater conditions (see Section 8.4.4.3). Therefore, evaluating sample data from areas representative of background conditions is important when determining whether fate and transport of AOIs is related to anthropogenic effects.

For contaminants with higher relative solubility, such as VOCs and nitrate, shallow groundwater (upper hydrostratigraphic unit [UHSU]) transport of contaminants is an important process, as shown on Figure 8.4. The infiltration of precipitation may carry soluble contaminants from soil through the subsurface to underlying groundwater. Chlorinated solvents or liquid hydrocarbon fuels may also have migrated as both dissolved and nonaqueous-phase liquids (NAPLs). Each of the sources may act as a long-term residual of dissolved contaminants to groundwater. (See Attachments 1 and 2 to this section for a discussion of VOC and NAPL persistence.) It is noted that no AOIs are identified for groundwater in the lower hydrostratigraphic unit (LHSU).

Many of the subsurface physical, chemical, and biological mechanisms act to retard, transform, or destroy AOIs as they migrate in groundwater. However, evaluation of specific RFETS AOIs suggests that, for those contaminants that biodegrade, the rate of biological contaminant degradation is low.

8.2.1.3 Actions Taken to Disrupt Environmental Pathways and Contaminant-Specific Evaluations

As discussed in Section 1.0, numerous accelerated actions have been taken that affect the fate and transport of the AOIs. Most of these actions were taken to eliminate historical sources of contamination. Some of these actions remain in effect and were implemented to disrupt subsurface pathways to surface water for specific AOIs. In addition, several contaminant-specific evaluations were conducted at RFETS to assess potential impacts of those AOIs on surface water quality.

Actions implemented to disrupt contaminant transport pathways included the installation of groundwater collection and/or treatment systems (Figure 8.5) as accelerated actions or in conjunction with Corrective Action Decisions/Records of Decisions (CAD/RODs) to treat contaminated groundwater that could potentially impact surface water quality. These actions include:

- Historical East Trenches and Historical 903 Pad (northern flow path) – East Trenches Plume Treatment System (ETPTS) that removes VOCs in groundwater prior to its discharge to South Walnut Creek. This system remains in operation.

- Historical Mound Site – Mound Site Plume Treatment System (MSPTS) that removes VOCs in groundwater prior to its discharge to South Walnut Creek. This system remains in operation.

- Historical Solar Evaporation Ponds (SEP) Site – Solar Ponds Plume Treatment System (SPPTS) that removes uranium and nitrate in groundwater prior to its discharge to North Walnut Creek. This system remains in operation.

- Present Landfill – Present Landfill Seep Treatment System that passively treats VOCs in groundwater prior to discharge to the East Landfill Pond. This system remains in operation.

- Historical 881 Hillside Area – A historical Operable Unit (OU) 1 groundwater system that collected VOCs and nitrates from a french drain routed to a groundwater collection well (891COLWEL). Water from the collection well was pumped to former Building 891 and treated in accordance with the OU 1 CAD/ROD. Due to the consistently decreasing groundwater contaminant levels (near the MCLs) and no downgradient impacts to surface water quality, the french drain system was decommissioned in April 2002 in accordance with the Major Modification to the OU 1 CAD/ROD (DOE 2001).

As shown on Figure 8.5, these groundwater systems intercept contaminated groundwater at the downgradient edge of many of the significant plumes.

8.2.1.4 Contaminant-Specific Evaluations

Contaminant-specific evaluations conducted at RFETS that are pertinent to this fate and transport analysis include: 1) VOC fate and transport modeling of UHSU groundwater to evaluate potential impacts on surface water, and 2) Actinide Migration Evaluation (AME) studies that evaluated environmental transport of radionuclide AOIs. No modeling of metals' fate and transport was conducted for any medium.

Groundwater VOC Modeling

Based upon the hydrologic flow MIKE SHE modeling (K-H 2002a), discussed in Section 2.0, VOC fate and transport modeling was conducted. The VOC transport modeling in UHSU groundwater focused on tetrachloroethene and carbon tetrachloride (and their degradation products). The modeling was conducted to evaluate the movement and fate of each VOC at potential groundwater discharge areas that could impact surface water quality (K-H 2004a, 2005b; DOE 2005a). The modeling scope included:

- Review of all historical UHSU water quality data;
- Development of a flow and transport model using historical conditions to determine appropriate parameter values; and
- Adaptation of the flow and transport model to the post-accelerated action configuration to predict long-term or maximum groundwater VOC concentrations that may discharge to surface water.

The model results were analyzed to assess whether the simulations conclusively[4] indicated that surface water standards would be exceeded at the groundwater discharge locations. Model simulations predicted that only tetrachloroethene, trichloroethene, and carbon tetrachloride would be above surface water standards at groundwater discharge locations (K-H 2004a; DOE 2005b) (see Attachment 2 to this section). The modeling results conclusively indicate that four VOC areas have potential groundwater discharge areas where groundwater AOIs will be discharged to the surface at concentrations above surface water standards. These areas are:

- Carbon Tetrachloride Plume (historical Individual Hazardous Substance Site [IHSS] 118.1);
- Historical Ryan's Pit and 903 Pad area;

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[4] Modeling results are identified as being "conclusive" if all sensitivity simulation results were above or all results were below the surface water standard. The results are identified as "inconclusive" if sensitivity simulation results are both above and below the surface water standard (see the Groundwater IM/IRA for details).

- Historical Mound Site/Oil Burn Pit No. 2 area; and
- Historical East Trenches area.

Further discussion of the VOC transport modeling is provided in Attachment 2 to this section and in the Groundwater Interim Measure/Interim Remedial Action (IM/IRA) (K-H 2005a).

The VOC modeling also noted that there were steady well concentration trends suggesting that residual contamination had reached steady-state, which could be indicative of residual dense nonaqueous-phase liquids (DNAPLs) that typically produce constant long-term dissolved-phase concentrations in groundwater (K-H 2004a, 2005b). Finally, the modeling confirmed that ET plays an important role in VOC attenuation at RFETS. Near-stream hydrology is dominated by losses to ET, which attenuates VOCs before the groundwater discharges as baseflow to surface water (K-H 2002b).

<u>AME Studies</u>

Extensive evaluation, research, and actinide modeling was conducted as part of the AME (K-H 2002a). The AME Pathway Analysis study was conducted to quantify the environmental transport of plutonium-239/240, americium-241, uranium-233/234, uranium-235, and uranium-238 in different environmental media at RFETS and to provide recommendations for long-term protection of surface water quality. The actinide transport pathways quantified included air, surface water, groundwater, and biota. The results of the study confirm that the dominant transport pathways for plutonium-239/240 and americium-241 are air and water erosion and for uranium the dominant pathway is dissolved transport. In addition, as part of the AME, RFETS samples from select groundwater and surface water monitoring locations were sent to Los Alamos National Laboratory (LANL) for specialized analyses (High-Resolution Inductively Coupled Plasma/Mass Spectrometry [HR ICP/MS] and Thermal Ionization Mass Spectrometry [TIMS]) to quantify uranium isotope fractions and thereby determine the proportions of natural versus anthropogenic uranium in samples of groundwater and surface water (K-H 2004b). Results of these analyses are discussed in Section 8.4.4.1.

8.3 Surface Transport Pathways – Analyte of Interest Fate and Transport Evaluation

The migration of surface contaminants involves the fate and transport of AOIs associated with surface soil and sediment and their potential impacts to surface water quality. Section 8.3.1 provides a discussion of the surface water AOIs observed at the representative surface water monitoring locations.

Surface soil is addressed in Sections 8.3.2 and 8.3.3, with the identification of surface soil AOIs and a discussion of surface soil contaminant migration, respectively. Sediment is addressed in Sections 8.3.4 and 8.3.5, with the identification of sediment AOIs and a discussion of sediment contaminant migration, respectively.

8.3.1 Surface Water Analytes of Interest

Eighteen surface water AOIs were identified in the nature and extent of surface water and sediment contamination (Section 4.0):

- Radionuclides – Americium-241, plutonium-239/240, uranium (sum-of-isotopes), gross alpha, and gross beta;

- VOCs – cis-1,2-dichloroethene, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride.

- Metals – Aluminum (dissolved), beryllium, chromium (total), lead, and nickel; and

- Water Quality Parameters – Nitrate/nitrite (as N).

As shown in Table 8.3, surface water AOIs observed above their respective surface water standards at representative (nonbackground) surface water monitoring locations include three radionuclides transported in particulate form (plutonium-239/240, americium-241, and uranium [sum of isotopes]). Americium-241 is observed intermittently above the surface water standard at surface water monitoring locations upstream of the terminal ponds in North Walnut Creek (SW093), South Walnut Creek (GS10), and the SID/Woman Creek drainage (GS51 and SW027). Plutonium-239/240 has been observed intermittently above the surface water standard at the same locations upstream from the terminal ponds as americium-241, as well as at station SW018 in the North Walnut Creek watershed. Uranium (sum of isotopes) was detected above the surface water standard in North Walnut Creek (GS13) and South Walnut Creek (GS10), although it is predominantly from natural uranium sources, based on analyses of uranium isotope fractions (see Section 8.4.4.1).

Surface water AOIs transported in a dissolved form and observed above the surface water standard at the representative (nonbackground) surface water locations are uranium (sum of isotopes) and nitrate/nitrite (as N). As discussed above, uranium observed in surface water at RFETS is predominantly from natural sources. Nitrate/nitrite (as N) was observed in North Walnut Creek (GS13) above the surface water standard.

All other surface water AOIs (gross alpha, gross beta, cis-1,2-dichloroethene, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethene, vinyl chloride, aluminum [dissolved], beryllium, chromium [total], lead, and nickel [total and dissolved]) were observed infrequently or not at all at the representative surface water locations. The VOCs are discussed in relation to the subsurface pathway in Section 8.4.

8.3.2 Surface Soil Analytes of Interest

Although surface soil[5] is the medium where many of the AOIs are detected, it is not a transport pathway itself. Instead, it serves as the medium that contributes contaminants to other environmental pathways. AOI transport from surface soil to other environmental media is dependent on physical and chemical mechanisms, such as soil erosion or sorption/desorption. The physical mechanisms are affected by the chemical properties of the AOI, in conjunction with other chemical and biological mechanisms that dictate how each AOI is transported in the environment.

Fourteen surface soil AOIs were identified in the nature and extent of soil contamination (Section 3.0):

- Radionuclides – Americium-241, plutonium-239/240, uranium-233/234, uranium-235, and uranium-238;
- Metals – Aluminum, arsenic, chromium (total), and vanadium;
- SVOCs – Benzo(a)pyrene and dibenz(a,h)anthracene;
- PCBs (Aroclors) – PCB-1254 and PCB-1260; [6] and
- Dioxins – total 2,3,7,8-Tetrachlorodibenzodioxin toxicity equivalency (TEQ) (TCDD).

8.3.3 Migration of Surface Soil Analytes of Interest

Results of the evaluation process to determine whether a complete pathway exists from surface soil to surface water are summarized, for each surface soil AOI, in Table 8.4. This evaluation is based on the general process portrayed in Flowchart 8.1. It consists of determining whether the AOI is available for transport, its primary transport mechanism, whether it is persistent in the environment, and whether the AOI in surface soil is co-located in the same drainage where the AOI has been detected at a representative surface water monitoring location above the highest of the surface water standard, background, or PQL. Numeric modeling was not conducted for this analysis to quantify the migration of surface soil AOIs. (A quantified estimate of the surface soil-to-surface water pathway is presented in the AME Pathway Analysis Report [K-H 2002a].) As discussed in Section 8.2, the results of this evaluation process were used to identify those analytes with a complete transport pathway from surface soil to surface water.

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[5] Surface soil measurements are for soil within the top 6 inches of the surface at the time of sampling. It is important to note that the RI/FS Report represents site conditions immediately following completion of accelerated actions and prior to any soil backfilling or recontouring to match the surrounding topography. Consequently, the RI/FS Report does not represent the final land configuration of the site. For further details, see Section 3.3.

[6] The PCBs listed herein are equivalent to Aroclors, for example PCB-1254 is the same as Aroclor-1254.

8.3.3.1 Surface Soil Radionuclide Migration

Americium-241

Americium-241 is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). Americium-241 has been detected in surface soil above the WRW preliminary remediation goal (PRG) in the former 700 Area[7] of the former Industrial Area (IA) (particularly at the location of former Building 776), and the historical 903 Pad/Lip Area.

The dominant transport mechanism for americium is particulate transport via runoff and erosion of surface soil with residual americium-241 (see Table 8.2). As discussed in Table 8.2, americium-241 (for this evaluation) is considered to persist in the environment indefinitely, because the radioactive half-life is over 400 years.

Americium-241 has been measured in surface soil at concentrations above the WRW PRG at locations throughout the three major RFETS drainages. It has also been observed intermittently in surface water above the surface water standard at representative surface water monitoring locations (SW093, GS10, GS51, and SW027, as denoted in Table 8.3 and Table 8.4) in North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages, respectively.

The primary historic source of americium-241 in surface soil was remediated at the historical 903 Pad and Lip area, which is expected to improve long-term surface water quality. In addition, removal of impervious surfaces (buildings and pavement) has decreased runoff volumes and peak discharge rates, which will reduce soil erosion, with its associated transport of americium-241 and impact on surface water quality. Although the surface movement of americium-241 is expected to be reduced, americium-241 is identified as having a complete pathway from surface soil to surface water.

Plutonium-239/240

Plutonium-239/240 is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the Wind Blown Area Exposure Unit (EU) (WBEU). Similar to americium-241, plutonium-239/240 is detected in surface soil above the WRW PRG at several locations in the former IA (particularly in the former 700 and 400 Areas, and most notably at the location of former Building 776),[8] and the historical 903 Pad/Lip Area (and east of this area, the WBEU).

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[7] The maximum surface soil americium-241 activity (51.2 picocuries per gram [pCi/g]) is located in the southwest corner of former Building 776. This confirmation sample (CE45-128) was collected from the floor of an excavation area approximately 5 feet (ft) below grade and was designated as a surface soil sample. Although the sample was not at the surface after imported clean backfill had been placed in the excavation, the sample was still classified as a surface soil sample in the database (DOE 2005b).

[8] The maximum plutonium-239/240 activity in surface soil (183 pCi/g) is located near the southeast corner of former Building 776 (sampling locations CE45-120 and CE45-134). These confirmation samples were

The dominant mechanisms that transport plutonium-239/240 from surface soil are wind and water erosion of surface soil. The erosion-based transport processes are consistent with the general body of scientific literature, as well as extensive RFETS-specific studies, that indicate plutonium-239/240 is typically transported as a highly insoluble actinide that sorbs strongly to soil particles (Table 8.2) (K-H 2002a). Plutonium-239/240 that remains in RFETS surface soil is considered to persist in the environment indefinitely (for this evaluation), because the radioactive half-lives of plutonium-239 and plutonium-240 exceed 24,000 years and 6,500 years, respectively (see Table 8.2).

Plutonium-239/240 is located in surface soil above the WRW PRG at locations throughout the surface water drainages. It is also observed intermittently in surface water above the surface water standard at representative surface water monitoring locations (SW018, SW093, GS10, GS51, and SW027, as denoted in Table 8.3 and Table 8.4) in North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages, respectively. The primary historic source of plutonium-239/240 in surface soil was remediated at the historical 903 Pad and Lip area, which is expected to improve long-term surface water quality. In addition, removal of impervious surfaces has decreased runoff volumes and peak discharge rates, which will reduce soil erosion, with its associated plutonium-239/240 transport and impact on surface water. Although the surface movement of plutonium-239/240 is expected to be reduced, plutonium-239/240 is identified as having a complete pathway from surface soil to surface water.

Uranium

Uranium-233/234, uranium-235, and uranium-238 are defined as surface soil AOIs in the nature and extent of soil contamination (Section 3.0). The analysis of uranium in surface soil addresses these isotopes, as well as the sum of these isotopes, to provide a comprehensive evaluation of the different surface soil AOIs related to uranium.

Uranium in surface soil is distributed in the IA OU (former Building 444, former SEP, and the Original Landfill) and in the Buffer Zone (BZ) OU (historical Ash Pit area). In addition to uranium that remains in surface soil following accelerated actions, naturally occurring uranium is present in surface soil and water throughout the site. As a result, observations of uranium in the environment above relevant standards do not necessarily indicate an anthropogenic (manmade) uranium source.

The dominant mechanisms that transport uranium from surface soil involve: 1) surface transport mechanisms, including wind or water erosion and particulate transport of surface soil that contains dispersed residual uranium, primarily from natural uranium in the soil, and 2) subsurface transport mechanisms, including migration of uranium from surface soil to subsurface soil and groundwater, via dissolved transport of soluble uranium (see Section 8.4.2.1 for this discussion). Uranium migrates in the surface as the

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collected from the floor of an excavation area approximately 5 ft below grade and were designated as surface soil samples. Although the samples are not at the surface after imported clean backfill has been placed in the excavation, the samples are still classified as surface soil samples in the database (DOE 2005b).

relatively insoluble uranium (IV) species that sorbs strongly to soil particles and is transported with surface erosion processes (Table 8.2). However, natural background uranium observed in soil and water at RFETS can complicate the understanding of whether the uranium is from a natural or anthropogenic source. Differentiating between natural and anthropogenic uranium was achieved for water media using techniques to quantify uranium isotope ratios, as described in Section 8.2.1.4.

Uranium that remains in RFETS surface soil is considered (for the purposes of this evaluation) to persist in the environment indefinitely, because the radioactive half-lives of uranium-234, uranium-235, and uranium-238 are approximately 244,000 years, 704 million years, and 4.5 billion years, respectively (Table 8.2).

Several types of accelerated actions have been taken for uranium. For the form of uranium that travels via particulate transport, the removal of impervious surfaces has decreased runoff volumes and peak discharge rates, with an associated reduction in the erosion of soil with uranium particulates and its corresponding impact on surface water. For the dissolved form of uranium, the SPPTS was installed to treat groundwater, as discussed in Section 8.4.4.1.

Uranium-233/234, uranium-235, and uranium-238 have not been measured individually in surface water. However, total uranium (sum of isotopes) is sampled for in surface water and is observed intermittently above the surface water standard at specific representative surface water monitoring locations in North and South Walnut Creeks (4 samples out of 136 total results for GS10, and 22 samples out of 55 total results for GS13, as shown in Table 8.3). The uranium in surface water is dominated (approximately two-thirds) by uranium from natural sources based on analysis of uranium isotope ratios (see Attachment 3 to this section). Based on the natural uranium fraction in the surface water samples (see Attachment 3 to this section), uranium-233/234, uranium-235, and uranium-238 (from anthropogenic sources) are identified as having a limited pathway from surface soil to surface water. However, subsurface migration of total uranium (sum of isotopes) is addressed in the subsurface soil and groundwater sections (Sections 8.4.2.1 and 8.4.4.1, respectively).

8.3.3.2 Surface Soil Metal Migration

Similar to uranium, the measurement of metals in environmental media is complicated by the presence of naturally occurring metals. Hence, elevated concentrations of metals cannot always be attributed to anthropogenic sources.

No accelerated actions were implemented to address nonradionuclide metals in surface water and groundwater, nor was modeling conducted to predict the transport of metals. However, the removal of impervious surfaces has caused a decrease in runoff volumes and peak discharge rates, which, in conjunction with erosion controls, will cause a reduction in soil erosion and the associated transport of metals.

Aluminum

Aluminum is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). In surface soil, aluminum has been detected throughout the former IA (in the former 400 and 700 Areas), and at limited locations throughout the BZ OU (East Firing Range), although not necessarily at concentrations that are statistically higher than background concentrations. These surface soil sample results are believed to be reflective of the natural abundance of aluminum in soil.

The dominant transport mechanism for aluminum is via surface transport, such as surface water erosion of surface soil with aluminum and particulate transport. Aluminum has not been observed above the highest of the surface water standard, background, or PQL at any of the representative surface water monitoring locations. In addition, background concentrations of aluminum in surface soil contribute to the concentrations in surface water and further obscure the identification of specific, discrete residual aluminum in surface soil. It is persistent in the environment indefinitely because aluminum is a stable element.

Aluminum is observed in surface water at one location in the northern part of the former 400 and 700 Areas, in Pond A-4 (North Walnut Creek basin) above the surface water standard[9] but below background. It is not observed at the representative surface water monitoring locations. Thus, aluminum is identified as having a limited transport pathway from surface soil to surface water.

Arsenic

Arsenic is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the IA EU (IAEU) and WBEU. Arsenic is detected in surface soil throughout the former IA (in the former 400 and 700 Areas and the historical SEP area), in the three major RFETS watersheds that receive runoff from the former IA (North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages), reflecting the natural abundance of arsenic in soil.

The dominant transport mechanism for arsenic is surface water erosion of surface soil and particulate transport. It is persistent in the environment indefinitely because metals do not degrade. Background arsenic levels in surface soil contribute to the concentrations in surface water and complicate the identification of specific, anthropogenic arsenic sources. The natural background sources of arsenic are reflected by the detection of arsenic in surface soil, at concentrations above the WRW PRG, in BZ OU drainages, including the Rock Creek, Smart Ditch, No Name Gulch, and McKay Ditch watersheds, despite these drainages not being downstream from the former IA. Surface soil concentrations of arsenic were co-located in the drainages, but were not observed at any

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[9] A surface water sample result at a former Building 779 footing drain had an aluminum sample result above the surface water standard. However, that drain outfall no longer exists in the post-accelerated action configuration, because the drain was disrupted.

of the representative surface water monitoring locations. As such, arsenic is identified as having limited migration from surface soil to surface water.

Chromium (Total)

Chromium (total) is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). Total (unfiltered) chromium in surface soil is distributed throughout the former IA (most notably in the former 400 and 700 Areas) at concentrations that exceed the WRW PRG. Chromium migration in the RFETS environment occurs via both surface (particulate) and subsurface (dissolved) transport mechanisms. With regard to its particulate transport, the surface water monitoring locations with chromium (total) concentrations above the highest of the surface water standard, background, or PQL are generally located near the historical soil source areas. However, it is also observed in background in surface water, suggesting that elevated chromium in surface water results from background concentrations in the soil. The second process for chromium migration involves subsurface dissolved groundwater transport, which is addressed in Section 8.4.4.3. Chromium persists in the environment indefinitely because it is a stable element.

Chromium has been detected at representative surface water station SW018 (2 samples out of 31 total results) and GS10 (1 sample out of 157 total results) in North and South Walnut Creek, respectively, and the background surface water monitoring location GS05 (two samples out of five total results) in Woman Creek. Due to the low number of detections at the representative surface water stations and the implementation of measures to further reduce erosion with its associated chromium transport, chromium is identified as having a limited pathway from surface soil to surface water.

Vanadium

Vanadium is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the No Name Gulch Drainage EU. Vanadium is identified as an AOI in surface soil only. Sampling locations above the WRW PRG are localized in the areas of the historical Property Utilization and Disposal (PU&D) Yard and former Oil Burn Pit No. 1. Although vanadium persists in the environment indefinitely, studies indicate vanadium is relatively immobile in soil (Martin and Kaplan 1998) (Table 8.2). Vanadium is not a surface water AOI; it has not been observed above the surface water standard at the representative surface water monitoring locations, and therefore it is identified as having a limited pathway from surface soil to surface water.

8.3.3.3 Surface Soil SVOC Migration

This section presents the discussion of surface soil SVOCs, which are distributed widely in the environment. The transport and fate of SVOCs were not modeled.

Benzo(a)pyrene

Benzo(a)pyrene is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the IA, Upper Woman Drainage, and Upper Walnut Drainage EUs. Benzo(a)pyrene is present in surface soil throughout the IA OU (most notably in the former 400 and 800 Areas), along the hillside north of the SID (in the former Building 881 Hillside area), and in the areas of the Present Landfill and Original Landfill.

Benzo(a)pyrene presence in the environment is widespread, as a product of incomplete combustion of fuels and the presence of asphalt (or where asphalt was placed, such as the Present Landfill). Polyaromatic hydrocarbons (PAHs) with a relatively high molecular weight, such as benzo(a)pyrene, sorb strongly to particulate matter, such as soil. Its transport is likely associated with erosion of surficial soil and particulate transport. Relative to other surface soil AOIs, benzo(a)pyrene is not persistent in the environment. Its half-life ranges from tens to hundreds of days (see Attachment 1 of this section for more details).

Benzo(a)pyrene has not been identified as an AOI in surface water and has not been observed above the surface water standard at representative surface water monitoring locations. Therefore, it is identified as having a limited pathway from surface soil to surface water.

Dibenz(a,h)anthracene

Dibenz(a,h)anthracene is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). Dibenz(a,h)anthracene is detected as an AOI in surface soil only. Results above the WRW PRG are observed throughout the former IA (most notably in the former 700 Area and the historical Oil Burn Pit No. 1 area) and in the Original Landfill area.

Similar to benzo(a)pyrene, the presence of dibenz(a,h)anthracene in the environment is associated with incomplete combustion of fuels. High-molecular-weight PAHs such as dibenz(a,h)anthracene have a tendency to adsorb to organic carbon and have somewhat limited mobility in the subsurface (Southworth 1979). Hence, the dominant transport mechanism of dibenz(a,h)anthracene is the surface pathway via particulate transport; therefore, dibenz(a,h)anthracene is not a groundwater AOI. Volatilization from surface soil to air is not an important loss mechanism for dibenz(a,h)anthracene (Park et al. 1990). Although there are differences in the biodegradation half-life values estimated by different investigators, studies suggest the biodegradation half-lives of PAHs such as dibenz(a,h)anthracene will range from over 20 days to hundreds of days.

Dibenz(a,h)anthracene is not a surface water AOI and has not been detected above the surface water standard at representative surface water monitoring locations. As such, it is identified as having a limited pathway from surface soil to surface water.

8.3.3.4 Surface Soil PCB Migration

PCB-1254 and PCB-1260

PCB-1254 and PCB-1260 are both defined as surface soil AOIs in the nature and extent of soil contamination (Section 3.0). PCB-1254 and PCB-1260 are detected above the WRW PRG in localized areas in the former IA (most notably at the former Building 771 area, east of the historical SEP, as well as near former Buildings 444, 883, and 964) and in the BZ OU (at the Original Landfill and historical PU&D Yard areas). PCB-1254 is an AOI in surface soil only. PCB-1260 is an AOI in surface and subsurface soil.

Not surprisingly, PCBs are not groundwater AOIs because they sorb strongly to soil as a result of low water solubility and do not leach extensively (Sklarew and Girvin 1987). PCBs tend to have moderate persistence in the environment, with half-lives on the order of months to years (Gan and Berthouex 1994; Kohl and Rice 1998). Biodegradation has been shown to occur under both aerobic and anaerobic conditions and is a major degradation process for PCBs in soil and sediment.

These PCBs are not surface water AOIs and have not been detected above the surface water standard at representative surface water monitoring locations. PCB-1254 and PCB-1260 are identified as having limited pathways from surface soil to surface water.

8.3.3.5 Surface Soil Dioxin Migration

Total 2,3,7,8-TCDD TEQ

2,3,7,8-TCDD TEQ is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the Upper Woman Drainage EU (UWOEU). 2,3,7,8-TCDD TEQ is an AOI in surface soil only. Based on a limited sample set with limited spatial extent, there is one sample result above the WRW PRG, located in the area of the former incinerator (historical Potential Area of Concern [PAC] SW-133.5) southwest of the former IA.[10] As a dioxin, 2,3,7,8-TCDD TEQ is characterized by low aqueous solubility and high hydrophobicity (Table 8.2). Therefore, 2,3,7,8-TCDD TEQ sorbs strongly to soil and has limited mobility. Its persistence in the environment is moderate with a half-life on the order of 20 years. 2,3,7,8-TCDD TEQ is not a surface water AOI and has not been detected above the surface water standard at representative surface water monitoring locations. It is identified as having a limited pathway from surface soil to surface water.

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[10] It is noted that the “surface soil” designation is misleading, because the soil where the samples were collected as confirmation samples is now buried under approximately 20 ft of soil following final land configuration. Confirmation samples collected from the floor of excavation areas (approximately 20 ft below grade) were designated as surface soil samples. Although the sampling locations are not at the surface after imported clean backfill has been placed in the excavation, the samples are still classified as surface soil samples in the database and the TEQ calculation is based on these samples.

8.3.4 Sediment Analytes of Interest

This section addresses the fate and transport of sediment AOIs. It immediately follows the evaluation of surface soil AOIs because both of these environmental media are subject to surface transport mechanisms. The effect of AOIs in these surface media is assessed in terms of their impact on surface water quality at representative surface water monitoring locations. The discussion of sediments includes: 1) a description of the sediment AOIs, 2) a brief summary of the mechanisms related to sediment contaminant transport, and 3) an evaluation of the RFETS sediment AOIs.

Five sediment AOIs were identified in the nature and extent of surface water and sediment contamination (Section 5.0). These are:

- Radionuclides – Americium-241 and plutonium-239/240;
- Metals – Arsenic and chromium; and
- SVOCs – Benzo(a)pyrene.

8.3.5 Migration of Sediment Analytes of Interest

The general fate and transport mechanisms for contaminants in sediments at RFETS are reflected in the conceptual diagram shown on Figure 8.2. The primary process by which sediments are contaminated is the erosion of contaminated surface soil, particulate transport, and deposition in stream channels and ponds. Surface water erosion and contamination of sediments is particularly important for low-solubility contaminants bound to soil particles, such as plutonium-239/240, americium-241, and chromium. Detection of these contaminants in surface water correlates with elevated concentrations of suspended solids and resulting sediment contamination. A summary of results of the fate and transport evaluation process for the sediment AOIs is presented in Table 8.5.

Sediment transport in the post-accelerated action site configuration at RFETS will be reduced compared with the historic developed condition, because the elimination of impervious surfaces will result in diminished runoff and reduced peak flow rates during storm events, when the majority of sediment transport occurs.

For individual AOIs, the fate and transport characteristics in sediments are summarized in Table 8.2.

8.3.5.1 Sediment Radionuclide Migration

<u>Americium-241</u>

Americium-241 is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). Two locations exist with sediment sample results above the americium-241 WRW PRG (7.69 picocuries per gram [pCi/g]). These sampling locations are in Pond B-3 in South Walnut Creek. As indicated previously in Section 8.3.3.1, americium-241 migrates in the environment via particulate transport and persists indefinitely. No modeling was conducted on americium-241 fate and transport in sediment for this analysis.

It is observed at concentrations above the surface water standard at several representative surface water monitoring locations, including surface water monitoring location GS10, located in South Walnut Creek. Based on the elevated americium-241 concentrations observed in the South Walnut Creek drainage in both sediment and surface water, americium-241 is identified as having a complete surface pathway between sediment and surface water.

Plutonium-239/240

Plutonium-239/240 is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). It is also defined as a COC for surface soil/sediment in the WBEU. Several locations exist with sediment sample results above the plutonium-239/240 WRW PRG (9.80 pCi/g). Locations above the WRW PRG include along the former Central Avenue Ditch, four locations in the North Walnut Creek drainage (in Ponds A-1 and A-2), three locations in the South Walnut Creek drainage (in Pond B-4), and near the former shooting range south of the historical 903 Pad/Lip area.

As indicated previously in Section 8.3.3.1, plutonium-239/240 migrates in the environment via particulate transport and persists, for the purposes of this evaluation, indefinitely. No modeling was conducted on plutonium fate and transport in sediment for this analysis.

Plutonium-239/240 has been observed at several representative surface water monitoring locations that are co-located in drainages where plutonium-239/240 has also been detected in sediment above the WRW PRG. These surface water monitoring locations include SW018 and SW093 in North Walnut Creek, GS10 in South Walnut Creek, and GS51 and SW027 in the Woman Creek/SID drainage. Based on the elevated plutonium-239/240 concentrations observed in three drainages in both sediment and surface water, plutonium-239/240 is identified as having a complete surface pathway between sediment and surface water.

8.3.5.2 Sediment Metal Migration

Arsenic

Arsenic is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). It is also defined as a COC for surface soil/sediment in the IAEU and WBEU. Sediment sampling locations are widely distributed across the site with sample results above the arsenic WRW PRG (2,410 micrograms per kilogram [µg/kg]). In addition, locations exist in all of the major drainages with sediment arsenic concentrations below the WRW PRG, but above the background mean plus two standard deviations (M2SD) (6,260 µg/kg). Drainages with results above the WRW PRG include Rock Creek and Smart Ditch, which are not in the watershed of the former IA. The highest sample result, at sampling location SED019, is located near Antelope Springs in the Woman Creek watershed south of the former IA and is representative of the substantial background contribution of arsenic to the concentrations observed in sediments at RFETS.

Most arsenic compounds have low solubility and are strongly sorbed to sediments; thus, arsenic transport from surface water to sediment is primarily associated with particle transport. Arsenic persists indefinitely in the environment. Transport of arsenic via sediment movement has not been modeled, and arsenic has not been observed above the surface water standard at representative surface water monitoring locations. The widespread detections of arsenic in sediment are suggestive of background conditions. Based on this information, arsenic is identified as having a limited surface pathway from sediment to surface water.

Chromium

Chromium is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). Numerous locations exist with sediment sample results above the chromium WRW PRG (28,417.9 µg/kg), including locations across the former IA and in the North Walnut Creek drainage (at Ponds A-1, A-2, and A-3), South Walnut Creek drainage (Pond B-4), and the Woman Creek drainage (Pond C-1).

Chromium is present in soil and sediment mainly as an insoluble oxide, and its transport is therefore dictated by surface water transport of particles. Chromium is a stable element and persists in the environment indefinitely.

Chromium has been observed above the surface water standard at representative surface water monitoring locations. It has been detected at station GS05, the background location in western Woman Creek. In addition, it was observed once at GS10 (out of 157 total results) and at SW018 twice (out of 31 total results). These elevated measurements were associated with widespread soil disturbance and associated erosion in the former IA, which occurred during site closure activities. Based on infrequent observations of elevated chromium at the representative surface water monitoring locations and the greatly diminished runoff and erosion from the former IA, there is a limited surface pathway for chromium from sediment to surface water.

8.3.5.3 Sediment SVOC Migration

Benzo(a)pyrene

Benzo(a)pyrene is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). It is also defined as a COC for surface soil/sediment in the IAEU, UWOEU, and Upper Walnut Drainage EU (UWNEU). Locations exist across the former IA and in the South Walnut Creek drainage with sediment sample results above the benzo(a)pyrene WRW PRG (379 µg/kg).

As discussed in Table 8.2, benzo(a)pyrene is associated with the removal or placement of asphalt and incomplete combustion of fuels. While PAHs such as benzo(a)pyrene have a tendency to sorb to organic carbon, they also biodegrade relatively quickly (with a half-life in the range from 20 days to hundreds of days) and thus are not persistent in the environment. Although numerical modeling of benzo(a)pyrene transport in sediment has not been conducted, other factors (such as not being an AOI in surface water, its short-term persistence in the environment, and its affinity to sorb to organic material) were the basis for determining that benzo(a)pyrene has a limited surface pathway from sediment to surface water.

8.4 Subsurface Transport Pathways – Analyte of Interest Fate and Transport Evaluation

The migration of subsurface contaminants involves the fate and transport of contamination associated with subsurface soil and groundwater. Subsurface soil is addressed in Sections 8.4.1 and 8.4.2, with the identification of subsurface soil AOIs and a discussion of subsurface soil contaminant migration, respectively. Groundwater is addressed in Sections 8.4.3 and 8.4.4, with the identification of groundwater AOIs, a listing of contiguous, mappable plume areas in Table 4.9, and a discussion of groundwater contaminant migration, respectively.

8.4.1 Subsurface Soil Analytes of Interest

Subsurface soil[11] is a medium that, by itself, is not a transport pathway. However, subsurface soil contributes to groundwater as a potential pathway for subsurface contaminant transport. AOI transport from subsurface soil to other environmental media is dependent on physical, chemical, and biological mechanisms, such as dissolution and sorption/desorption processes. It can also be influenced by subsurface conduits that can potentially bring the subsurface to the surface.

Fourteen subsurface soil AOIs were identified in the nature and extent of soil contamination section (Section 3.0):

- Radionuclides – Americium-241, plutonium-239/240, uranium-235, and uranium-238;
- VOCs – Tetrachloroethene, trichloroethene, 1,1,2,2-tetrachloroethane, carbon tetrachloride, chloroform, and methylene chloride;
- Metals – Chromium (total) and lead;
- SVOCs – Benzo(a)pyrene; and

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[11] Subsurface soil measurements are for soil deeper than 6 inches from the surface at the time of sampling. It is important to note that the RI/FS Report represents site conditions immediately following completion of accelerated actions and prior to any soil backfilling or recontouring to match the surrounding topography. Consequently, the RI/FS Report does not represent the final land configuration of the site. For further details, see Section 3.3.

- PCBs – PCB-1260.

8.4.2 Migration of Subsurface Soil Analytes of Interest

An assessment was made to determine whether each subsurface soil AOI has a complete pathway to surface water based on the following information: 1) the nature and extent of the subsurface soil AOIs (Section 3.0), 2) the general environmental characteristics of these AOIs, 3) the persistence of the subsurface AOIs in the environment, 4) the results of predictive modeling of the AOIs, and 5) the potential of the AOIs to impact surface water quality measured at representative groundwater monitoring locations. A summary of results of the subsurface fate and transport evaluation process for each AOI is presented in Table 8.6.

AOI data for subsurface media (subsurface soil and groundwater) are evaluated in terms of observed impacts at representative groundwater monitoring locations (AOC and Sentinel wells). Consistent with the FY2005 IMP, Revision 1, the AOC and Sentinel wells were selected because of their close proximity to areas where groundwater discharges to surface water and, hence, reflect potential impacts to surface water via groundwater. Table 8.7 and Table 8.8 provide a summary of the AOC and Sentinel well data, the frequency of detection, and the results of a Seasonal-Kendall (S-K) trending analysis at locations where sufficient data exist to conduct the analysis (see Attachment 4 of this section). No modeling was conducted for subsurface soil, but results of VOC groundwater transport modeling are discussed in relation to the subsurface soil VOCs, where applicable.

8.4.2.1 Subsurface Soil Radionuclide Migration

Americium-241

Americium-241 is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). In subsurface soil, americium-241 exists above the WRW PRG in one area in the South Walnut Creek watershed, at the historical East Trenches at a depth interval from 3.0 to 8.0 feet (ft).

As discussed in the evaluation of americium-241 in surface soil (Section 8.3.3.1), the dominant transport mechanism is via surface mechanisms (see Table 8.2) (K-H 2002a). The subsurface mobility of americium-241 is extremely limited because of its low solubility and the strong tendency of americium hydroxides to sorb to surfaces. However, americium-241 historically may have been transported vertically into subsurface soil due to entrainment in a liquid, such as oil and/or solvent, that would have fostered limited downward transport (such as at the historical 903 Pad). Americium-241 transport below the ground surface also could occur via a subsurface conduit that facilitated subsurface movement. This subsurface transport pathway, distinctly different than groundwater transport of a dissolved constituent, occurred at the former Building 771 where americium-241 was transported to the surface via subsurface drains that were intact; these subsurface drains were subsequently disrupted. Therefore, the presence of americium-241 in the subsurface is attributed to being placed directly into the subsurface, not from groundwater transport.

No subsurface transport numerical modeling has been conducted on americium-241 for this evaluation. (A quantified estimate of subsurface transport is presented in the AME Pathway Analysis Report [K-H 2002a].) For the purpose of this evaluation, americium-241 is considered to persist indefinitely.

Because of the surface transport mechanisms that americium-241 is associated with, americium-241 has not been measured at the AOC or Sentinel wells. While it has been detected intermittently in surface water above the standard in the same drainage (South Walnut Creek) where americium-241 was detected in subsurface soil above the WRW PRG, the impact to surface water is attributed to americium-241 from surface media (that is, surface soil and sediment), not from groundwater transport of a dissolved form. Therefore, americium-241 is identified as having a limited transport pathway from subsurface soil to surface water.

Plutonium-239/240

Plutonium-239/240 is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). In subsurface soil, plutonium-239/240 exists above the WRW PRG at three locations. These are in the North Walnut Creek watershed in the former 700 Area of the IA (at depth intervals from 3.0 to 8.0 ft and 8.0 to 12.0 ft), in the South Walnut Creek watershed at the historical East Trenches (at a depth interval from 3.0 to 8.0 ft), and at the historical 903 Pad (on the boundary of the South Walnut Creek and SID watersheds at a depth interval from 3.0 to 8.0 ft).

As discussed in the evaluation of plutonium-239/240 in surface soil (Section 8.3.3.1), the dominant transport mechanism is via surface transport. The subsurface mobility of plutonium-239/240 is extremely limited due to its strong tendency to form plutonium hydroxides/oxides which sorb to surfaces (see Table 8.2) (K-H 2002a). The subsurface soil plutonium-239/240 is related to either subsurface plutonium placed below the ground surface (former 700 Area and historical East Trenches) or vertical transport caused by plutonium entrained in oil and/or solvent (historical 903 Pad) that is not reflective of plutonium environmental transport. For the purpose of this evaluation, plutonium-239/240 is considered to persist indefinitely due to its long half-life.

No subsurface transport modeling has been conducted on plutonium-239/240 for this evaluation. (A quantified estimate of subsurface transport is presented in the AME Pathway Analysis Report [K-H 2002a].) For the purpose of this evaluation, plutonium-239/240 is considered to persist indefinitely.

Because of the surface transport mechanisms that plutonium-239/240 is associated with, plutonium-239/240 has not been measured at the AOC or Sentinel wells. While it has been detected intermittently in surface water above the standard in the same drainages (North Walnut Creek, South Walnut Creek, and Woman Creek/SID watersheds) where plutonium-239/240 was detected in subsurface soil above the WRW PRG, the impact to surface water is attributed to plutonium-239/240 from surface media such as surface soil and sediment. Therefore, plutonium-239/240 is identified as having a limited transport pathway from subsurface soil to surface water.

Uranium-235 and Uranium-238

Uranium-235 and Uranium-238 are defined as subsurface soil AOIs in the nature and extent of soil contamination (Section 3.0). In subsurface soil, uranium-235, and uranium-238 exist above the WRW PRG at one location, the historical Ash Pits, at depth intervals from 3.0 to 8.0 ft and 8.0 to 12.0 ft. As discussed in Section 8.3.3.1, these uranium isotopes are transported by both surface and subsurface transport mechanisms. For subsurface transport, uranium migrates as a soluble uranium (VI) species that is mobile in the subsurface environment.

Measurements of uranium in the environment are strongly influenced by the high concentration of natural uranium which makes it difficult to distinguish from anthropogenic (manmade) uranium. The differentiation of natural and anthropogenic uranium was evaluated for water media using specialized analytical techniques, discussed in 8.4.4.1. For the purposes of this evaluation, these uranium isotopes are considered to persist indefinitely. No uranium fate and transport modeling was conducted for this evaluation. (A quantified estimate of subsurface transport is presented in the AME Pathway Analysis Report [K-H 2002a].)

Uranium-235 and uranium-238 have not been measured at the representative groundwater monitoring locations in North Walnut Creek, South Walnut Creek, and No Name Gulch. Summaries of uranium sum-of-isotope groundwater data at the AOC and Sentinel wells, are shown in Table 8.7 and Table 8.8, respectively. As shown in these tables, AOC well 10594 and Sentinel well 51605 (formerly 1386) have elevated uranium that is entirely from natural sources. Sentinel wells 70299 and 15699 have uranium concentrations above the surface water standard but below background levels.

Several types of accelerated actions have been implemented to address uranium transport. For the form of uranium that travels by particulate transport via surface mechanisms, the removal of impervious surfaces has decreased runoff volumes and peak discharge rates, which reduces soil erosion, with associated uranium in particle form, and its impact on surface water. For the dissolved form of uranium transported via groundwater, the SPPTS was installed.

Uranium-235 and uranium-238 are identified as having a limited pathway from subsurface soil to surface water (via groundwater), based on the absence of co-located elevated concentrations in subsurface soil and groundwater. However, in groundwater, total uranium (sum of isotopes) (including at the historical Ash Pits) is identified as having a complete subsurface pathway from groundwater to surface water (Section 8.4.4.1).

8.4.2.2 Subsurface Soil VOC Migration

The following sections discuss the subsurface transport and fate of VOCs. Their environmental persistence and associated groundwater fate and transport modeling are provided in Section 8.4.4.2.

Carbon Tetrachloride

Carbon tetrachloride is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Carbon tetrachloride is observed in subsurface soil at concentrations above the WRW PRG at seven sampling locations in the 12-to-30-ft depth interval at the historical IHSS 118.1 site, south of former Building 771.[12]

RFETS data indicate that carbon tetrachloride migrates in the environment via subsurface transport as a soluble AOI. It exhibits moderate mobility and degrades anaerobically to chloroform and methylene chloride, as shown on Figure 8.6 and discussed in Table 8.2. The persistence of carbon tetrachloride will be addressed in the groundwater discussion in Section 8.4.4.2.

Carbon tetrachloride has been observed at multiple representative groundwater monitoring locations (AOC and Sentinel wells as shown in Table 8.7 and Table 8.8, respectively) in the North Walnut Creek, South Walnut Creek, and Woman Creek drainages. Discussion of the AOC and Sentinel well comparisons are provided in the groundwater discussion in Section 8.4.4.2. Numerical groundwater modeling results consistently predict concentrations of carbon tetrachloride at groundwater discharge locations at the Carbon Tetrachloride Plume (south of former Building 771), the historical East Trenches, and the historical 903 Pad/Ryan’s Pit areas above the surface water standard.

In surface water, carbon tetrachloride was observed above the surface water standard in the South Walnut Creek basin (near the historical Mound Site discharge). Based on the subsurface soil fate and transport evaluation, carbon tetrachloride is identified as having a complete pathway from subsurface soil to surface water via groundwater.

Chloroform

Chloroform is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). The chloroform in subsurface soil is spatially similar to carbon tetrachloride, with concentrations above the WRW PRG at one sampling location, in the 12-to-30-ft depth interval at the historical IHSS 118.1, south of former Building 771.

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[12] The historical IHSS 118.1 site in the North Walnut Creek basin contained carbon tetrachloride above AOI criteria in subsurface soil and groundwater. In 2005, the majority of the groundwater source and observed dense nonaqueous-phase liquid (DNAPL) was reduced from historical IHSS 118.1 via an accelerated action, and a biodegradation enhancement product (Hydrogen Release Compound [HRC®]) was placed on the subsurface soil.

Chloroform is a degradation daughter product of carbon tetrachloride, as shown on Figure 8.6 and, similar to carbon tetrachloride, chloroform exhibits high subsurface mobility because of its low soil adsorption. The persistence of chloroform is discussed in the groundwater section (Section 8.4.4.2).

The subsurface soil results for chloroform above the WRW PRG are not co-located with AOC and Sentinel well locations with sample results above the surface water standard. Chloroform is identified as a subsurface soil AOI based on soil samples above the WRW PRG concentrations in the historical IHSS 118.1 area. Groundwater samples from AOC and Sentinel wells in that area are not above the respective surface water standards for chloroform. Therefore, based strictly on the criteria for the groundwater pathway evaluation Step 5a, there are no complete pathways to surface water for chloroform. However, subsurface soil samples in several other areas (for example, historical Mound, historical 903 Pad, and historical East Trenches areas) are above background for this AOI, and in those areas it is detected in downgradient AOC and Sentinel wells, thereby indicating chloroform has a complete pathway from subsurface soil to surface water via groundwater.

Methylene Chloride

Methylene chloride is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). The methylene chloride in subsurface soil is similar to carbon tetrachloride, with concentrations above the WRW PRG at one sampling location in the 12-to-30-ft depth interval at the historical IHSS 118.1, south of former Building 771. This is expected because methylene chloride is a reductive dechlorination byproduct of carbon tetrachloride. It is also detected above the WRW PRG in subsurface soil at the Oil Burn Pit No. 1 and Mound Site/Oil Burn Pit No. 2 areas. As discussed in Table 8.2, methylene chloride is not strongly sorbed to soil and is generally highly mobile in the subsurface. The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. Groundwater modeling results are not conclusive with respect to methylene chloride concentrations being above surface water standards at groundwater discharge locations.

Methylene chloride has not been detected at an AOC well, but has been observed at several Sentinel wells in North and South Walnut Creek and in Woman Creek (see Section 8.4.4.2 for details on the well comparison). It has been detected in surface water in South Walnut Creek, downgradient from the historical Mound Site/Oil Burn Pit No. 2 area. Based on the detections of methylene chloride above the surface water standard at Sentinel wells, the results of the subsurface soil fate and transport evaluation identify methylene chloride as having a complete subsurface pathway from subsurface soil to surface water via groundwater.

Tetrachloroethene

Tetrachloroethene is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Tetrachloroethene is detected in subsurface soil at concentrations above the WRW PRG at several sampling locations, including historical

IHSS 118.1 (located north of former Buildings 776/777), the historical Oil Burn Pit No. 1, the historical Mound Site, the historical Oil Burn Pit No. 2, and south of former Building 991. Tetrachloroethene is detected above the WRW PRG at depth intervals from 3.0 to 8.0 ft (historical Oil Burn Pit No. 2 and south of former Building 991), 8.0 to 12.0 ft (historical Oil Burn Pit No. 2), and 12.0 to 30.0 ft (historical Mound Site, historical Oil Burn Pit No. 2, and historical IHSS 118.1).

The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. It biodegrades into trichloroethene (see Figure 8.6 for degradation chain). Tetrachloroethene has moderate to high mobility in soil, and it is denser than water. Its environmental persistence is discussed in the groundwater section (Section 8.4.4.2).

Tetrachloroethene is observed in many representative groundwater monitoring locations in all three surface water drainages (see Section 8.4.4.2 for details on the well comparison). It is detected at surface water monitoring locations in North and South Walnut Creeks. It is co-located in subsurface soil with surface water drainages. At the historical Mound Site/Oil Burn Pit No. 2 area, in the South Walnut Creek basin, tetrachloroethene was detected in subsurface soil, groundwater, and surface water. Modeling results indicate that predicted results at groundwater discharge locations are conclusively above surface water standards at the Carbon Tetrachloride Plume, the historical East Trenches, and the historical 903 Pad/Ryan’s Pit areas. Based on the measured data and model results, the subsurface soil fate and transport evaluation identifies tetrachloroethene as having a complete pathway from subsurface soil to surface water via groundwater.

Trichloroethene

Trichloroethene is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Trichloroethene is present in subsurface soil at concentrations above the WRW PRG at two sampling locations in the South Walnut Creek watershed: the historical East Trenches and historical Oil Burn Pit No. 2 sites (at a depth interval from 12.0 to 30.0 ft).

The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. It biodegrades into cis-1,2-dichloroethene (see Figure 8.6 for degradation chain). Trichloroethene has moderate to high mobility in soil, and it is denser than water. Its environmental persistence is discussed in Section 8.4.4.2.

Trichloroethene was detected in representative groundwater monitoring locations (AOC and Sentinel wells) throughout all three surface water drainages (see Section 8.4.4.2 for details on well comparison). It was also observed in surface water in South Walnut Creek and Woman Creek. At the historical Mound Site/Oil Burn Pit No. 2 area, trichloroethene was detected above AOI criteria for subsurface soil, groundwater, and surface water. Groundwater modeling results indicate that predictions at groundwater discharge locations are conclusively above surface water standards at the Carbon Tetrachloride Plume, the historical East Trenches, and the historical 903 Pad/Ryan’s Pit areas. Based on the measured data and numerical model results, the subsurface soil fate and transport evaluation identifies trichloroethene as having a complete pathway from subsurface soil to surface water via groundwater.

1,1,2,2-Tetrachloroethane

1,1,2,2-Tetrachloroethane is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). 1,1,2,2-Tetrachloroethane is an AOI in subsurface soil only. 1,1,2,2-Tetrachloroethane is detected in subsurface soil at concentrations above the WRW PRG at one location, in the 12-to-30-ft depth interval at the historical IHSS 118.1 site south of former Building 771. It degrades anaerobically to 1,1,2-trichloroethane and will not adsorb appreciably to soil. Its half-life is estimated to be in the range of several weeks, although no RFETS-specific data are available. No modeling has been conducted for 1,1,2,2-tetrachloroethane.

1,1,2,2-Tetrachloroethane has not been detected at any of the representative groundwater monitoring locations, and subsurface soil measurements are not co-located with surface water detections. Based on the subsurface soil fate and transport evaluation, 1,1,2,2-tetrachloroethane is identified as having a limited pathway between subsurface soil and surface water.

8.4.2.3 Subsurface Soil Metal Migration

Chromium

Total chromium is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Chromium is present in subsurface soil from natural sources and can also be present as a result of historic releases from anthropogenic sources. Total chromium in subsurface soil is detected above the WRW PRG in the former IA in several locations, including the former 700 and 400 Areas, historical East Trenches, and historical Ash Pits where AOIs were placed into the environment at depth.

As discussed in Section 8.3.3.2 regarding surface soil, chromium may be transported via the surface (particulate) pathway, its dominant pathway, or the subsurface (dissolved) pathway. Under oxidizing conditions, chromium(VI) may remain dissolved as the chromate anion, and may be highly mobile in groundwater. Chromium is a stable element and persists indefinitely.

Total chromium was not observed at any of the AOC wells. It has been observed at Sentinel well 23296, located between Ponds B-2 and B-3 in the South Walnut Creek drainage, although only 2 samples out of 15 total results had concentrations above the surface water standard. (The surface water standard for total chromium is above the background and PQL values, and subsequent samples were either below the detection limit or below the surface water standard.) There may also be influences from well construction and sampling materials. At the historical East Trenches and former 700 Areas, elevated concentrations of chromium are detected in both the subsurface soil and groundwater. No chromium fate and transport modeling has been conducted. Based on the limited detection of chromium at one Sentinel well, chromium is identified as having a limited pathway from subsurface soil to surface water.

<u>Lead</u>

Lead is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Lead in subsurface soil at concentrations above the WRW PRG is detected in the South Walnut Creek basin (former 400 Area) and Woman Creek basin (historical Ash Pits and historical firing ranges on the north and south sides of Woman Creek).

Lead is typically retained strongly in soil, with migration in the environment generally associated with particle transport (that is, colloidal particles or larger particles of lead carbonate, lead oxide, lead hydroxide, or other lead compounds). Therefore, lead in subsurface soil is likely contributing little to surface water. The stable form of lead, addressed in this evaluation, persists indefinitely.

Lead has not been detected at any AOC or Sentinel wells. The locations of subsurface soil with elevated concentrations of lead are not co-located with surface water monitoring locations that have elevated lead concentrations, other than a general association with the former 400 Area. No fate and transport modeling has been conducted for lead. Lead is identified as having a limited pathway from subsurface soil to surface water.

8.4.2.4 Subsurface Soil SVOC Migration

<u>Benzo(a)pyrene</u>

Benzo(a)pyrene is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the IAEU, UWOEU, and UWNEU. Benzo(a)pyrene is present in subsurface soil in several locations throughout the IA OU, including the former 300 and 700 Areas, historical East Trenches, and former Building 881 Hillside area.

As discussed in Section 8.3.3.3, benzo(a)pyrene is a high-molecular-weight PAH with a tendency to adsorb to organic carbon, is associated with asphalt or incomplete combustion of fuels, and has somewhat limited mobility in the subsurface (Southworth 1979). Benzo(a)pyrene is not persistent in the environment; its half-life ranges from tens to hundreds of days (see Attachment 1 of this section for more details).

Benzo(a)pyrene has not been observed at any AOC or Sentinel wells, and detections are attributed to benzo(a)pyrene in surface soil and/or sediment, not subsurface transport. Based on the subsurface soil fate and transport evaluation, benzo(a)pyrene is identified as having a limited pathway from subsurface soil to surface water.

8.4.2.5 Subsurface Soil PCB Migration

PCB-1260 is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). PCB-1260 is detected in subsurface soil above the WRW

PRG in a localized portion of the former 700 Area, specifically in the area of former Building 776.

PCBs do not leach extensively and are strongly sorbed to soil as a result of low water solubility (Sklarew and Girvin 1987). PCBs tend to have moderate persistence in the environment, with half-lives on the order of months to years (Gan and Berthouex 1994; Kohl and Rice 1998). No fate and transport modeling has been conducted on PCBs because their subsurface migration is limited.

PCB-1260 has not been observed at any representative groundwater monitoring location, and its co-located detections are attributed to residual PCBs in surface soil and/or sediment, not subsurface transport. Therefore, PCB-1260 is identified as having a limited pathway from subsurface soil to surface water.

8.4.3 Groundwater Analytes of Interest

In accordance with RFCA, protection of surface water quality is the basis for groundwater cleanup and management decisions (DOE et al. 1996). Using the site hydrologic data (presented in Section 2.0), AOI contiguous, mappable plume maps (presented in Section 4.0, Table 4.9), and the VOC fate and transport modeling results (discussed in Section 8.2.1.4), the AOI fate and subsurface transport evaluation process was applied at representative groundwater monitoring locations (AOC and Sentinel wells) to determine whether AOIs had a complete pathway from groundwater to surface water (see discussion in Section 8.2 and diagrammed in Flowchart 8.1). AOC and Sentinel wells were selected because of their close proximity to areas where groundwater discharges to surface water and, hence, reflect potential impacts to surface water via groundwater.

As part of the evaluation process, time-series graphs were generated (with the surface water standard, background value, and PQL) and a S-K statistical analysis was conducted on representative groundwater monitoring locations (the AOC and Sentinel wells). The time-series plots, provided to graphically portray sample results over time, are provided in Attachment 4.0 (CD-ROM). The S-K analysis results, provided to give a statistical analysis of trends (whether upward, downward, or nonexistent) are provided in Table 8.9. The results of the assessment for AOC wells are provided in Table 8.7 and for Sentinel wells in Table 8.8 (along with the main groundwater contamination areas). The results of the VOC transport modeling are provided in Table 8.10. The results of the groundwater AOI evaluation process are summarized in Table 8.11.

Nineteen shallow (UHSU) groundwater AOIs (no AOIs were determined from the LSHU) were identified in the nature and extent of groundwater contamination (Section 4.0):

- Radionuclides – Uranium (sum of isotopes uranium-233/234, uranium-235, and uranium-238);[13]

- VOCs – cis-1,2-Dichloroethene, 1,2-dichloroethane, 1,1-dichloroethene, benzene, carbon tetrachloride, chloroform, chloromethane, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride;

- Metals – Arsenic (dissolved), chromium (total), nickel (dissolved), and nickel (total); and

- Water quality parameters, including inorganic parameters – Fluoride, nitrate/nitrite (as N),[14] and sulfate.

8.4.4 Migration of Groundwater Analytes of Interest

A conceptual model of general fate and transport processes influencing groundwater is shown as Figure 8.4. Physical, chemical, and biological processes are depicted on Figure 8.2. They control the fate and transport of AOIs in groundwater, as addressed above in Section 8.2.1.2. AOI persistence is based upon the type of residual contamination and its physical, chemical, and radiological processes in the environment, as discussed in Section 8.2.1.2.

Dense solvents (such as tetrachloroethene, trichloroethene, and carbon tetrachloride) may collect on impermeable sediments or bedrock to form a separate phase referred to as DNAPL. DNAPLs are of importance with respect to contaminant fate and transport because they sometimes migrate under the action of gravity at different velocities and can move in different directions relative to associated groundwater. Residual pockets of DNAPL may be retained at various depths in the porous subsoil because of capillary forces. Consequently, DNAPLs may produce constant long-term dissolved-phase concentrations in groundwater. DNAPLs have been identified and remediated down to the UHSU water table by soil excavation at historical IHSS 118.1, at historical Oil Burn Pit No. 2, and in some of the historical East Trenches (T-3 and T-4).

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[13] The sum of uranium isotopes uranium-233/234, uranium-235, and uranium-238 is based on activity measurements for each monitoring location and sampling event having data. Therefore, uranium isotopes are a calculated result that represents total uranium.

[14] Nitrogen is ubiquitous in the environment and can form a variety of compounds in different oxidation states. Nitrogen occurs in water in anionic form as ammonium (NH_4^+), and in cationic form as nitrite (NO_2^-) or nitrate (NO_3^-), as well as in intermediate oxidation states as part of organic solutes (Hem 1989). Nitrification refers to the biological oxidation of ammonium ions, which occurs in two steps: 1) ammonium is oxidized to nitrite, and 2) nitrite is further oxidized to nitrate. The transformation reactions from ammonium to nitrate occur rapidly and, hence, the intermediate nitrite concentrations at any time are relatively low (Canter 1997). Nitrites are particularly unstable in aerobic environments, such as those generally observed at RFETS, which facilitate the oxidation and conversion of nitrites to nitrates. Therefore, at RFETS, when analytical procedures measure nitrate and nitrite together, in the form of total nitrogen, the vast majority of the combined nitrite/nitrate concentration can typically be attributed to nitrate.

Recent EPA findings indicate that, depending on the type of residual DNAPL contamination, a given VOC could persist in the environment from decades to hundreds of years (EPA 2003) (Attachment 1 to this section). This is the case at RFETS, even given the completion of multiple source removal accelerated actions.[15]

This section presents the current distribution of contaminants in shallow (UHSU) RFETS groundwater and provides an evaluation of the extent of their migration and potential impact on surface water (using AOC/Sentinel well data and VOC fate and transport numerical modeling results). As noted previously, no AOIs are identified for groundwater in the LHSU. Section 4.0 (Table 4.9) provides a discussion of areas at the site where contiguous, mappable plumes[16] exist for each AOI. Although two dozen areas of contamination have been identified, the majority of the groundwater AOIs are VOCs associated with plumes (shown on Figure 8.5).

8.4.4.1 Groundwater Radionuclide Migration

Uranium Isotopes

Uranium (sum of isotopes uranium-233/234, uranium-235, and uranium-238) is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Mappable, contiguous plumes of total uranium isotopes are displayed on Figure 4.20 in the groundwater nature and extent section. This figure shows the plumes occurring at and downgradient of the historical SEP and the former 700 Area Northeast Plume.[17] Data from 2000 through 2005 indicate the highest uranium isotope activities were approximately 500 picocuries per liter (pCi/L). The highest concentrations of uranium are decreasing in groundwater beneath the SEP. This attenuation is probably due to sorption to the porous medium, dispersion, and dilution as the plume migrates.

Although they did not meet the criteria for a contiguous, mappable plume, concentrations of total uranium (sum of isotopes) have been observed in groundwater at the historical Ash Pits above the surface water standard. However, unsaturated conditions exist here for much of the year and thereby limit the potential for uranium migration. An evaluation of the groundwater in this area concluded that the subsurface uranium from the historical Ash Pits has not impacted the partly saturated groundwater and surface water in the area (K-H 2005e). As discussed in Section 8.3.3.1, uranium migrates both in the surface environment by particulate transport and in the subsurface as a dissolved constituent and is influenced by natural uranium contributions. For the purposes of the evaluation

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[15] A one-dimensional estimate was conducted using the Buschek and Alcantar method (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and modeling at RFETS, it is likely that VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Table 8.2 and Attachment 1 for details).

[16] A contiguous, mappable plume is defined by three or more adjacent wells that represent a contaminant area with sufficient spacial extent that are above a defined “level” (see nature and extent of groundwater contamination, Section 4.0, of the RI/FS or the Groundwater IM/IRA for more details) (DOE 2005a).

[17] Flow paths indicate that the former 700 Area Northeast Plume is captured by the SPPTS.

process, uranium persists indefinitely because of the long half-lives of its various isotopes.

As discussed above in Section 8.2.1.4, the natural versus anthropogenic uranium components in RFETS water were evaluated using analyses of uranium isotopic ratios. From 1997 to 2005, RFETS groundwater and surface water samples from select locations were sent to LANL for HR ICP/MS or TIMS analyses. These analyses measure mass ratios of the four uranium isotopes (masses 234, 235, 236, and 238). Isotopic ratios provide a signature that indicates whether the source of uranium is natural or anthropogenic (manmade). The pre-2005 data are summarized in a report on uranium in RFETS surface soil, surface water, and groundwater (K-H 2004b) and the Groundwater IM/IRA (DOE 2005a). These data have been compiled into a LANL report provided in Attachment 3 to this section.

The LANL report provides a summary of the HR ICP/MS and TIMS results and calculations of uranium isotopic mixtures (mixtures of natural and anthropogenic [enriched and depleted] uranium). The analysis concludes that the uranium in the UHSU groundwater and surface water is predominantly[18] from natural uranium sources. However, a portion of the uranium in isolated areas does have uranium from anthropogenic sources (primarily depleted uranium). Locations with a fraction of anthropogenic uranium in groundwater include the historical SEP area, as well as other isolated areas (historical Ryan’s Pit, the Original Landfill, historical Trench T-1, historical East Trenches, and historical Mound areas), although not necessarily at concentrations above the surface water standard.

As shown in Table 8.7 and Table 8.8, AOC wells 10594 and 00997 and Sentinel well 51605 (formerly well 1386) show elevated uranium that is entirely natural. (No ICP/MS or TIMS was conducted on well 00997, but given its location, it is highly likely that the uranium is from natural sources.) Sentinel well 70299 showed concentrations below background. In the South Walnut Creek drainage, well 23296 showed elevated values that were dominated by natural uranium. At the Present Landfill, well 4087 shows only approximately 1 percent of the uranium is from anthropogenic sources. The uranium in Sentinel well B206989 is from natural sources. In Woman Creek, the uranium in Sentinel well 90399 is below background. Surface water samples from North Walnut, South Walnut, and Woman Creeks show mixtures of depleted and natural uranium; they are also dominated by natural uranium.

In the historical SEP area, accelerated actions included excavation of pond sludge and soil removal. Hence, the contaminant source was remediated and the groundwater uranium plumes are expected to slowly attenuate through dispersion and dilution from groundwater recharge. The SPPTS, installed in 1999, continues to treat uranium-

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[18] Herein, when referring to natural uranium contributions to the total uranium concentration, dominant refers to approximately two-thirds of the total being from natural uranium, predominantly means that approximately 90 percent is from natural uranium, and entirely means that all of the observed uranium is from natural sources.

contaminated groundwater migrating from the historical SEP toward North Walnut Creek. In South Walnut Creek, the MSPTS treats contaminated water migrating from the historical Mound site toward South Walnut Creek, and use of phytoremediation technologies as a one-time enhancement was conducted in the vicinity of well 23296 because it was the only reasonable and practicable action that could be taken at that location.

No uranium fate and transport modeling was conducted; however, analyses were conducted as part of the AME. Given the results of the groundwater transport evaluation, uranium is identified as having a complete subsurface pathway from groundwater to surface water, although its natural component ranges from dominated by to entirely due to natural sources.

8.4.4.2 Groundwater VOC Migration

Besides benzene, the VOC AOIs include the common chlorinated solvents carbon tetrachloride, tetrachloroethene, and trichloroethene (both a degradation product of tetrachloroethene and a solvent used historically at RFETS). They also include the solvent degradation daughter products chloroform, methylene chloride, cis-1,2-dichloroethene, 1,1-dichloroethene, 1,2-dichloroethane, and vinyl chloride. Degradation chains for these AOIs are presented on Figure 8.6. As discussed above in Section 8.2.1.4, tetrachloroethene and carbon tetrachloride (and their degradation products) were numerically modeled and compared against surface water standards. These results will be incorporated into the following section because it is a component of the fate and transport evaluation process.

Eight VOC AOIs have been identified with contiguous, mappable plumes (Table 4.9). Summaries of the AOI plumes, results of the VOC modeling, and detections at AOC and Sentinels wells are provided below.

<u>cis-1,2-Dichloroethene</u>

cis-1,2-Dichloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of cis-1,2-dichloroethene in UHSU groundwater are primarily downgradient of the historical Mound site (refer to Figure 4.11 and Table 4.9 in the nature and extent of groundwater contamination).

cis-1,2-Dichloroethene is the result of reductive dechlorination of trichloroethene (K-H 2005a) as shown on Figure 8.6. The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. It is further degraded to vinyl chloride, and is mobile in groundwater. Its groundwater persistence is estimated at weeks to 10 years at RFETS (see Table 8.2). Soil and groundwater accelerated actions and enhancements have been taken at the ETPTS and MSPTS to remove contaminated soil and treat groundwater with contaminants, including cis-1,2-dichloroethene.

cis-1,2-Dichloroethene has not been detected above the surface water standard at any AOC wells. It has been observed above the surface water standard at Sentinel wells 23296 (downgradient of the ETPTS) and 15699 (Mound Site). cis-1,2-Dichloroethene has also been observed in surface water above the surface water standard (at former location SW056[19]). Modeling results do not show conclusively that predicted concentrations at the groundwater discharge locations are above the surface water standard. Because this AOI has been observed at Sentinel wells, cis-1,2-dichloroethene is identified as having a complete subsurface pathway from groundwater to surface water.

1,2-Dichloroethane

1,2-Dichloroethane is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The only 1,2-dichloroethane contiguous, mappable plume is associated with the Mound area (refer to Figure 4.6 and Table 4.9 in the nature and extent of groundwater contamination). 1,2-Dichloroethane is the biodegradation product of 1,1-dichloroethene, and it persists in groundwater from a range of 1 year to tens of years. 1,2-Dichloroethane has not been observed at any AOC well, but it has been observed at Sentinel well 15699 at the historical Mound site. The MSPTS was installed in 1999 to capture groundwater contamination in that area, including 1,2-dichloroethane. Numerical modeling has not been conducted to evaluate the fate and transport of 1,2-dichloroethane in groundwater. Although it is a groundwater AOI, 1,2-dichloroethane is not an AOI in surface water. Based on its limited extent in groundwater, 1,2-dichloroethane is identified as having a limited subsurface pathway from groundwater to surface water.

1,1-Dichloroethene

1,1-Dichloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The areal extent of contiguous, mappable plumes of 1,1-dichloroethene includes the historical Oil Burn Pit No. 2, the historical East Trenches, historical OU 1 (historical IHSS 119.1), north of former Building 771, and the former IA Plume Sources (refer to Figure 4.5 and Table 4.9 in the nature and extent of groundwater contamination).

1,1-Dichloroethene is the product of reductive dechlorination of trichloroethene and 1,1,1-trichloroethane. The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. Its persistence in groundwater is in the range of a few years, although it may be longer (Table 8.2).

1,1-Dichloroethene has not been observed at any AOC wells. It has been observed above the surface water standard at two Sentinel wells, well 15699 in the Mound area and well 20505 (formerly 20598) north of former Building 771 (although 1,1-dichloroethene was

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[19] The disruption of surface water monitoring location SW056 was completed as an accelerated action. This action included removal of the french drain and associated gravel pack, placement of HRC® where contaminated groundwater pooled, and installation of a monitoring well.

observed above the surface water standard only once and subsequent data were below the detection limit). The MSPTS was installed in 1999 to capture groundwater contamination in the Mound area, including 1,1-dichloroethene. While it is a groundwater AOI, 1,1-dichloroethene is not a surface water AOI. Based on the limited extent of 1,1-dichloroethene in groundwater and results of the groundwater fate and transport evaluation process, 1,1-dichloroethene is identified as having a limited subsurface pathway from groundwater to surface water.

Benzene

Benzene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Benzene is detected in groundwater in a localized area at the Present Landfill (refer to Figure 4.7 and Table 4.9 in the nature and extent of groundwater contamination). The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. Benzene has relatively short-term persistence in the environment, and it has not been observed above the surface water standard at any AOC well. It has been detected above the surface water standard at Sentinel well 1986 (which was replaced by well 52505), for 1 sample (from 1999) out of 33 total results. Subsequent samples at that well have been below the surface water standard.

Downgradient of the Present Landfill, benzene in groundwater is treated by the Present Landfill Seep Treatment System. Based on the limited extent of benzene in RFETS groundwater and its relatively short-term persistence, benzene is identified as having a limited subsurface pathway from groundwater to surface water.

Carbon Tetrachloride

Carbon tetrachloride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Carbon tetrachloride was detected above the WRW PRG in subsurface soil (refer to Section 8.4.2.2) and is a widespread constituent in groundwater. Mappable, contiguous carbon tetrachloride plumes are primarily found south of former Building 771 (Carbon Tetrachloride Plume) (historical IHSS 118.1), the historical Oil Burn Pit No. 2, the historical East Trenches, the historical 903 Pad, the historical IA Plume Sources, historical 700 Area Northeast Plume Area, and at historical OU 1 (historical IHSS 119.1) (refer to Figure 4.8 and Table 4.9 in the nature and extent of groundwater contamination).

As discussed in Section 8.4.2.2, carbon tetrachloride's primary transport mechanism is via subsurface dissolved transport as a soluble AOI. It exhibits moderate mobility and degrades anaerobically to chloroform and methylene chloride. Its persistence in groundwater is varied, but may exist for decades to hundreds of years, depending whether DNAPL is present.

Groundwater modeling results show conclusively that predicted concentrations of carbon tetrachloride at the groundwater discharge locations at the Carbon Tetrachloride Plume, the historical East Trenches, the historical 903 Pad, and historical Ryan's Pit are above the surface water standard.

Soil and groundwater accelerated actions and enhancements have been taken at the Carbon Tetrachloride Plume, the historical Mound Site/Oil Burn Pit No. 2, historical East Trenches, historical IHSS 118.1, historical OU 1, and historical 903 Pad to reduce the contaminants in soil and treat contaminated groundwater. In 2005, the majority of the soil source and observed DNAPL at the Carbon Tetrachloride Plume was removed. In addition, Hydrogen Release Compound (HRC) was placed as a one-time enhancement at the former Carbon Tetrachloride Plume, former Mound Site/Oil Burn Pit No. 2, and former 903 Pad areas to facilitate the biodegradation of groundwater contaminants. Carbon tetrachloride has not been detected at any AOC wells. However, it has been detected at several Sentinel wells, including well 15699 at the historical Mound site, well 23296 in South Walnut Creek near Pond B-3, well 91203 at the historical Oil Burn Pit No. 2, well 04091 on the eastern mesa top east of the trenches (although numerical model results [Plume Signature Area (PSA) East] predict it would not reach surface water above the standard [DOE 2005a; K-H 2005b]), well 99405 (formerly 99401) (although only one out of four total results), and wells 90299 and 90399 in the southern flow path downgradient of the historical 903 Pad. Based upon the results of the groundwater fate and transport evaluation process, carbon tetrachloride is identified as having a complete subsurface pathway from groundwater to surface water.

Chloroform

Chloroform is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The contiguous, mappable plumes of chloroform occur in the same areas as carbon tetrachloride: at the Carbon Tetrachloride Plume (historical IHSS 118.1), historical 903 Pad/Ryan's Pit area, the historical East Trenches, the historical Mound Site/Oil Burn Pit No. 2 areas, the former IA Plume Sources, and the former 700 Area Northeast Plume (refer to Figure 4.9 and Table 4.9 nature and extent of groundwater contamination).

The primary transport mechanism for chloroform is via subsurface dissolved transport as a soluble AOI. Chloroform is attributed to the reductive dechlorination of carbon tetrachloride. It persists in groundwater for a period ranging from days to decades, depending on the contamination characteristics.

As discussed in Section 8.2.1.3, accelerated actions and enhancements have been taken at the historical Mound Site/Oil Burn Pit No. 2, historical East Trenches, historical IHSS 118.1, and historical 903 Pad to reduce the quantity of contaminants in subsurface soil and groundwater.

As shown in Table 8.7, chloroform has not been detected above the surface water standard at any AOC wells. However, it has been detected at several Sentinel wells above the surface water standard (see Table 8.8). The Sentinel wells include well 23296 in South Walnut Creek (near Pond B-3), well 15699 (at the historical Mound site), well 91203 (at the historical Oil Burn Pit No. 2) in South Walnut Creek, and wells 90299 and 90399 (along the southern flow path of the historical 903 Pad). Numerical modeling results do not predict conclusively that concentrations of chloroform at the groundwater discharge locations will be above the surface water standard. However, based upon the observed extent in groundwater and results of the groundwater fate and transport evaluation process, chloroform is identified as having a complete subsurface pathway from groundwater to surface water.

Chloromethane

Chloromethane is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Chloromethane is detected in groundwater in one isolated location, at the historical IHSS 118.1 area south of former Building 771 (refer to Figure 4.10 and Table 4.9 in the nature and extent of groundwater contamination). The presence of chloromethane in groundwater is attributed to reductive dechlorination of carbon tetrachloride, chloroform, and methylene chloride. It travels as a soluble species in groundwater, and its persistence is similar to these other compounds. Chloromethane has not been observed at any AOC or Sentinels wells, and impacts to surface water are not detected. Based upon the results of the fate and transport evaluation process for chloromethane in groundwater, chloromethane is identified as having a limited subsurface pathway from groundwater to surface water.

Methylene Chloride

Methylene chloride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The one contiguous, mappable plume of methylene chloride is observed at the historical Carbon Tetrachloride Plume (historical IHSS 118.1) (refer to Figure 4.12 and Table 4.9 in the nature and extent of groundwater contamination). This is logical because methylene chloride is a daughter product of reductive declorination of carbon tetrachloride, which has been detected at this historical IHSS. The primary transport mechanism is via subsurface dissolved transport as a soluble AOI. Its persistence in groundwater ranges from days to years or more, depending on the AOI characteristics.

As discussed in Section 8.2.1.3, accelerated actions and enhancements have been taken at the historical Mound Site/Oil Burn Pit No. 2, historical East Trenches, historical IHSS 118.1, and historical 903 Pad to reduce the quantity of contaminants, including methylene chloride, in subsurface soil and groundwater.

Numerical modeling results do not predict conclusively that estimated concentrations of methylene chloride at the groundwater discharge locations will be above the surface water standard.

Methylene chloride has not been detected at any AOC well, but it has been observed at several Sentinel wells, including well 15699 (downgradient of the historical Mound site), well 20505 (formerly well 20598, north of former Building 771, with one out of five total results above the surface water standard), well 91305 (formerly well 2187, with 1 out of 20 results above the surface water standard), well 23296 in South Walnut Creek, and well 90399 (15 out of 15 results above the standard) in the Woman Creek drainage downgradient of the historical 903 Pad and Ryan’s Pit areas. Methylene chloride has also been detected in South Walnut Creek, downgradient from the Mound Site/Oil Burn Pit

No. 2 area. While the extent of methylene chloride in RFETS groundwater is somewhat limited, relative to other groundwater AOIs, the results of the groundwater fate and transport evaluation process indicate that methylene chloride has been identified as having a complete subsurface pathway from groundwater to surface water.

Tetrachloroethene

Tetrachloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The predominant contiguous, mappable tetrachloroethene plumes occur in the historical East Trenches, the historical 903 Pad (northern and southern flow paths), the historical Ryan's Pit, the historical Mound Site/Oil Burn Pit No. 2 area, former Buildings 443/444, south of former Building 771 (carbon tetrachloride plume, historical IHSS 118.1), historical OU 1 (IHSS 119.1), historical Oil Burn Pit No. 1, historical PU&D Yard, and historical IA Plume Sources (refer to Figure 4.13 and Table 4.9 in the nature and extent of groundwater contamination). The spatial tetrachloroethene distribution suggests that several areas of contamination are likely to contribute to these localized tetrachloroethene occurrences (K-H 2004a, 2005b).

Tetrachloroethene's primary migration mechanism is via dissolved subsurface transport. It biodegrades to trichloroethene (as shown on Figure 8.6). Tetrachloroethene has low to moderate solubility in water and is more dense than water. Its persistence in water is estimated at decades to hundreds of years depending on the AOI characteristics.

As discussed in Section 8.2.1.3, soil and groundwater accelerated actions and enhancements have been taken at the historical Mound Site/Oil Burn Pit No. 2 area, historical East Trenches, historical IHSS 118.1, and historical 903 Pad to remove soil contamination and treat groundwater contaminants, including tetrachloroethene.

Groundwater numerical modeling results consistently predict that concentrations of tetrachloroethene at the groundwater discharge locations at the Carbon Tetrachloride Plume, the historical East Trenches, the historical 903 Pad, and historical Ryan's Pit will be above the surface water standard. For AOC wells, tetrachloroethene has been detected only at well 00997, in South Walnut Creek near Pond B-5 (1 out of 17 total results above the surface water standard). Tetrachloroethene has been observed at several Sentinel wells, including wells 95199 and 23296 in South Walnut Creek, well 20505 (formerly well 20598, north of former Building 771, with one sample out of five total results above the surface water standard), well 15699 (downgradient of the historical Mound site), wells 95099 and 95199 at the ETPTS, well 11502 near former Building 444, well 37505 (formerly well 37501) near former Building 371, well 88104 (formerly well 88101, with 1 out of 7 total results above the surface water standard) south of former Building 881, wells 90299 and 90399 downgradient of the historical 903 Pad, and well 99301 downgradient of former Building 991. Tetrachloroethene was also detected at well 04091 in the eastern BZ, although transport modeling (PSA East) showed that it would not reach surface water at concentrations above surface water standards (K-H 2005b). Based upon the results of the groundwater fate and transport evaluation process, tetrachloroethene is identified as having a complete subsurface pathway from groundwater to surface water.

Trichloroethene

Trichloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Trichloroethene is the most common and widespread chlorinated aliphatic hydrocarbon (CAH) in groundwater at RFETS. Besides its use on site, it is a reductive dechlorination product of tetrachloroethene. The contiguous, mappable trichloroethene plumes occur in the historical East Trenches area, historical 903 Pad (northern and southern flow paths), historical Ryan's Pit, former Building 444 area, historical Oil Burn Pit No. 1, historical Mound Site/Oil Burn Pit No. 2, the former 700 Area Northeast plume area, along the unnamed drainage between former Buildings 371/374 and 771, historical OU 1 (historical IHSS 119.1), former Building 444, the historical PU&D Yard, and the former IA Plume Source Areas (refer to Figure 4.14 and Table 4.9 in the (refer to Figure 4.14 and Table 4.9 in the groundwater nature and extent section). The spatial distribution of trichloroethene suggests that several areas with contamination likely contribute to these localized trichloroethene occurrences (K-H 2004a, 2005b).

Trichloroethene's primary migration mechanism is via dissolved subsurface transport. It biodegrades to cis-1,2-dichloroethene (Figure 8.6). Trichloroethene has low to moderate solubility in water and is more dense than water. Its persistence in water is estimated to range from decades to hundreds of years, depending on the AOI characteristics and environmental conditions.

Groundwater numerical modeling results consistently predict that concentrations of trichloroethene at the groundwater discharge locations at the Carbon Tetrachloride Plume, historical East Trenches, historical 903 Pad, and historical Ryan's Pit will be above the surface water standard.

As discussed in Section 8.2.1.3, accelerated actions and enhancements have been taken at historical IHSS 118.1, historical Mound Site/Oil Burn Pit No. 2, historical East Trenches, and historical 903 Pad/Ryan's Pit areas to remove soil contamination and treat groundwater contaminants, including trichloroethene.

Trichloroethene has been observed in AOC well 10594 (one out of seven total results above the surface water standard). Trichloroethene was also observed above the surface water standard at the following Sentinel wells: wells 95199, 91203, and 23296 in the South Walnut Creek drainage, well 15699 (downgradient of the historical Mound site), well 99301 (downgradient of former Building 991), and well 04091 in the eastern BZ, although transport modeling (PSA East) showed that it would not reach surface water above standards (K-H 2005b). Sentinel wells in the North Walnut Creek drainage with trichloroethene observed above the surface water standard include well 52505 (formerly well 1986 in the drainage between former Buildings 771 and 371, with 1 out of 33 total samples above the surface water standard) and 20505 (formerly well 20598, north of the former Building 771). In the SID drainage, Sentinel wells 90299 and 90399 (downgradient of the historical 903 Pad) have trichloroethene results above the surface water standard. Based upon the results of the groundwater fate and transport evaluation process, trichloroethene is identified as having a complete subsurface pathway from groundwater to surface water.

Vinyl Chloride

Vinyl chloride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The distribution of vinyl chloride is limited and occurs within known areas of VOC contamination. Contiguous, mappable plumes of vinyl chloride plume are located at the historical Oil Burn Pit No. 1 (historical IHSS 128), the historical Mound site north of former Building 771, and at the Present Landfill (refer to Figure 4.15 and Table 4.9 in the nature and extent of groundwater contamination).

Vinyl chloride migrates in the environment as a dissolved species and is highly mobile in groundwater. It is a daughter product of the reductive dechlorination of tetrachloroethene and trichloroethene and is not relatively persistent in aerobic environments, degrading rapidly under those conditions.

Vinyl chloride was not detected at any of the AOC wells and is observed above the surface water standard only at Sentinel wells 20505 (formerly well 20598, located north of former Building 771) and 91305 (formerly well 2187, located in the former IA in the South Walnut Creek drainage). Numerical modeling results do not show conclusively that predicted concentrations of vinyl chloride at the groundwater discharge locations will be above the surface water standard. As discussed in Section 8.2.1.3, accelerated actions and enhancements have been taken at historical IHSS 118.1 and historical Mound Site/Oil Burn Pit No. 2 area to remove soil contamination and treat groundwater contaminants.

Despite its relatively limited extent, because of its observed concentrations in two Sentinel wells and based upon the results of the groundwater fate and transport evaluation process, vinyl chloride is identified as having a complete subsurface pathway from groundwater to surface water.

8.4.4.3 Groundwater Metal Migration

Metal plumes in groundwater at RFETS that can be attributed to anthropogenic sources are limited in extent. Numerical modeling was not conducted to analyze the movement of metals in RFETS groundwater. Evaluation of the fate and transport of metals in groundwater was based on interpretation of measured groundwater sample data.

Arsenic

Arsenic is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0) and a COC in the IAEU. A contiguous, mappable dissolved arsenic plume in UHSU groundwater is shown on Figure 4.16 and Table 4.9 in the nature and extent of groundwater contamination and is present only at the Present Landfill.

Arsenic is strongly sorbed by soil, as discussed in Table 8.2, and its dominant transport mechanism is particulate transport. Elevated background concentrations obscure the identification of specific areas with anthropogenic contamination. Arsenic is a stable element and persists in the environment indefinitely. No modeling of arsenic has been conducted, and no accelerated actions have been taken for arsenic in groundwater.

Dissolved arsenic is observed at two AOC wells: well 00193 (located near Pond C-2 in the Woman Creek watershed) with one out of four total results above the surface water standard, and with nondetect results subsequent to the one detected result; and well 00997 (1 result out of 14 above the surface water standard and with nondetect results subsequent to the one detected sample result).

Dissolved arsenic has been observed at several Sentinel wells at concentrations above the surface water standard, including well 52505 (formerly 1986, in the drainage between former Buildings 371 and 771), wells 20205 (formerly 20298) and 20705 (formerly 20798) north of former Building 771, well 37505 (formerly 37501) adjacent to former Building 371, well 90299 along Woman Creek downgradient of the historical 903 Pad, well 99305 adjacent to South Walnut Creek (formerly well 99301, with one out of seven results above the surface water standard), well 99405 adjacent to South Walnut Creek (formerly well 99401, with one out of six total samples above the surface water standard), and well B206989 downgradient of the Present Landfill (with 4 out of 19 total results above the surface water standard). There is widespread distribution of arsenic in sediment and surface soil suggesting that this is likely attributed to background conditions, especially given the very limited use of arsenic at RFETS.

Given the isolated contiguous, mappable plume at the Present Landfill (and low number of sample results above the surface water standard, background, and/or PQL), its dominant form of transport as a particle (versus a soluble species), and the influence of background arsenic in groundwater samples, arsenic is identified as having a limited subsurface pathway from groundwater to surface water.

Chromium

Chromium is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Total chromium has been identified as having contiguous, mappable plumes in the Carbon Tetrachloride Plume (south of former Building 771), the historical East Trenches, historical Ryan's Pit, and historical OU 1 areas (refer to Figure 4.17 and Table 4.9 in the nature and extent of groundwater contamination).

The transport characteristics of chromium are discussed in Table 8.2. Chromium is moderately to highly mobile in groundwater and persists in the environment indefinitely. No numerical modeling of chromium transport has been conducted, and no accelerated actions have been taken for chromium in groundwater.

There is evidence that some of the elevated chromium concentrations in groundwater at RFETS may be derived from corrosion of stainless-steel well casing, pump parts, and well tubing stabilizers (Boylan 2004a, 2004b). Wells with stainless-steel construction or sampling equipment are shown on Figure 8.7. Table 8.12 shows that out of 16 locations identified as having elevated chromium concentrations, 7 wells had stainless-steel casing and an additional well had a steel casing of unknown type. However, to be conservative, total chromium data were compared directly to the surface water standard without regard for their potential origin.

Total chromium was not observed at any of the AOC wells. It has been observed at Sentinel well 23296 (twice out of 15 total results, and subsequent data were nondetects or below the surface water standard). There may also be influences from well construction and sampling materials. Based on these results, chromium is identified as having a limited subsurface pathway from groundwater to surface water.

Nickel

Nickel is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of dissolved nickel are present south of the historical Ryan's Pit and near former Building 850 (refer to Figure 4.18 and Table 4.9 in the nature and extent of groundwater contamination). (Total nickel plumes are in the historical SEP and historical Ryan's Pit areas; see Figure 4.19.)

Migration of nickel in the environment is via both surface particulate transport and subsurface dissolved transport. It is highly mobile in groundwater and persists indefinitely in the environment. No numerical modeling of nickel fate and transport has been conducted, and no accelerated actions have been taken for total or dissolved nickel in groundwater.

As discussed in the text regarding total chromium in groundwater, there is evidence that some of the elevated nickel concentrations in groundwater at RFETS may be derived from corrosion of stainless-steel well casing, pump parts, and well tubing stabilizers (Boylan 2004a, 2004b). Table 8.12 shows that out of nine locations identified as having elevated nickel concentrations, four wells had stainless-steel casing. However, to be conservative, dissolved nickel data were compared directly to the surface water standards without regard for their potential origin.

Dissolved and total nickel have not been observed above the surface water standard at any of the AOC wells. At the Sentinel wells, dissolved and total nickel have been observed above the surface water standard sporadically at several locations, including well 52505 (formerly well 1386, located near Pond A-1 in North Walnut Creek) for dissolved and total nickel (observed more frequently as dissolved nickel), well 51205 for dissolved nickel (formerly 1986, located in the drainage between former Buildings 771 and 371, observed above the surface water standard once out of 27 total samples), well 23296 for total nickel (detected above the surface water standard once in 15 total samples), and well P210089 for both dissolved and total nickel (detected above the surface water standard once out of 11 dissolved and 3 total samples, respectively).

Given the absence of dissolved and total nickel at the AOC wells, the sporadic nature of the observations at the Sentinel wells, and the potential interferences due to well construction and sampling materials, total and dissolved nickel are identified as having limited subsurface pathways from groundwater to surface water.

8.4.4.4 Groundwater Water Quality Parameter Migration

Fluoride

Fluoride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Three small contiguous, mappable plumes of fluoride are observed in UHSU groundwater at locations south of the former Building 707 area, at historical OU 1, and south of the historical SEP area (refer to Figure 4.21 and Table 4.9 in the nature and extent of groundwater contamination). Fluoride is highly mobile in groundwater and migration occurs via subsurface soluble transport. Its water chemistry is affected by the aluminum concentration and pH (ATSDR 2003a), and it is relatively persistent in the environment because it forms strong complexes with aluminum. Fluoride fate and transport modeling was not conducted at RFETS.

Fluoride has not been observed at any AOC wells and has only been observed at Sentinel well 4087 downgradient of the Present Landfill. Fluoride has a very limited extent in groundwater at RFETS. The source of fluoride is uncertain, but has been hypothesized to be from natural processes involving ET and mineralization (DOE 2004). Based upon the results of the groundwater fate and transport evaluation process, fluoride is identified as having a limited transport pathway from groundwater to surface water.

Nitrate/Nitrite

Nitrate/nitrite (as N) is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of nitrate/nitrite (as N) exist in the North Walnut Creek drainage in the historical SEP area, former 700 Area Northeast Plume area, and above Pond A-1.

In the South Walnut Creek drainage, contiguous, mappable plumes of nitrate/nitrite (as N) exist, at the historical 903 Pad and historical OU 1 areas (refer to Figure 4.22 and Table 4.9 in the nature and extent of groundwater contamination).

Because RFETS UHSU groundwater is generally oxic (that is, well oxygenated) and nitrite is easily oxidized to nitrate, nitrate is likely the predominant dissolved nitrogen species in site waters (DOE 2005a). However, local areas of detectable nitrite may occur where the groundwater is anoxic and reducing conditions exist. In groundwater at near neutral pH, as observed at RFETS, nitrate is not typically attenuated and thus persists indefinitely unless there is a reduction in redox potential so that denitrification can occur (Canter 1997). Nitrate/nitrite is a conservative dissolved constituent, meaning its transport is not retarded and therefore it travels at the same velocity as groundwater, so hydrologic flow modeling may be used to assess its transport.

Accelerated actions completed for nitrate/nitrite at the former SEP included excavation of pond sludge and soil removal. In addition, the nitrate plume continues to be collected and treated by the SPPTS. Installed in 1999, the SPPTS continues to treat nitrate-contaminated groundwater migrating from the SEP toward North Walnut Creek.

Nitrate/nitrite has not been observed at any of the AOC wells, but it has been observed at Sentinel wells B206989 (downgradient of the Present Landfill), P210089 (at the historical SEP), and 37505 (formerly 37501, located adjacent to former Building 371). Based upon the results of the groundwater fate and transport evaluation process, nitrate/nitrite (as N) is identified as having a complete subsurface transport pathway from groundwater to surface water.

Sulfate

Sulfate is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of sulfate in UHSU groundwater are found downgradient of the East Landfill Pond dam, the historical SEP, and between Ponds B-4 and B-5 (refer to Figure 4.23 and Table 4.9 in the nature and extent of groundwater contamination).

Sulfate's chemical behavior is strongly related to the redox properties of groundwater. The most highly oxidized form of sulfur is sulfate (SO_4^{-2}), which is the most likely aqueous sulfur species at RFETS given the highly oxygenated groundwater in the UHSU. Sulfate is a ubiquitous and important anion in natural waters. In natural waters above pH 4, it is the predominant form of aqueous sulfur. In groundwater at near neutral pH, like RFETS, sulfate is not typically attenuated and thus persists indefinitely unless there is a reduction in pH (Rai et al. 1984).

Sulfate has been observed above background concentrations, which is above the surface water standard, at two AOC wells and six Sentinel wells. These include AOC wells 00193 in Woman Creek and 10594 in North Walnut Creek, and Sentinel wells 4087 (above background in 6 out of 23 sample results), B206989 downgradient of the Present Landfill, 04091 on the mesa east of the East Trenches, 00797 downgradient of former Building 881 (above background in 1 out of 12 sample results), P210089 at the historical SEP, and 91305 (formerly 2187) in South Walnut Creek. Sulfate is not an AOI in surface water. However, based on the groundwater fate and transport evaluation process and because sulfate has been observed above the surface water standard at representative groundwater monitoring locations, sulfate is identified as having a complete subsurface pathway from groundwater to surface water.

8.5 Air Analyte of Interest Fate and Transport

This section describes the expected fate and transport of air AOIs from RFETS following completion of accelerated actions. As noted in Section 8.2, air transport was not included in the AOI fate and transport evaluation process. Air is assessed in a different manner than the other media; it is assessed in relation to a receptor via the airborne pathway measured against applicable EPA annual dose limits.

The air assessment included in this section is based on the assumption that the future land use is a National Wildlife Refuge and that disturbance of soils containing residual radionuclide contamination will be minimal. As reported in the nature and extent of air contamination section (Section 6.0), many historical RFETS airborne contaminants are no longer emitted following completion of accelerated actions, or are emitted at rates that do not and will not pose a threat to human health or the environment. Given their persistence in the environment, expected downwind concentrations of long-lived radionuclide contaminants are quantified and discussed below.

A conceptual model of ongoing, post-accelerated action airborne emissions from RFETS is shown on Figure 8.8. The concentration and deposition of radionuclides in the RFETS environment depends on the local patterns of wind flow. Figure 8.9 shows a joint frequency distribution of wind speed and direction (wind rose) for 2004, a representative year. The figure shows that prevailing winds occur from the northwest quadrant, but that winds from other directions also occur, with reduced frequency.

8.5.1 Air Analytes of Interest

Historical sources of air AOIs were described in Section 6.0 and are summarized in Table 8.13. Air pollutants historically emitted from RFETS sources included:

- Plutonium-239/240, americium-241, and uranium-233/234, -235, and -238;
- Tritium;
- Beryllium;
- VOCs;
- Particulate matter and fine particulate matter (PM/PM_{10});
- Carbon monoxide (CO);
- Sulfur dioxide (SO_2);
- Nitrogen oxides (NO_x);
- Landfill gas (primarily methane and carbon dioxide [CO_2]);
- Hazardous air pollutants (HAPs); and
- Ozone-depleting substances.

During the weapons production era at RFETS, the major sources of airborne contamination comprised releases of radionuclides, VOCs, and metals from stacks venting building processes and operations; conventional pollutant sources such as fuel combustion in boilers and generators, street sanding, traffic, refrigerant leaks, and fugitive dust from disturbed soils; and resuspension of contaminants deposited on surface soil by prior events (such as fires or leakage of radioactively contaminated oils and VOCs from drums stored at the historical 903 Pad). During the cleanup phase, accelerated action activities and building decommissioning represented additional sources of emissions to air, while simultaneously both stack emissions and resuspension of contaminated surface soil decreased their relative contribution as buildings were demolished and soil contamination was cleaned up.

The nature and extent of air contamination discussion noted that most sources of the above-listed air pollutants historically emitted from RFETS have been eliminated at the site. Nonfugitive and regulated sources of most air pollutants of potential concern, including boilers, generators, vehicle refueling operations, paint spray booths, aggregate storage piles, tanks containing volatile substances, open burning, refrigerant leaks, and so forth, are no longer present following completion of accelerated actions.

With the completion of accelerated actions under RFCA, sources of ongoing emissions to air include only 1) resuspension of residual radioactive contaminants attached to surface soil particles, and 2) volatilization/release of VOCs from surface water, shallow groundwater, residual subsurface contamination, and the closed landfills. As described in Section 6.0, VOC emissions are rapidly decreasing and offer no health or environmental concerns at present and future levels. As a result, they have not been evaluated further in this section. The screening process carried out in the nature and extent discussion identified only resuspended plutonium-239/240, americium-241, and uranium-233/234, uranium-235, and uranium-238 from surface soil as air AOIs worth quantifying further, primarily because their long-radioactive half-lives (as discussed in Table 8.2) mean they will persist in the environment and, therefore, represent an ongoing source of potential emissions in the future.

Accelerated actions have reduced surface soil contaminated with plutonium, americium, and uranium, greatly limiting potential future emissions. However, the diffuse, residual contamination in surface soil will continue to result in small amounts of radionuclide particles in air due to the ongoing resuspension and movement of soil (fugitive dust) by wind, such as occurs on all open lands along the Front Range of Colorado. Ongoing emissions of plutonium-239/240, americium-241, uranium-233/234, uranium-235, and uranium-238 from the remaining areas with actinide contamination above background levels are further evaluated below to quantify airborne concentrations.

8.5.2 Migration of Air Analytes of Interest

During FY1999 through FY2001, as part of the AME, an RFETS-specific emission estimating method was developed to calculate fugitive particulate matter and radionuclide emissions due to resuspension of contaminated soil particles by wind. That methodology is employed here to estimate expected impacts due to ongoing radionuclide emissions from the remaining areas with residual surface soil contamination at RFETS. Details of the modeling are provided in Attachments 2 and 4 to this section.

Modeling of chronic wind erosion emissions of radionuclides following completion of accelerated actions showed that maximum post-accelerated action concentrations of radionuclides due to residual contamination will be one or more orders of magnitude below the EPA 10-millirems (mrem) annual benchmark level for the airborne pathway, even when added to regional background concentrations of actinides. While dose estimates due to residual radionuclide contamination in RFETS soil becoming airborne are low, this pathway will continue for many years due to the long radioactive half-lives of the isotopes involved, as well as their relative insolubility.

Modeling of wind erosion following a hypothetical fire in the historical 903 Pad area was predicted to increase annual airborne actinide concentrations by as much as a factor of 11 when compared to unburned conditions (particulate matter concentrations would increase by smaller amounts). The increases in particulate matter and actinide concentrations would vary with the location of the hypothetical fire and the time of year the fire occurred. A hypothetical fall fire would cause greater concentration increases than a hypothetical spring fire because vegetation would recover more slowly over the winter months than during the spring and summer. It is noted that the area modeled generally corresponds with the area of highest residual plutonium in surface soil in the post-accelerated action site condition. Even when added to regional background airborne actinide concentrations, plus the contribution of wind erosion emissions from unburned areas of RFETS, the maximum annual effective dose equivalent (EDE) was projected to be less than 15 percent of the EPA 10-mrem annual benchmark level for the airborne pathway. Thus, no air AOIs are further evaluated.

8.6 Fate and Transport Summary and Conclusions

This section provides the summary and conclusions of the contaminant fate and transport discussion and evaluation. Contaminants evaluated for fate and transport include those AOIs identified in the nature and extent of contamination sections for each medium (Sections 3.0 through 6.0), as well as COCs and ECOCs identified in the CRA.

8.6.1 Contaminant Fate and Transport Evaluation Process

To assess their potential impact on surface water quality, AOIs in surface soil, sediment, subsurface soil, and groundwater were evaluated using a six-step process, described in Section 8.2. The evaluation process takes into consideration a range of information, including site hydrologic data presented in Section 2.0; AOI maps presented in soil, groundwater, surface water, and sediment nature and extent sections (Sections 3.0 through 5.0); contaminant persistence information (discussed in Table 8.2); and VOC fate and numerical transport modeling results (discussed in Section 8.2.1.4). The steps of the evaluation process are summarized below.

Step 1: Identify analytes to evaluate for each environmental medium (AOIs from the nature and extent sections, COCs, and ECOCs from the CRA, collectively referred to as AOIs).

Step 2: Identify dominant transport mechanism(s) for the AOI, either surface transport mechanisms or subsurface mechanisms, or both in the case of certain analytes.

Step 3: Identify whether the AOI is present and available (or mobile) for transport in the environmental medium of interest.

Step 4: Identify the relative persistence of the AOI in the environment.

Step 5: Identify whether transport of the AOI in the medium of interest is linked to a potential surface water quality impact. AOI data for surface media (surface soil and sediment) are evaluated in terms of observed impacts on surface water quality at representative surface water monitoring locations. AOI data for subsurface media (subsurface soil and groundwater) are evaluated in terms of observed impacts at representative groundwater monitoring locations (AOC and Sentinel wells). The representative groundwater monitoring locations were selected because of their close proximity to areas where contaminated groundwater discharges to surface water and, hence, reflect potential impacts to surface water quality.

Step 6: Based on the results of the preceding evaluation steps, identify whether the AOI has a complete or limited transport pathway to surface water.

Surface water and air were not evaluated using the process described above. Surface water AOIs are not subject to the same fate and transport evaluation because the evaluation focused on potential impacts on surface water quality. The surface water data are provided for reference because they confirm the AOI's presence in surface water (necessary to confirm a complete pathway to surface water exists). Air AOIs are not evaluated using this process because air is evaluated based on the potential contaminant exposure received by a human receptor via the airborne pathway, as measured against the EPA 10-mrem annual benchmark level for the airborne pathway. The evaluation of the air AOIs' fate and transport is presented in Section 8.5.

8.6.1.1 Surface Transport Pathway – Summary of Evaluation Results

Environmental media with contaminants subject to surface transport mechanisms are surface soil and sediment. Results of the fate and transport evaluation for AOIs in these media are discussed below.

Surface Soil

Complete pathways from surface soil to surface water were identified for two surface soil AOIs: americium-241 and plutonium-239/240 (see Section 8.3.3.1 and Table 8.3). These AOIs have been observed intermittently above the surface water standard (which is higher than background or the PQL) at representative surface water locations upstream of the terminal ponds in the North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages.

Other than americium-241 and plutonium-239/240, all other surface soil AOIs are identified as having limited surface transport pathways to surface water. These include uranium-233/234, uranium-235, uranium-238, aluminum, arsenic, total chromium, vanadium, benzo(a)pyrene, dibenz(a,h)athracene, PCB-1254, PCB -1260, and 2,3,7,8-TCDD TEQ. Uranium-233/234, uranium-235, and uranium-238 are identified as having limited pathways from surface soil (anthropogenic sources) to surface water because uranium in surface water has been observed above the surface water standard infrequently, despite the abundance of natural uranium in soil. Natural uranium is the primary source of uranium in surface water, based on analyses of uranium isotope ratios.

Aluminum, arsenic, and total chromium are identified as having limited pathways from surface soil to surface water because observations of those AOIs above the highest of the surface water standard, background, or PQL at representative surface water monitoring locations occur infrequently or not at all, despite the natural background concentrations of those metals in soil. Vanadium is identified as having a limited surface transport pathway as demonstrated by its limited extent in other environmental media (vanadium is an AOI in surface soil only). Benzo(a)pyrene, dibenz(a,h)athracene, PCB-1254, PCB-1260, and 2,3,7,8-TCDD TEQ are identified as having limited surface transport pathways because of their limited extent in surface soil and limited presence in surface water (they are not surface water AOIs).

The primary historic source of americium-241 and plutonium-239/240 in surface soil was remediated at the historical 903 Pad/Lip area, which is expected to improve long-term surface water quality. In addition, removal of impervious areas has decreased runoff volumes and peak discharge rates resulting in reduced soil erosion and associated particulate transport of americium-241 and plutonium-239/240 from surface soil to surface water.

For the surface soil AOIs, the most current data for those analytes measured in surface water show concentrations below the highest of the surface water standard, background, or PQL at the representative surface water locations downstream of the terminal ponds in the North Walnut Creek, South Walnut Creek, and SID/Woman Creek drainages.

<u>Sediment</u>

Complete pathways from sediment to surface water are identified for two sediment AOIs: americium-241 and plutonium-239/240 (see Section 8.3.5.1 and Table 8.5). These are the same AOIs identified in surface soil as having a complete pathway to surface water. Americium-241 and plutonium-239/240 have been observed intermittently in surface water above the surface water standard (which is higher than background or the PQL) at representative surface water locations upstream of the terminal ponds in the North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages.

All other sediment AOIs are identified as having limited transport pathways to surface water. These include arsenic, total chromium, and benzo(a)pyrene. Arsenic and total chromium in sediment are identified as having limited pathways to surface water (from anthropogenic sources) because, despite their elevated natural background concentrations, observations at representative surface water monitoring locations above the surface water standard (background or PQL) do not exist for arsenic and are very infrequent for chromium. Benzo(a)pyrene is identified as having a limited pathway from sediment to surface water because of its limited extent in sediment, short-term persistence, and not being a surface water AOI.

Accelerated actions taken to remediate contaminants in sediments include sediment removal at the historical Bowman's Pond (historical PAC 700-1108) and vicinity, located north of former Building 774, and at Ponds B-1, B-2, and B-3 (historical IHSSs NE-142.5, -142.6, and -142.7, respectively) in the South Walnut Creek drainage. As noted for surface soil, removal of impervious areas has decreased runoff volumes and peak discharge rates resulting in reduced sediment erosion and decreasing the associated transport of americium-241 and plutonium-239/240 from sediment to surface water.

For the sediment AOIs, the most current data for those analytes measured in surface water have concentrations below the highest of the surface water standard, background, or PQL at the representative surface water locations downstream of the terminal ponds in the North Walnut Creek, South Walnut Creek, and the SID/Woman Creek drainages.

8.6.1.2 Subsurface Transport Pathway – Summary of Evaluation Results

Environmental media with contaminants subject to subsurface transport mechanisms are subsurface soil and groundwater. Results of the fate and transport evaluation for AOIs in these media are discussed separately below, although it is recognized there is overlap between contaminant transport in subsurface soil and groundwater, because groundwater acts as the transport mechanism for subsurface soil AOIs that are mobile in the subsurface environment.

Subsurface Soil

Complete pathways from subsurface soil to surface water (via groundwater) were identified for five subsurface soil AOIs, all of which are VOCs. These AOIs include carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, and trichloroethene (see Section 8.4.2.2 and Table 8.6). All of these subsurface soil AOIs are associated with one or more groundwater areas, discussed in the groundwater section below. Consequently, these subsurface soil AOIs are also detected in groundwater at concentrations above the surface water standard at one or more Sentinel wells. It is noted that tetrachloroethene was observed in subsurface soil at a location south of former Building 991, but it does not form a contiguous, mappable plume in groundwater in that area.

All other subsurface soil AOIs are identified as having limited transport pathways from subsurface soil to surface water via groundwater. These AOIs include americium-241, plutonium-239/240, uranium-235, uranium-238, 1,1,2,2-tetrachloroethane, total chromium, lead, benzo(a)pyrene, and PCB-1260. Americium-241 and plutonium-239/240 have limited pathways from subsurface soil to surface water because their low solubility and affinity to sorb to soil particles greatly inhibits their subsurface mobility. Uranium-235 and uranium-238 are identified as having limited pathways from subsurface soil to surface water based on the absence of locations where elevated uranium in subsurface soil is co-located in the same drainage as surface water sampling locations with uranium above the surface water standard. However, the mobility of total uranium (sum of isotopes) in groundwater is discussed further in the groundwater summary text. 1,1,2,2-Tetrachloroethane is identified as having a limited pathway from subsurface soil to surface water based on its limited presence in other environmental media (it is an AOI in subsurface soil only).

Total chromium is identified as having a limited transport pathway from subsurface soil to surface water because it is not observed in groundwater above the surface water standard at any of the AOC wells and only infrequently at Sentinel well 23296. The presence of chromium in groundwater may be associated with stainless-steel well construction or sampling equipment, which can cause sample results that are not representative of actual groundwater conditions. Lead is identified as having a limited pathway because it is not observed above the surface water standard at representative surface water monitoring locations, despite its elevated natural background concentrations. Benzo(a)pyrene and PCB-1260 are identified as having limited subsurface pathways from subsurface soil to surface water because of their low solubility, affinity to sorb to soil particles, limited extent in subsurface soil, and not being identified as surface water AOIs.

Accelerated actions related to the subsurface soil AOIs (subsurface soil removals) have been taken at the historical Mound Site/Oil Burn Pit No. 2 area, historical East Trenches, Carbon Tetrachloride Plume (historical IHSS 118.1), and historical 903 Pad/Ryan’s Pit area. These actions were taken to disrupt the pathway from subsurface soil to surface water via groundwater, by reducing residual subsurface soil contamination.

For the subsurface AOIs, the most current data for those analytes measured in groundwater show concentrations below the highest of the surface water standard, background, or PQL at all AOC wells.

<u>Groundwater</u>

Complete pathways from shallow (UHSU) groundwater to surface water are identified for 10 groundwater AOIs: uranium (sum of isotopes uranium-233/234, uranium-235, and uranium-238), cis-1,2-dichloroethene, carbon tetrachloride, tetrachloroethene, trichloroethene, chloroform, methylene chloride, nitrate/nitrite (as N), fluoride, and sulfate (see Section 8.4.5 and Table 8.11). No AOIs are identified for groundwater in the LHSU. Groundwater AOIs with complete subsurface pathways (with the potential to impact surface water quality) are primarily associated with one or more Sentinel wells in five groundwater areas. These areas are identified based on groundwater AOIs with complete pathways being detected above the highest of the surface water standard, background, or PQL at Sentinel wells. These five groundwater areas, shown on Figure 8.10, are:

- North of former Building 771 (north of the Carbon Tetrachloride Plume) – Trichloroethene.
- The historical East Trenches area – Carbon tetrachloride, chloroform, tetrachloroethene, trichloroethene, methylene chloride, and cis-1,2-dichloroethene.
- The historical SEP area (downgradient portion between the SPPTS and North Walnut Creek)—Nitrate/nitrite (as N), sulfate, and uranium (although uranium at the AOC and Sentinel wells downgradient from the SEP is predominantly from

natural uranium sources, based on analyses of uranium isotope ratios). Nitrate is observed at a Sentinel well in the former 700 Area Northeast Plume which is captured by the SPPTS.

- The historical Mound Site/Oil Burn Pit No. 2 area (downgradient portion between South Walnut Creek and the MSPTS) – Chloroform, trichloroethene, tetrachloroethene, 1,2-dichloroethane, cis-1,2-dichloroethene, 1,1-dichloroethene, and methylene chloride. These AOIs may exceed the surface water standards between the MSPTS and South Walnut Creek. Carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, and sulfate exceed the surface water standards between Oil Burn Pit No. 2 and the MSPTS (contaminated groundwater from the historical Oil Burn Pit No. 2 is treated at the MSPTS).

- The historical 903 Pad/Ryan's Pit area (both the northern flow path downgradient of the 903 Pad area toward South Walnut Creek and the southern flow path downgradient of the 903 Pad/Ryan's Pit areas toward Woman Creek) – Carbon tetrachloride, chloroform, tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene.

South of former Building 991, tetrachloroethene and trichloroethene are observed in subsurface soil and groundwater in Sentinel well 99305, although they do not form a contiguous, mappable plume. To improve surface water quality south of former Building 991, an accelerated action was conducted at the former SW056 location (see footnote 19 of this section for details).

Downgradient of the East Landfill Pond, nitrate/nitrite (as N), fluoride, and sulfate have been observed in groundwater at two Sentinel wells. The source of the fluoride and sulfate is uncertain but has been hypothesized to be from natural processes involving ET and mineralization (DOE 2004).

The groundwater AOIs identified as having a limited groundwater pathway include 1,2-dichloroethane, benzene, chloromethane, 1,1,2,2-tetrachloroethane, vinyl chloride, arsenic (dissolved), chromium (total), nickel (total and dissolved), and lead. 1,2-Dichloroethane, benzene, chloromethane, 1,1,2,2-tetrachloroethane, and vinyl chloride are identified as having a limited groundwater pathway because of their limited extent in groundwater and their infrequent or absence of detection above the surface water standard or PQL (whichever is higher) at AOC and Sentinel wells.

Total chromium is identified as having a limited transport pathway from groundwater to surface water because it is not observed above the surface water standard at any of the AOC wells and only infrequently at Sentinel well 2329. Nickel (dissolved and total) is identified as having a limited groundwater pathway because it has not been observed above the surface water standard, background, or PQL at any of the AOC wells and is detected only sporadically at four Sentinel wells. The presence of chromium and nickel may be associated with stainless-steel well construction or sampling equipment, which can cause sample results that are not representative of actual groundwater conditions.

Accelerated actions related to the groundwater AOIs (that is, installation of groundwater treatment systems) have been taken at the historical Mound Site/Oil Burn Pit No. 2, historical East Trenches, and historical SEP. These actions were taken to disrupt the pathway from groundwater to surface water by collecting and treating contaminated groundwater.

For the groundwater AOIs, the most current data for those analytes measured in shallow groundwater show concentrations below the highest of the surface water standard, background, or PQL at all AOC wells with the exception of well 10594 (located downgradient of Pond A-1 in North Walnut Creek with sulfate results above background, which is higher than the surface water standard or PQL, in samples collected in 1995 and 1996).

8.6.2 Summary of Surface Water AOI Results

The extent of surface water AOIs in the RFETS environment is discussed to provide perspective with respect to AOIs in other environmental media. As summarized in Table 8.4, four surface water AOIs are observed intermittently above the highest of the surface water standard, background, or PQL at representative (nonbackground) surface water locations. These AOIs are plutonium-239/240, americium-241, uranium (sum of isotopes), and nitrate/nitrite (as N). Americium-241 is observed intermittently above the surface water standard at surface water monitoring locations upstream of the terminal ponds in North Walnut Creek (SW093), South Walnut Creek (GS10), and the SID/Woman Creek drainage (GS51 and SW027). Plutonium-239/240 has been observed intermittently above the surface water standard at the same locations upstream from the terminal ponds as americium-241, as well as at station SW018 in the North Walnut Creek watershed. Uranium (sum of isotopes) was detected above the surface water standard in North Walnut Creek (GS13) and South Walnut Creek (GS10), although it is predominantly from natural uranium sources, based on analyses of uranium isotope fractions. Nitrate/nitrite (as N) was observed in North Walnut Creek (GS13) above the surface water standard. All other surface water AOIs (gross alpha and beta, cis-1,2-dichloroethene, carbon tetrachloride, chloroform, methylene chloride, trichloroethene, tetrachloroethene, vinyl chloride, aluminum [dissolved], chromium [total], lead, and nickel) are observed infrequently or not at all at concentrations above the highest of the surface water standard, background, or PQL at the representative surface water locations.

For the surface water AOIs, the most current data for those analytes (which represent the most current conditions) show measurements below the highest of the surface water standard, background, or PQL at the representative surface water locations downstream of the terminal ponds in the North Walnut Creek, South Walnut Creek, and SID/Woman Creek drainages.

8.6.3 Summary of Air AOI Fate and Transport Results

Air AOIs identified that warranted a numerical modeling analysis are plutonium-239/240, americium-241, uranium-233/234, uranium-235, and uranium-238 (see Section 8.5). These analytes were modeled because of their diffuse, residual presence in surface soil and long-term persistence in the environment, which suggest a potential long-term impact on air quality. Air modeling results predict that emissions, even for hypothetical post-fire scenarios at the historical 903 Pad area, will be well below the EPA 10-mrem annual benchmark level for the airborne pathway (see discussion in Section 8.5.2 and Attachments 2 and 4). Therefore, all of the air AOIs are identified as having a limited migration pathway in the RFETS airborne environment.

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Figure 8.4
Groundwater - Conceptual Model of General Fate and Transport Mechanisms

Figure 8.5
Composite Plume Map

Figure 8.6
Degradation Pathways of Chlorinated Aliphatic Hydrocarbons

Figure 8.7
Groundwater Monitoring Locations with Stainless-Steel Well Construction or Sampling Equipment

Figure 8.8
Air – Conceptual Model of Contaminant Fate and Transport Mechanisms

Figure 8.9
2004 RFETS Wind Rose

Figure 8.10
Groundwater Areas With Sentinel Wells Above the Highest of the Surface Water Standard, Background, or PQL Values

TABLES

Table 8.1
Nature and Extent AOIs – Summary by Media

Analyte Group	AOI	Environmental Media					
		Surface Soil	Subsurface Soil	Ground - water[a]	Surface Water[a]	Sediment	Air[b]
Radio-nuclides	Americium-241	x	x	-	x	x	x
	Plutonium-239/240	x	x	-	x	x	x
	Uranium-233/234	x	-	-	-	-	x
	Uranium-235	x	x	-	-	-	x
	Uranium-238	x	x	-	-	-	x
	Uranium (sum of isotopes)	-	-	x	x	-	-
	Gross alpha	-	-	-	x	-	-
	Gross beta	-	-	-	x	-	-
VOCs	cis-1,2-Dichloroethene	-	-	x	x	-	-
	1,2-Dichloroethane	-	-	x	-	-	-
	1,1-Dichloroethene	-	-	x	-	-	-
	Benzene	-	-	x	-	-	-
	Carbon Tetrachloride	-	x	x	x	-	-
	Chloroform	-	x	x	x	-	-
	Chloromethane	-	-	x	-	-	-
	Methylene chloride	-	x	x	x	-	-
	Tetrachloro-ethene	-	x	x	x	-	-
	Trichloroethene	-	x	x	x	-	-
	1,1,2,2-Tetrachloro-ethane	-	x	-	-	-	-
	Vinyl chloride	-	-	x	x	-	-
Metals	Aluminum	x	-	-	x (dissolved)	-	-
	Arsenic	x	-	x (dissolved)	-	x	-
	Beryllium	-	-	-	x	-	-
	Chromium (total)	x	x	x	x	x	-
	Lead	-	x	-	x	-	-
	Nickel	-	-	x (total and dissolved)	x	-	-
	Vanadium	x	-	-	-	-	-

Table 8.1
Nature and Extent AOIs – Summary by Media

Analyte Group	AOI	Environmental Media					
		Surface Soil	**Subsurface Soil**	**Ground - water[a]**	**Surface Water[a]**	**Sediment**	**Air[b]**
SVOCs	Benzo(a)pyrene	**x**	**x**	-	-	**x**	-
	Dibenz(a,h)-anthracene	**x**	-	-	-	-	-
PCBs[c]	PCB-1254	**x**	-	-	-	-	-
	PCB-1260	**x**	**x**	-	-	-	-
Dioxins	2,3,7,8-TCDD TEQ	**x**	-	-	-	-	-
Water Quality Parameters	Fluoride	-	-	**x**	-	-	-
	Nitrate/Nitrite (as N)	-	-	**x**	**x**	-	-
	Sulfate	-	-	**x**	-	-	-

[a] Analytes in groundwater and surface water are “total” (unfiltered) unless noted as “dissolved” (filtered).

[b] Air AOIs are defined as those constituents that were modeled for airborne transport (plutonium-239/240, americium-241, uranium-233/234, uranium-235, and uranium-238), although the historic airborne concentrations of these radionuclides have been well below the allowable standard.

[c] The PCBs listed herein are equivalent to Aroclors, for example PCB-1254 is the same as Aroclor-1254.

Table 8.2
AOIs – Contaminant Behavior and Persistence in the Environment

Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
Americium-241 (Radionuclide)	Surface Soil / Subsurface Soil The strong tendency of americium hydroxides to sorb onto surfaces is a dominant and often controlling feature in americium geochemistry. Therefore, americium is generally transported with soil particles or colloids, carried by wind and water movement. The major reactions influencing the environmental fate of americium are formation of complexes with anions and natural organic matter, precipitation, and sorption. Americium migration in the environment can also occur due to its association with particles or colloids (pseudocolloids); pseudocolloids are present in nearly all waters and are formed as a result of the weathering of rocks, soil, and plant material. Am(III) ions are also prone to undergo polymerization reactions under environmental conditions to form colloidal polymers. Although americium can exist in multiple oxidation states, the most likely redox state of americium in soils is Am(III) (Bondietti et al. 1977; Nelson and Orlandini 1986), which forms relatively insoluble oxides and hydroxides. Leaching studies of surface-deposited americium-241 indicates it has low relative mobility. Three soils of widely differing characteristics found that 98 percent of the americium was retained in upper 2 centimeters of soil (Vyas and Mistry 1980). RFETS studies indicate the majority of americium-241 is confined to the top 20 centimeters (K-H 2002a). Air Although not an AOI americium-241 is a pollutant of potential concern in air. In the atmosphere, americium is associated with particulate matter, and the transport of americium in air will therefore be governed by that of its host particles (Bennett 1979). Dry deposition and precipitation remove americium from the air and deposit it on the ground or in water. Smaller or lighter particles will travel farther from their origin before being deposited than larger or denser particles. Once deposited on the land, the particles may be resuspended. Surface Water / Sediment In aerated waters, americium is invariably in the Am(III) state, in the absence of oxidants other than atmospheric oxygen (Bondietti et al. 1977; Nelson and Orlandini 1986). Americium hydroxide, resulting from rapid hydrolysis of americium in solution, is insoluble in both fresh and marine waters, precipitating as particulate matter or sorbing to suspended particulates (Warner and Harrison 1993, Chapter 1). The association of americium with particulate matter and sediments controls its behavior and distribution in the aquatic environment. The main processes by which americium becomes associated with solids are: • Adsorption of americium to solid surfaces of soils, sediments, and colloids; • Ion exchange of americium to charged sites on clay and mineral surfaces and humic material; • Precipitation of hydrolyzed americium as polyhydroxides and oxides; and • Coprecipitation and occlusion of americium with other precipitating minerals, such as oxides of aluminum, iron, and manganese. Americium released to water is rapidly depleted from the water column and deposited in surface sediment (Murray and Avogadro 1979). In sediments, the highest americium concentrations are generally associated with the smallest particle sizes.	The half-life of americium-241 is 432.2 years.	Americium-241 has been detected in surface soil above the WRW Preliminary Remediation Goal (PRG) in the former 700 Area of the former Industrial Area (IA) (particularly at the location of former Building 776), and the historical 903 Pad/Lip area. In subsurface soil, americium-241 exists above the WRW PRG in one area in the South Walnut Creek watershed, at the historical East Trenches at a depth interval from 3.0 to 8.0 ft. As discussed in the evaluation of americium-241 in surface soil (Section8.3.3.1), the dominant transport mechanism is via surface mechanisms (K-H 2002a). The subsurface mobility of americium-241 is extremely limited because of its low solubility and the strong tendency of americium hydroxides to sorb to surfaces. However, americium-241 historically may have been transported vertically into subsurface soil due to entrainment in a liquid, such as oil and/or solvent, that would have fostered limited downward transport (such as occurred at the historical 903 Pad). Americium-241 transport below the ground surface also could occur via a subsurface conduit that facilitated subsurface movement (this subsurface transport pathway, distinctly different than groundwater transport of a dissolved constitutent, occurred at the former Building 771 where americium-241 was transported to the surface via subsurface drains that were intact; these subsurface drains were subsequently disrupted). Americium-241 is defined as a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). Two locations exist with sediment sample results above the americium-241 WRW PRG value (7.69 pCi/g). These sampling locations are in Pond B-3 in South Walnut Creek. At RFETS, americium has been extensively studied in the AME. Americium at RFETS is almost entirely (around 99 percent) in solid forms, either bound to soil and sediment particles or precipitated as oxides and hydroxides (this percentage is essentially the same as that found worldwide) (K-H 2002a). The AME Pathway Analysis Report provides information indicating that the solubility of americium solids under the oxidizing environmental conditions most common at RFETS is very low, around 10^{-15} moles/liter. Although reducing conditions are likely to exist in the treatment ponds and in landfill locations, there is evidence that reducing conditions do not increase americium mobility at RFETS (K-H 2002a).

Table 8.2
AOIs – Contaminant Behavior and Persistence in the Environment

Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
			A result of the observations above is that subsurface mobility of americium is expected to be very low (K-H 2002a). Historic data demonstrate the fate and transport of americium is associated with the migration of soil and sediment particles it is associated with, via wind and water erosion (both are viable mechanisms). Surface water data demonstrate sedimentation is effective for removing americium from the water column in the RFETS ponds (K-H 2002a). While the removal of buildings and pavement makes more surface soil available for erosion, the amount of runoff and peak discharge rates will decrease significantly with the impervious surfaces removed. Since runoff drives soil erosion (and its associated contaminant transport), the migration of contaminants bound to surface soil is expected to be reduced. With respect to the ponds, during remediation and reconfiguration of the site, the ponds served to protect surface water quality; however, the ponds will not be relied on as part of the final remedy for the site.
Plutonium-239/240 (Radionuclide)	<u>Surface Soil / Subsurface Soil</u> Plutonium in the environment exists mostly as precipitated oxides (PuO_2) and in a strongly sorbed state to the organic and oxide fractions of surface soils and sediments (Livens et al. 1986). The strong tendency of the plutonium hydroxides to sorb onto surfaces is a dominant and often controlling feature in plutonium geochemistry. Therefore, plutonium is generally transported with soil particles or colloids, carried by wind and water movement. Plutonium can exist in four oxidation states: III, IV, V and VI (Allard and Rydberg 1983; Choppin et al. 1997). A fifth oxidation state Pu(VII) can be created, but is not found in nature (K-H 2002a). Pu(IV) hydrolyzes readily to form hydrolytic species with the general formula, $Pu(OH)_m^{(4-m)+}$ (m = 1, 2, 3, 4). For m = 1, 2 or 3, plutonium forms the cations $Pu(OH)^{3+}$, $Pu(OH)_2^{2+}$, and $Pu(OH)_3^{+}$, which can contribute significantly to the overall solubility of plutonium. However, the case of m = 4 leads to amorphous $Pu(OH)_4(s)$, which has very low solubility. Plutonium found in soils may undergo oxidation/reduction reactions in places where soil contacts water. In addition to oxidation/reduction reactions, plutonium can react with other ions in soil to form complexes. These complexes may then be absorbed by roots and move within plants; however, the relative uptake by plants is low. In plants, the complex can be degraded but the elemental plutonium will remain. <u>Air</u> Although not an AOI plutonium-239/240 is a pollutant of potential concern in air. In the atmosphere, plutonium is associated with particulate matter, and the transport of plutonium in air will therefore be governed by that of its host particles. Dry deposition and precipitation remove plutonium from the air and deposit it on the ground or in water. Smaller or lighter particles will travel farther from their origin before being deposited than larger or denser particles. Once deposited on the land, the particles may be resuspended. <u>Surface Water / Sediment</u> Plutonium dissolved in environmental waters tends to be progressively eliminated from the water as it encounters surfaces to which it can sorb and conditions that result in precipitation. Over 99 percent of plutonium released to arid environments ends up in soil and sediments (Warner and Harrison 1993, Chapter 4; Watters et al. 1983). In natural waters, plutonium solubility is generally limited by the formation of amorphous hydroxides or oxides. Sorption of hydrolyzed Pu(IV) in natural water on mineral surfaces and surfaces coated with organic material is often accountable for the very low observed concentrations of dissolved plutonium. The main processes by which plutonium becomes associated with solids are: • Adsorption of plutonium to solid surfaces of soils, sediments, and colloids;	The half-life of plutonium-239 is 24,390 years, and the half-life of plutonium-240 is 6,537 years.	Plutonium-239/240 is defined as a surface and subsurface soil AOI in the nature and extent of soil contamination (Section 3.0) and a sediment AOI in the nature and extent of surface water and sediment contamination (Section 5.0). It is also defined as a COC for surface soil/sediment in the Wind Blown Area Exposure Unit. Similar to americium-241, plutonium-239/240 is detected in surface soil above the WRW PRG at several locations in the former IA (particularly in the former 700 and 400 Areas, and most notably at the location of former Building 776), and the historical 903 Pad/Lip area. In subsurface soil, plutonium-239/240 exists above the WRW PRG at three locations. These are in the North Walnut Creek watershed in the former 700 Area of the IA, in the South Walnut Creek watershed at the historical East Trenches, and at the historical 903 Pad, on the boundary of the South Walnut Creek and SID watersheds). Locations of Plutonium-239/240 above the WRW PRG value (9.80 pCi/g) include along the former Central Avenue Ditch, four locations in the North Walnut Creek drainage (in Pond A-1 and A-2), three locations in the South Walnut Creek drainage (in Pond B-4), and near the former shooting range south of the historical 903 Pad/Lip area. The dominant transport mechanism is via surface transport mechanisms. The subsurface mobility of plutonium-239/240 is extremely limited due to its

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	• Ion exchange of plutonium to charged sites on clay and mineral surfaces and humic material; • Precipitation of hydrolyzed plutonium as polyhydroxides and oxides; • Coprecipitation and occlusion of dissolved plutonium with other precipitating minerals, such as oxides of aluminum, iron, and manganese; and • Polymerization of plutonium ions into colloidal solids with molecular weights up to about 10,000 Daltons. The estimated solubility of amorphous $Pu(OH)_4$ is around $10^{-9(\pm 2)}$ M and that of PuO_2(c) around $10^{-15(\pm 3)}$ M. The solubilities of the solid forms of plutonium impose an upper limit on the total amount of dissolved plutonium that can be present, even if Pu(V) or Pu(VI) is the more stable dissolved state. When $Pu(OH)_4$(am) and PuO_2(c) are present, they limit the concentrations of soluble plutonium species to about 10^{-8} M to 10^{-10} M (Langmuir 1997; Rai et al. 1980; Delegard 1987).		strong tendency to form plutonium hydroxides/oxides which sorb to surfaces (K-H 2002a). The subsurface soil plutonium-239/240 is related to either subsurface plutonium placed below the ground surface (former 700 Area and historical East Trenches) or vertical transport caused by plutonium entrained in oil and/or solvent (historical 903 Pad) that is not reflective of plutonium environmental transport At RFETS, plutonium has been extensively studied in the AME. In environmental conditions common at RFETS, plutonium is in its least soluble oxidation state, Pu(IV). LANL studied the speciation of plutonium in contaminated soils from RFETS. The data from X-ray absorption spectroscopy (XANES, EXAFS) indicated that plutonium was present in the Pu(IV) state as expected and was structurally similar to the highly stable and immobile PuO_2 (K-H 2002a). Measurements of plutonium in RFETS soils from the 903 Pad and IA buildings support many earlier studies indicating that plutonium at RFETS is almost entirely present as PuO_2, generally accepted to be immobile in the subsurface, except for potential colloid-facilitated movement (K-H 2002a). Plutonium at RFETS is almost entirely (around 99 percent) in solid forms, either bound to soil and sediment particles or precipitated as oxides and hydroxides (this percentage is essentially the same as that found worldwide) (K-H 2002a). The solubility of plutonium solids under the oxidizing environmental conditions most common at RFETS is very low, around 10^{-15} moles/liter. Although reducing conditions are likely to exist in the treatment ponds and in landfill locations, there is evidence that reducing conditions do not increase plutonium mobility at RFETS (K-H 2002a). A result of the observations above is that subsurface mobility of plutonium is expected to be very low. Its transport mechanism is by water or wind erosion and sediment transport (K-H 2002a). Erosion (by both surface water and wind) can also cause transport plutonium in sediment. Surface water data demonstrate sedimentation is effective for removing plutonium from the water column in the RFETS ponds (K-H 2002a). While the removal of buildings and pavement makes more surface soil available for erosion, the amount of runoff and peak discharge rates will decrease significantly with the impervious surfaces removed. Since runoff drives soil erosion (and its associated contaminant transport), the migration of contaminants bound to surface soil is expected to be reduced. With

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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
			respect to the ponds, during remediation and reconfiguration of the site, the ponds served to protect surface water quality; however, the ponds will not be relied on as part of the final remedy for the site.
Uranium-233/234 Uranium-235 Uranium-238 Uranium (sum of isotopes) (Radionuclides)	Surface Soil / Subsurface Soil Uranium minerals in ore deposits are commonly found in association with carbonaceous matter (Breger 1974). It appears that mobile U(VI) sorbs to organic matter and is reduced to form solid phases like uraninite. Based on its mineralogy, in the absence of elevated concentrations of vanadate, orthophosphate, or silica, the mobility of uranium is high under oxidizing conditions (as uranyl carbonate and hydroxide complexes), but low under reducing conditions and/or in the presence of organic matter. Significant reactions of uranium in soil are formation of complexes with anions and ligands or humic acid, and reduction of soluble U(VI) to insoluble U(IV). Other factors that control the mobility of uranium in soil are the redox potential, the pH, and the sorbing characteristics of the sediments and soils (Allard et al. 1979, 1982; Brunskill and Wilkinson 1987; Herczeg et al. 1988; Premuzie et al. 1995). Retention of uranium by the soil may be due to adsorption, chemisorption, ion exchange, or a combination of mechanisms (Allard et al. 1982). The sorption of uranium in most soils is such that it may not leach readily from soil surface to groundwater, particularly in soils containing clay and iron oxide (Sheppard et al. 1987). Numerous investigators have measured K_d values under a wide range of experimental conditions for uranium sorption on various geologic materials including pure mineral phases, soils, sediments, clays, and crystalline rocks. A number of compilations and reviews of uranium K_ds have been published. EPA (1999) also compiled many of these published uranium K_ds and plotted them as a function of pH. Air Although not an AOI, uranium is a pollutant of potential concern in air. The transport of uranium particles in the atmosphere will depend on the particle size distribution and density. Dry deposition and precipitation remove uranium particles from the air and deposit them on the ground or in water. Smaller or lighter particles will travel farther from their origin before being deposited than larger or denser particles. Once deposited on the land, the particles may be resuspended. Groundwater / Surface Water / Sediment The transport of uranium in surface water and groundwater are affected by adsorption and desorption of uranium on aquatic sediments. In most waters, sediments act as a sink for uranium and the uranium concentrations in sediments and suspended solids are several orders of magnitude higher than in surrounding water (Brunskill and Wilkinson 1987; Swanson 1985). Uranium is a redox-sensitive element that can exist in the III, IV, V, and VI oxidation states under laboratory conditions. However, in groundwater and surface water, only the U(IV) and U(VI) valence states are important. U(VI) aqueous species predominate in oxic and moderately oxidizing groundwater, and in the pH range of 6 to 9 the major species are predicted to be $UO_2(CO_3)_2^{2-}$, $UO_2(CO_3)_3^{4-}$, $UO_2CO_3^0$, $(UO_2)_2CO_3(OH)_3^-$, and $UO_2(OH)_2^0$ (EPA 1999). The uncomplexed uranyl cation (UO_2^{2+}) is unimportant at pH >5.5. Uranyl phosphate complexes can be important if the water contains sufficient orthophosphate (i.e., total PO_4/CO_3 >0.1) (Langmuir 1978; EPA 1999). U(IV) aqueous species at pH >3 are mainly hydrolysis species like $U(OH)_3^+$ and $U(OH)_4^0$ (EPA 1999). U(IV) complexes with anions like sulfate, phosphate, chloride, and fluoride are not significant at normal groundwater pHs. Groundwater chemistry in terms of REDOX environment, pH, availability of ligands, and ionic strength will control the distribution of aqueous uranium species and the overall proportion in U(VI) versus U(IV) oxidation states. Numerous uranium-bearing minerals have been identified. Important U(VI) minerals in an oxidizing environment are associated with vanadium, or orthophosphate, or with silica (DeVoto 1978). U(IV) minerals form in a reducing environment. U(IV) minerals tend to be very insoluble, and may control dissolved uranium at very low concentrations in reducing groundwater. The concentration of uranium in contaminated groundwater, not associated with uranium ore deposits, may not be solubility-limited. If it is solubility-limited, the identity of the controlling solid phase is probably unknown at most contamination sites. Uranium K_ds are pH-dependent and for many different sorbents they appear to have a sorption maximum in the pH 6 to 7 range. For a given sorbent, uranium becomes more mobile in increasingly alkaline waters above pH 7.5, and more mobile in increasingly acidic waters below pH 5.5. Assuming a groundwater of pH 7, the log K_d data appear to span about 4 log units corresponding to uranium K_ds of approximately 100 mL/g to 1 million mL/g. At pH 8 the data span about 5 log units, or a K_d range of 1 to 100,000 mL/g. These large ranges suggest that site-specific uranium sorption data are necessary to predict the transport of uranium at a site such as RFETS.	U isotopes are persistent in the environment due to their long radioactive half-lives: uranium-234: 244,000 years, uranium-235: 704 million years, and uranium-238: 4.5 billion years.	Natural uranium is ubiquitous in the Front Range of Colorado and complicates studies of uranium contamination at RFETS. High uranium granites occur throughout the Front Range and uranium ore (utilized by the Schwartzwalder mine near Ralston Reservoir) is located in the headwaters of Ralston Creek within 10 miles of RFETS. Uranium-235 and Uranium-238 are defined as soil and subsurface soil AOIs in the nature and extent of soil contamination (Section 3.0). Uranium has been detected in surface soil is distributed in the former 700 Area, former Building 444, historical SEP, the Original Landfill, and in the historical Ash Pit area. In subsurface soil, uranium-235 and uranium-238 exist above the WRW PRG at one location, the historical Ash Pits. Uranium (sum of isotopes uranium-233/234, uranium-235, and uranium-238) is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Mappable, contiguous plumes of total uranium isotopes are displayed on Figure 4.20 in the nature and extent of groundwater contamination. This figure shows the plumes occurring at and downgradient of the historical SEP and the former 700 Area Northeast Plume. Although they did not meet the criteria for a contiguous, mappable plume, concentrations of total uranium (sum of isotopes) have been observed in groundwater at the historical Ash Pits above the surface water standard. However, unsaturated conditions exist here for much of the year and thereby limit the potential for uranium migration. An evaluation of the groundwater in this area concluded that the subsurface uranium from the historical Ash Pits has not impacted the partly saturated groundwater and surface water in the area (K-H 2005e). At RFETS, uranium has been extensively studied in the AME. Isotopic abundances (by weight) in uranium used at RFETS differ significantly from natural values (DOE 1997), and this may be useful in determining the fraction of uranium in on-site groundwater and surface water that represents RFETS contamination (anthropogenic). Some of the uranium used at RFETS for manufacture of nuclear weapons components was enriched in uranium-234 and uranium-235 and some was depleted in uranium-234 and uranium-235 (K-H 2004b).

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			Using appropriate analytical techniques, the isotopic signatures of anthropogenic uranium can be distinguished from natural uranium in water samples. The results of these analyses are provided in Attachment 4, and indicate the following: 1) less than 1 percent enriched uranium has been measured in water at RFETS; 2) anthropogenic uranium (mainly depleted U) is detected in groundwater from the historical SEP, historical Ryan's Pit, Original Landfill, historical T-1, historical East Trenches, and historical Mound areas; and 3) surface water shows a mixture of depleted and natural U, although it is greatly dominated by natural uranium (see Section 8.4.3 in main text and Attachment 3 for more details). Table TA-3-4 from the AME Pathway Analysis Report Technical Appendix (K-H 2002a) includes reported values for uranium empirical K_ds specific to RFETS. The values range from essentially 30 to 170 mL/g. These values are certainly within the range of K_ds reported for uranium worldwide.
Gross Alpha (Radionuclides)	<u>Surface Water</u> Gross alpha measurements are used to indicate the presence of specific radionuclides.	NA – Dependent on specific radioisotope.	At RFETS, AOI isotopes that decay primarily by alpha particle emissions include plutonium-239, plutonium-240, americium-241, uranium-234, uranium-235, and uranium-238. See entries for these specific isotopes.
Gross Beta (Radionuclides)	<u>Surface Water</u> Gross beta measurements are used to indicate the presence of specific radionuclides.	NA – Dependent on specific radioisotope.	Many isotopes detected at RFETS are beta emitters, including potassium-40, Cesium-137, and strontium-90. None of these are AOIs.
cis-1,2-Dichloroethene (VOCs)	<u>Groundwater / Surface Water</u> CAHs are a group of VOCs in which chlorine atoms have replaced one or more hydrogen atoms in an alkane or alkene hydrocarbon compound. The alkenes are distinguished by a carbon-to-carbon double bond. Because functional groups are not free to rotate about a double bond, "cis" and "trans" geometric isomers can be separately identified for some chlorinated alkenes, such as cis-1,2-dichloroethene. They are the anaerobic degradation products of trichloroethene (see Figure 8.6 for the full degradation chains). The relative mobility of certain CAHs in groundwater is estimated based on sorption and water solubility characteristics. cis-1,2-Dichloroethene has a K_d value less than 1 mL/g indicating very high mobility in groundwater. These K_{0c} values also suggest that adsorption to soil, sediment, and suspended solids in water is not a significant fate process. Without significant adsorption to soil, cis-1,2,-dichloroethene can leach into groundwater where very slow biodegradation should occur (HSDB 1995). Volatilization occurs from surface water but is relatively unimportant for groundwater, except for very shallow groundwater, perhaps less than 1 meter below the surface. The degree of volatilization of a chemical from water depends on its vapor pressure and water solubility and is best quantified by the Henry's Law constant (H) (Howard 1991). The larger the Henry's Law constant, the greater the CAH concentration in air relative to its aqueous concentration. A very important fate process for most CAHs is that under anoxic conditions, they undergo biodegradation, liberating chloride ion and forming simpler organic compounds. Numerous investigations have shown that microorganisms indigenous to groundwater environments can degrade a variety of manmade organic chemicals (EPA 1998a). This biologically mediated degradation is termed biodegradation and at many sites it is the most important process by which CAHs in the environment are destroyed.	Volatilization occurs rapidly from surface water, with an estimated half-life of 3 to 6 hours based on a model river (Thomas 1982). Experimental data indicate that anaerobic biodegradation in groundwater occurs with a half-life of about 13 to 48 weeks (Barrio-Lage et al. 1986).	cis-1,2-Dichloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of cis-1,2-dichloroethene in UHSU groundwater are primarily downgradient of the historical Mound site (refer to Figure 4.11 in the nature and extent of groundwater contamination). Ratios of the cis- and trans-stereoisomers of 1,2-dichloroethene have been used in the published literature as a qualitative indicator of biodegradation. Commercial solvents are a mixture of cis- and trans-1,2-dichloroethene. In contrast, biological processes (biodegradation) produce mainly cis-1,2-dichloroethene (EPA 1998a). The cis/trans ratio is typically greater than 25 to 1 in groundwater where biodegradation is actively occurring. The cis/trans ratio was computed for each well and sampling event at RFETS with detectable isomer concentrations. Although some wells have low ratios, most wells had high ratios between 26 and 684, suggesting that CAH biodegradation is occurring in those areas (K-H 2004c).

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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
			Estimates of the biodegradation half-life of cis-1,2-dichloroethene in RFETS groundwater fall in a wide range, starting with approximately 10 years, using the Buschek and Alcantar 1-dimensional estimation method (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details). A range of sorption (K_d) values has been calculated based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For cis-1,2-dichloroethene, the K_d values at RFETS are calculated to range from 2.6 x 10^{-8} to 2.3 x 10^{-6} L/mg (K-H 2004a).
1,2-Dichloroethane 1,1-Dichloroethene Chloromethane Vinyl chloride (clustered because of like properties) (VOCs)	Groundwater CAHs are a group of VOCs in which chlorine atoms have replaced one or more hydrogen atoms in an alkane or alkene hydrocarbon compound. The alkenes are distinguished by a carbon-to-carbon double bond, while the alkanes contain only single bonds. 1,2-Dichloroethane is the daughter product of 1,1,2-trichloroethane. 1,1-Dichloroethene is the degradation product of 1,1,1-trichloroethane or tetrachloroethene. Chloromethane is due to the degradation of methylene chloride. Vinyl chloride is the daughter product of tetrachloroethene → trichloroethene →cis- and trans-1,2-dichloroethene and 1,1-dichloroethene → vinyl chloride, 1,2-dichloroethane, or 1,1-dichloroethane. Refer to Figure 8.6 for descriptions of the full degradation chains. Both 1,1-dichloroethene and vinyl chloride have K_d values indicating high to very high mobility in groundwater. 1,2-Dichloroethane will also migrate relatively freely within groundwater (EPA 1982a). None of the compounds listed here is expected to adsorb to suspended solids or sediments (ATSDR 1994, 1998, 2004a). Volatilization is relatively unimportant from groundwater, except for very shallow groundwater, perhaps less than 1 meter below the surface. The degree of volatilization of a chemical from water depends on its vapor pressure and water solubility and is best quantified by the Henry's Law constant (H) (Howard 1991). The larger the Henry's Law constant, the greater the CAH concentration in air relative to its aqueous concentration. A very important fate process for certain CAHs is that under anoxic conditions, they undergo biodegradation, liberating chloride ion and forming simpler organic compounds. Numerous investigations have shown that microorganisms indigenous to groundwater environments can degrade a variety of manmade organic chemicals (EPA 1998a). This biologically mediated degradation is termed biodegradation and at many sites it is the most important process by which CAHs in the environment are destroyed. In groundwater, hydrolysis may be the only removal mechanism available to chloromethane; data regarding biodegradation of this compound are equivocal and biodegradation rates are thought to be highly variable (ATSDR 1998). Degradation of vinyl chloride occurs slowly in anaerobic groundwater; however, under certain reducing conditions, anaerobic degradation occurs more rapidly (ATSDR 2004a). Surface Water The primary transport process for vinyl chloride from natural water systems is volatilization into the atmosphere. The Henry's Law constant of vinyl chloride has been measured as 0.0278 atm-m^3/mol at 24.8 °C (Gossett 1987), which suggests that vinyl chloride should partition rapidly to the atmosphere. The half-life for vinyl chloride volatilization from a typical pond, river, and lake has been estimated to be 43.3, 8.7, and 34.7 hours, respectively. These values are based on an experimentally determined reaeration rate ratio of approximately 2 and assumed oxygen reaeration rates of 0.008, 0.04, and 0.01 per hour for a typical pond, river, and lake, respectively (EPA 1982a). Predicted half-lives should be considered rough estimates because the presence of various salts in natural water systems may affect the volatility of vinyl chloride significantly (EPA 1979). Many salts have the ability to form complexes with vinyl chloride and can increase its water solubility; therefore, the presence of salts in natural waters may significantly influence the amount of vinyl chloride remaining in the water (EPA 1979). The half-life of vinyl chloride in bodies of water is also affected by depth and turbidity. The half-life of 1,2-dichloroethene is 3 to 6 hours in a model river.	McCarty et al. (1986) found that 1,1-dichloroethene was reduced to vinyl chloride under anaerobic conditions after 108 days. In another study, reductive dechlorination of 1,1-dichloroethene by microorganisms in anoxic microcosms occurred after 1 to 2 weeks incubation (Barrio-Lage et al. 1996). In the field, the biodegradation half-life of 1,2-dichloroethane in groundwater can range from less than a year to 30 years depending on the conditions (Bosma et al. 1998). Chloromethane in groundwater has an estimated half-life of approximately 4 years, based on data concerning hydrolysis rates (Elliott and Rowland 1995; Mabey and Mill 1978). Experimental data regarding biodegradation of vinyl chloride are variable. In anaerobic aquifer microcosms supplemented with Fe(III) and held under Fe(III) reducing conditions, approximately 34 percent of vinyl chloride was mineralized in 84 hours; mineralization is expected to occur more slowly under other conditions (Bradley and Chapelle 1996). All of these compounds degrade to other CAHs as shown on Figure 8.6. The primary removal process for vinyl chloride from surface waters is volatilization into the atmosphere. Vinyl chloride in water does not absorb ultraviolet	1,1-Dichloroethene is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The areal extent of contiguous, mappable plumes of 1,1-dichloroethene includes the historical Oil Burn Pit No. 2, the historical East Trenches, historical OU 1 (historical IHSS 119.1), north of the former Building 771, and the former IA Plume Sources (refer to Figure 4.5 in the nature and extent of groundwater contamination). 1,2-Dichloroethane is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The only 1,2-dichloroethane contiguous, mappable plume is associated with the Mound area (refer to Figure 4.6 in the nature and extent of groundwater contamination). Chloromethane is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Chloromethane is detected in groundwater in one isolated location, at the historical IHSS 118.1 area south of the former Building 771 (refer to Figure 4.10 in the nature and extent of groundwater contamination). Vinyl chloride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The distribution of vinyl chloride is limited and occurs within known areas of VOC contamination. Contiguous, mappable plumes of vinyl chloride plume are located at the historical Oil Burn Pit No. 1 (historical IHSS 128), the historical Mound site, and at the Present Landfill (refer to Figure 4.15 in the nature and extent of groundwater contamination).

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		radiation above 218 nm; therefore, direct photolysis in the aquatic environment is expected to occur very slowly, if at all (EPA 1976). In sun-lit surface waters containing photosensitizers, such as humic materials, photodegradation may be more rapid. If so, in some waters, sensitized photodegradation may be an important removal mechanism (EPA 1976).	The mean biodegradation half-life in groundwater at RFETS calculated using the Buscheck and Alcantar 1-dimensional method for chloromethane was 8.1 years and for 1,1-dichloroethene was 3.0 years (considered the low end of the range for half-life estimates). 1,2-Dichloroethane was never used at RFETS, but it is assumed to biodegrade at approximately the same rate as 1,1-dichloroethane, which for RFETS was calculated to be 30.3 years (K-H 2004c) (considered to be at the low end of the range for half-life estimates). 1,1-Dichloroethane was also never used at RFETS, but it is the degradation product of 1,1,1-trichloroethane (which was used at the site). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details). A range of sorption (K_d) values has been calculated based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For vinyl chloride, the maximum K_d values at RFETS were calculated to be 1.7×10^{-6} L/mg. For chloromethane, the K_d values at RFETS were calculated to range from 1.6×10^{-9} to 1.0×10^{-6} L/mg (K-H 2004a).
Benzene (VOCs)	Groundwater Benzene has a K_{oc} value of 60-83 (Karickhoff 1981; Kenaga 1980) and is considered highly mobile in groundwater. Benzene shows a tendency to adsorb to aquifer solids. Greater absorption was observed with increasing organic matter (Uchrin and Mangels 1987). Volatilization and leaching would be the principal factors in determining the persistence of benzene in sandy soils. Aerobic biodegradation is expected to be the primary mechanism for degradation of benzene in groundwater, with volatilization accounting for 5 to 10 percent of natural attenuation at most sites (McAllister and Chiang 1994). Within 1 to 1.5 years, biotransformation will remove 80 to 100 percent of benzene in groundwater plumes.	One study reported a half-life for benzene in groundwater of 28 days (ATSDR 1997a).	Benzene occurrences are mainly associated with the Present Landfill.
Carbon tetrachloride (VOCs)	Subsurface Soil CAHs are a group of VOCs in which chlorine atoms have replaced one or more hydrogen atoms in an alkane or alkene hydrocarbon compound. Carbon tetrachloride is a stable chemical that is degraded very slowly in the environment. It degrades under anaerobic conditions to its daughter product, chloroform (see Figure 8.6 for full carbon tetrachloride degradation chain). Groundwater Carbon tetrachloride exhibits moderate mobility in soil and groundwater. Chloroform and methylene chloride, both degradation products of carbon tetrachloride, are considerably more mobile than the parent solvent compound. The carbon atom in carbon tetrachloride is in its most oxidized state and is therefore much more likely to undergo reductive degradation than oxidative degradation. Carbon tetrachloride may undergo reductive dechlorination in aquatic systems in the presence of free sulfide and ferrous ions, or naturally occurring minerals providing those ions (Kreigman-King and Reinhard 1991). A very important fate process for certain CAHs is that under anoxic conditions, they undergo biodegradation, liberating chloride ion and forming simpler organic compounds. Numerous investigations have shown that microorganisms indigenous to groundwater environments can degrade a variety of manmade organic chemicals (EPA 1998a). This biologically mediated degradation is termed biodegradation and at many sites it is the most important process by which CAHs in the environment are destroyed.	Most of the carbon tetrachloride released to soil evaporates within a few days (EPA 1991). The transformation rate of carbon tetrachloride to chloroform in simulated groundwater showed half-lives of 380 days for carbon tetrachloride alone, 2.9 to 4.5 days with minerals and sulfide ion present, and 0.44 to 0.85 days in the presence of natural iron sulfides (Kreigman-King and Reinhard 1991). Figure 8.6 shows the degradation chain of carbon tetrachloride → chloroform → methylene chloride → chloromethane → methanol/methane.	Carbon tetrachloride is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0) and a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Carbon tetrachloride is observed in subsurface soil at concentrations above the WRW PRG at seven sampling locations in the 12 to 30 ft depth interval at the historical IHSS 118.1 site south of the former Building 771. Carbon tetrachloride was detected above the WRW PRG in subsurface soil (refer to Section 8.4.2.2) and is a widespread constituent in groundwater. Mappable, contiguous carbon tetrachloride plumes are primarily found south of the former Building 771 (Carbon Tetrachloride Plume) (historical IHSS 118.1), the historical Mound Site/Oil Burn Pit No. 2,

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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
	Surface Water Carbon tetrachloride dissolved in water does not photodegrade or oxidize in any measurable amounts (Howard et al. 1991). The rate of hydrolysis is extremely slow, 1 to 2 orders of magnitude less than for other chlorinated alkanes (Haag and Yao 1992). Biodegradation occurs much more rapidly than hydrolysis, particularly under anaerobic conditions (Tabak et al. 1981). The degree of volatilization of a chemical from water depends on its vapor pressure and its water solubility and is best quantified by the Henry's Law constant (H) (Howard 1991). The larger the Henry's Law constant, the greater the CAH concentration in air relative to its aqueous concentration.	The aqueous aerobic half-life of carbon tetrachloride was estimated to be 6 to 12 months (Howard et al. 1991). The aqueous anaerobic half-life was estimated to be 7 to 28 days (Howard et al. 1991).	the historical East Trenches, the historical 903 Pad, the historical IA Plume Sources, historical 700 Area Northeast Plume Area, and at historical OU 1 (historical IHSS 119.1) (refer to Figure 4.8 in the nature and extent of groundwater contamination). Carbon tetrachloride occurrences above the surface water standard are primarily found at the former footing drain outfalls for former Buildings 771. A range of sorption (K_d) values has been calculated based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For carbon tetrachloride, K_d values at RFETS were calculated to range from 1.8×10^{-7} to 4.0×10^{-6} L/mg (K-H 2004a). None of the RFETS carbon tetrachloride plumes were considered to be at steady-state. However, an approximate biodegradation rate can be estimated by averaging the rates for 10 nonsteady-state carbon tetrachloride plumes. This estimated carbon tetrachloride biodegradation rate is 0.163 per year, which is 760 times slower than carbon tetrachloride biodegradation at non-RFETS sites (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details).
Chloroform (VOCs)	Subsurface Soil Because of its low soil adsorption and slight, but significant, water solubility, chloroform will readily leach from soil to groundwater. Based on data for degradation in water, chemical degradation in soil is not expected to be significant. The available data suggest that chloroform biodegradation rates in soil may vary, depending on conditions. Concentrations of chloroform above certain threshold levels may inhibit many bacteria (ATSDR 1997b). Groundwater Chloroform exhibits very high mobility. Volatilization is relatively unimportant from groundwater, except for very shallow groundwater, perhaps less than 1 meter below surface. The degree of volatilization of a chemical from water depends on its vapor pressure and water solubility and is best quantified by the Henry's Law constant (H) (Howard 1991). The larger the Henry's Law constant, the greater the CAH concentration in air relative to its aqueous concentration. Chemical hydrolysis is not a significant removal process. While microbial biodegradation can take place, such reactions are generally possible only at fairly low concentration levels because of chloroform's toxicity. Studies of natural waters and wastewaters yield a wide variety of results on the efficiencies of chloroform biodegradation. Under proper conditions, chloroform appears to be much more susceptible to anaerobic biodegradation, where it degrades to methylene chloride. These biodegradation reactions generally lead to mineralization of the chloroform to chlorides and carbon dioxide (Bouwer and McCarty 1983; Rhee and Speece 1992). Degradation under anaerobic conditions occurs faster at lower concentrations than at higher concentrations. Surface Water The dominant fate process for chloroform in surface water is volatilization. Chloroform is not expected to adsorb significantly to sediment or suspended organic matter in surface water (Sabljic 1984). Direct photolysis of chloroform will not be a significant degradation process because the compound does not absorb light at the necessary wavelengths (Hubrich and Stuhl 1980). Biodegradation in aerobic surface water is expected to be less than that under anaerobic	In the absence of toxicity from other solvents, chlorinated hydrocarbons, or heavy metals, and where chloroform concentrations can be held below approximately 100 ppb, both aerobic and anaerobic bacteria can biodegrade chloroform, with removal rates well over 80 percent in a period of 10 days (Long et al. 1993). It degrades to methylene chloride (see Figure 8.6). In surface water, chloroform will volatilize in a period of minutes to days (ATSDR 1997b).	Chloroform is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0) and a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The chloroform in subsurface soil is spatially similar to carbon tetrachloride, with concentrations above the WRW PRG at one sampling location at the historical IHSS 118.1 south of the former Building 771. A range of sorption (K_d) values has been calculated for chloroform based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For chloroform, K_d values at RFETS were calculated to range from 1.9×10^{-8} to 2.5×10^{-6} L/mg (K-H 2004a). An estimate of the biodegradation half-life of chloroform in RFETS groundwater is approximately 0.8 years, using the Buschek and Alcantar 1-dimensional estimation method (K-H 2004c) (considered to be at the low end of the range for half-

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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
	conditions.		life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details).
Methylene chloride (VOC)	Subsurface Soil Methylene chloride is not strongly sorbed to soils or sediments (Dilling et al. 1975; Dobbs et al. 1989). Methylene chloride is likely to be highly mobile in soils and may be expected to leach from soils to groundwater. The rate of biodegradation of methylene chloride in soils was found to be dependent on soil type, substrate concentration, and redox state of the soil. Methylene chloride biodegradation has been reported to occur under both aerobic and anaerobic conditions (Davis and Madsen 1991). The biodegradation of methylene chloride appears to be accelerated by the presence of elevated levels of organic carbon (Davis and Madsen 1991). It degrades to acetic acid or chloromethane. Groundwater/Surface Water Methylene chloride undergoes slow hydrolysis in water. Both aerobic and anaerobic biodegradation may be important fate processes for methylene chloride in water (Brunner et al. 1980; Davis et al. 1981; EPA 1985; Stover and Kincannon 1983; Tabak et al. 1981). Methylene chloride tends to volatilize to the atmosphere from water. The half-life under experimental conditions is 21 minutes, although in natural water is dependent on the rate of mixing, temperature, and other factors.	Methylene chloride has been observed to undergo degradation at a rapid rate under aerobic conditions. Reported total methylene chloride loss was 100 percent after 7 days in a static culture flask biodegradability screening test (Tabak et al. 1981) and 92 percent after 6 hours in a mixed microbial system (Davis et al. 1981). Volatilization loss was not more than 25 percent (Tabak et al. 1981). It degrades to acetic acid or chloromethane.	Methylene chloride is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0) and a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). The methylene chloride concentrations in subsurface soil are above the WRW PRG at one sampling location at the historical IHSS 118.1 south of the former Building 771. The one methylene chloride contiguous, mappable plume of methylene chloride is observed at the historical Carbon Tetrachloride Plume (historical IHSS 118.1 - refer to Figure 4.12 in the nature and extent of groundwater contamination). A range of sorption (K_d) values has been calculated based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For methylene chloride, K_d values at RFETS were calculated to range from 2.8×10^{-9} to 1.7×10^{-6} L/mg (K-H 2004a). An estimate of the biodegradation half-life of methylene chloride in RFETS groundwater is approximately 0.8 years, using the Buschek and Alcantar 1-dimensional estimation method (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details).
Tetrachloroethene Trichloroethene (VOCs)	Subsurface Soil CAHs are a group of VOCs in which chlorine atoms have replaced one or more hydrogen atoms in an alkane or alkene hydrocarbon compound. The alkenes are distinguished by a carbon-to-carbon double bond, while the alkanes contain only single bonds. Trichloroethene is the daughter product of the anaerobic degradation of tetrachloroethene (see Figure 8.6 for the full degradation of these CAHs). Both tetrachloroethene and trichloroethene have only low to moderate solubility in water and moderate to high mobility in soil. Because they are denser than water, the amount that does not volatilize into the atmosphere may sink and be transported into groundwater. Both trichloroethene and tetrachloroethene on surface soil will readily volatilize into the atmosphere or leach into the subsurface, although volatilization is less rapid from soil than from water. Once in the soil, trichloroethene does not appear to undergo chemical transformation or covalent bonding with soil components. Sorption of trichloroethene to soil particles is dependent on soil moisture, because water molecules compete with trichloroethene for sorption sites (Petersen et al. 1994). Volatilization and movement in the gas phase accounts for a large portion of trichloroethene movement in soils (Gimmi et al. 1993). For tetrachloroethene, studies found a direct relationship between the concentration of the chemical in soil and rate of volatilization, which contrasts with results seen in water (Zytner et al. 1989). In soil, biodegradation of both trichloroethene and tetrachloroethene are favored only under limited conditions. Biodegradation of trichloroethene increases with the	In soil, measured biodegradation rates have been variable; under methanogenic conditions, 100 percent transformation occurred after 10 days (Vogel and McCarty 1985). Measured and estimated volatilization half-lives of trichloroethene in water range from minutes to days. Volatilization from soil is somewhat slower, with experimental results showing 37 to 45 percent volatilization from soils after 7 days (Park et al. 1988). Tetrachloroethene also volatilizes rapidly. Volatilization half-lives from water ranged	Trichloroethene and tetrachloroethene are defined as surface soil and subsurface soil AOIs in the nature and extent of soil contamination (Section 3.0), as groundwater AOIs in the nature and extent of groundwater contamination (Section 4.0), and as surface water AOIs in the nature and extent of surface water and sediment contamination (Section 5.0). A range of sorption (K_d) values for tetrachloroethene has been calculated based on published (EG&G 1995) ranges of RFETS-specific soil parameters (organic matter content [f_{oc}] and clay content) and VOC partitioning constants. A linear sorption isotherm was assumed. For tetrachloroethene, K_d values at RFETS were calculated to range from 1.5×10^{-7} to 1.7×10^{-6}

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	organic content of the soil (Barrio-Lage et al. 1987). Degradation occurs faster in vegetated than in nonvegetated soils. Trichloroethene may inhibit total soil biomass and fungi, thus slowing biodegradation processes (Kanazawa and Filip 1986). Aerobic biodegradation of trichloroethene occurs by cometabolism with aromatic compounds, such as phenol or toluene. Trichloroethene may also be broken down by methanotrophs. A possible reason for the persistence of trichloroethene in the environment lies in the sensitive balance that must be maintained between enough cosubstrate to induce degrading enzymes and too much cosubstrate, which may inhibit decomposition. Such balance may rarely be achieved in nature (Ensley 1991). Tetrachloroethene is probably degraded to some extent in aerobic soil environments (Freedman and Gossett 1989; Milde et al. 1988; Parsons et al. 1985; Wakeham et al. 1983) but only to a limited degree. Degradation rates appear to vary with soil type, temperature, and initial concentration of the chemical (Yagi et al. 1992). <u>Groundwater / Surface Water</u> Neither oxidation nor hydrolysis of trichloroethene in aquatic environments appears to be significant fate process. Chemical hydrolysis only occurs at elevated temperatures in a high pH environment and, even then, at a very slow rate. Biotransformation is strongly indicated as a factor in the degradation of trichloroethene in groundwater. Reductive dehalogenation is the primary reaction (Parsons et al. 1985; Wilson et al. 1986). Tetrachloroethene does not readily transform in water. Photolysis does not contribute substantially to the transformation of tetrachloroethene and chemical hydrolysis occurs only slowly at elevated temperatures in high pH environments, much like trichloroethene (Chodola et al. 1989). In natural waters, biodegradation may be the most important transformation process for tetrachloroethene; however, this occurs only slowly (Bouwer and McCarty 1982; Bouwer et al. 1981; Wakeham et al. 1983). Degradation occurs largely due to reductive dehalogenation by microorganisms. Since neither biodegradation nor hydrolysis occurs at a rapid rate, most trichloroethene and tetrachloroethene in surface waters can be expected to volatilize into the atmosphere.	from 4.2 hours to 25 days in various studies (Dilling et al. 1975; Thomas 1982; Wakeham et al. 1983). Like trichloroethene, volatilization from soil is slower, with losses from soil between 10- and 100-fold slower than from water (Park et al. 1988; Zytner et al. 1989). It degrades to trichloroethene. Biodegradation of trichloroethene in water was measured at 80 to 90 percent after 1 to 4 weeks in various studies (Jensen and Rosenberg 1975; Tabak et al. 1981). Biodegradation in soils was highly variable and ranged from no degradation after 16 weeks (Wilson et al. 1983) to 100 percent transformation after 10 days (Vogel and McCarty 1985). Biodegradation of tetrachloroethene is described as “slow” in the literature and, at least for one aquifer in England, it has been estimated that tetrachloroethene will likely persist for decades (Lawrence et al. 1990). The RFETS estimate is that the VOCs could persist for decades to hundreds of years (see Attachment 1 for more details).	L/mg, and for trichloroethene, were calculated to range from 5.0 x 10^{-8} to 3.0 x 10^{-6} L/mg (K-H 2004a). An estimate of the biodegradation half-life of tetrachloroethene in RFETS groundwater is approximately 11 years, using the Buschek and Alcantar 1-dimensional estimation method (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details). Estimates of the biodegradation half-life of trichloroethene in RFETS groundwater fall in a wide range, starting with approximately 22 years, using the Buschek and Alcantar 1-dimensional estimation method (K-H 2004c) (considered to be at the low end of the range for half-life estimates). Based on data and numerical modeling at RFETS, it is likely that inferred VOC sources and associated downgradient groundwater concentrations will persist for decades to hundreds of years, if not longer, even with source removal (considered to be the upper range for half-life estimates) (see Attachment 1 for details).
1,1,2,2-Tetrachloroethane (VOCs)	<u>Subsurface Soil</u> CAHs are a group of VOCs in which chlorine atoms have replaced one or more hydrogen atoms in an alkane or alkene hydrocarbon compound. The alkanes contain only single bonds. If released to soil, some of the 1,1,2,2-tetrachloroethane would be expected to volatilize, with the remainder leaching into the subsurface soil and possibly groundwater. 1,1,2,2-Tetrachloroethane will not adsorb appreciably to soil. Both hydrolysis and anaerobic biodegradation appear to be significant transformation processes in soil and sediments. Hydrolysis is sensitive to pH and occurs faster under neutral or basic conditions. 1,1,2,2-Tetrachloroethane slowly degrades by losing chlorine atoms. The resulting chemicals include 1,1,2-trichloroethane, 1,2-dichloroethane, and chloroethanol (K-H 2004c).	Limited information is available on the half-life of 1,1,2,2-tetrachloroethane in soil. One study showed between 34 percent and 74 percent transformation in a 6-day period, with the results varying with pH. In groundwater, the half-life is estimated at 13 weeks (ATSDR 1996). 1,1,2,2-Tetrachloroethane degrades to 1,1,2-trichloroethane (see Figure 8.6 for the full degradation chain).	1,1,2,2-Tetrachloroethane is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). 1,1,2,2-Tetrachloroethane is an AOI in subsurface soil only. 1,1,2,2-tetrachloroethane is detected in subsurface soil at concentrations above the WRW PRG at one location at the historical IHSS 118.1 site south of the former Building 771.
Aluminum (Al) (Metal)	<u>Surface Soil</u> The aluminum content of soils is strongly correlated with their clay content (Ma et al. 1997). Aluminum is present in many primary minerals. The weathering of these primary minerals over time results in the deposition of sedimentary clay minerals, such as the aluminosilicates kaolin and montmorillonite (ATSDR 1999). The adsorption of aluminum onto clay surfaces can be a significant factor in controlling aluminum mobility in the environment, and these adsorption reactions, measured in one study at pH 3.0-4.1, have been observed to be very rapid (Walker et al. 1988). However, clays may act either as a sink or a source for soluble aluminum depending on the degree of aluminum saturation on the clay surface (Walker et al. 1988). <u>Surface Water</u> Aluminum partitions between solid and liquid phases by reacting and complexing with water molecules and anions such as chloride, fluoride, sulfate, nitrate, and phosphate, and negatively charged functional groups on humic materials and clay. In groundwater or surface water systems, an equilibrium with a solid phase or form is established that largely controls the extent of aluminum dissolution that can occur.	Aluminum is a stable metal; it does not degrade in the environment. Thus it will persist indefinitely. In addition, aluminum compounds occur in only one oxidation state, Al(+3). Aluminum can complex with electron-rich species that occur in the environment (ATSDR 1999).	Aluminum is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). In surface soil, aluminum has been detected throughout the former IA (in the former 400 and 700 areas), and at limited locations throughout the BZ OU (East Firing Range), although not necessarily at concentrations that are statistically higher than background concentrations (see Section 3, Nature and Extent of Soil Contamination). Dissolved aluminum occurrences above the surface water standard are primarily found at the former footing drain outfall (SW085) of former Building 779 and SW061 along South Walnut Creek below the

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	Bioconcentration of aluminum has also been reported for several aquatic invertebrate species as well as for aquatic insects. Accumulation of aluminum in mayfly nymphs has been reported at low pH (4.5) (Frick and Herrmann 1990). Within the pH range of 5-6, aluminum complexes with phosphate and is removed from solution. Because phosphate is a necessary nutrient in ecological systems, this immobilization of both aluminum and phosphate may result in depleted nutrient states in surface water (Brusewitz 1984). In general, decreasing pH (acidification) results in an increase in mobility for monomeric forms of aluminum (Goenaga and Williams 1988).		former SEP Pond 207-C.
Arsenic (As) (Metals)	<u>Surface Soil</u> Arsenic in soil may be transported by wind or in runoff or may leach into the subsurface soil. However, because many arsenic compounds tend to partition to soil or sediment under oxidizing conditions, leaching usually does not transport arsenic to any great depth (EPA 1982b; Moore et al. 1988; Pantsar-Kallio and Manninen 1997; Welch et al. 1988). Arsenic is largely immobile in agricultural soils; therefore, it tends to concentrate and remain in upper soil layers indefinitely. Downward migration has been shown to be greater in a sandy soil than in a clay loam (Sanok et al. 1995). Terrestrial plants may accumulate arsenic by root uptake from the soil or by absorption of airborne arsenic deposited on the leaves, and certain species may accumulate substantial levels (EPA 1982b). Yet even when grown on highly polluted soil or soil naturally high in arsenic, the arsenic level taken up by the plants is comparatively low (Gebel et al. 1998; Pitten et al. 1999). The arsenic cycle in soils is complex, with many biotic and abiotic processes controlling its overall fate and environmental impact. Arsenic in soil exists in various oxidation states and chemical species, depending upon soil pH and redox potential (ATSDR 2000a). <u>Groundwater</u> Elemental arsenic is the least soluble in water and the least toxic. Arsenic may also be removed from water by coprecipitation with iron oxides or by isomorphic substitution with phosphorus in minerals. Arsenic in water can undergo a complex series of transformations, including oxidation-reduction reactions, ligand exchange, precipitation, and biotransformation (EPA 1979, 1984a; Sanders et al. 1994; Welch et al. 1988). Rate constants for these various reactions are not readily available, but the factors most strongly influencing fate processes in water include Eh (the oxidation-reduction potential), pH, metal sulfide and sulfide ion concentrations, iron concentrations, temperature, salinity, and distribution and composition of the biota (EPA 1979; Wakao et al. 1988). <u>Sediment</u> Most arsenic compounds are strongly sorbed by sediments and are relatively immobile. Adsorption on hydrous iron oxides (Pierce and Moore 1980), clays, aluminum hydroxides, manganese oxides, and organic materials or coprecipitation (EPA 1995), or combination with sulfide in reduced bottom sediments (Kobayashi and Lee 1978), appear to be the major inorganic factors that control arsenic concentrations under most environmental conditions. Because many arsenic compounds are strongly sorbed onto sediments, leaching by precipitation usually results in limited transport (EPA 1995).	Arsenic is a stable metal; it does not degrade in the environment. Thus it will persist indefinitely.	Arsenic is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0) and as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). It is also defined as a COC for surface soil/sediment in the IAEU and WBEU. Arsenic is detected in surface soil throughout the former IA (in the former 400 and 700 areas and the former SEP area), in the three major RFETS watersheds that receive runoff from the former IA (North Walnut Creek, South Walnut Creek, and SID/Woman Creek drainages), reflecting the natural abundance of arsenic in soil. A contiguous, mappable dissolved arsenic plume in UHSU groundwater is shown on Figure 4.16 in the nature and extent of groundwater contamination and is present only at the Present Landfill. Because RFETS groundwater is generally oxic (i.e., well oxygenated), arsenate is likely the predominant dissolved arsenic species in site waters. However, under locally reducing conditions arsenite may dominate in groundwater contaminant plumes or surface water bottom sediments. Elemental arsenic and arsine are not expected in RFETS groundwater. If past arsenic releases occurred at RFETS, sorption or coprecipitation appears to be the predominant transport-control mechanism at RFETS since no discernable arsenic contaminant plumes are observed in groundwater. Arsenic associated with the historical PU&D Yard in groundwater may have been liberated upon insertion of HRC$^{®}$ at the historical PU&D Yard.
Beryllium (Be) (Metal)	<u>Surface Water</u> Beryllium metal is used as a hardener in alloys. There is little information available on the environmental fate of beryllium and its compounds. Beryllium compounds of very low water solubility appear to predominate in soils. Leaching and transport through soils to groundwater appears unlikely to be of concern. Water erosion and bulk transport of soil may bring beryllium to surface waters, but most likely in particulate rather than dissolved form (EPA 1998b, 2005). Beryllium exhibits only the +2 oxidation state in water. In the pH range of 6-8, typical of most waters, the speciation of beryllium is controlled by the formation solid beryllium hydroxide, $Be(OH)_2$, which has a very low solubility (solubility product, $K_{sp}=10^{-21}$).	Beryllium is stable and does not degrade in the environment.	In former Building 447 materials handled included beryllium. Beryllium was a primary material used in pit construction in former Building 707. In former Building 444, beryllium was chemically milled. On November 25, 2002, there was a spill of low-level mixed waste from the RCRA-regulated Tank T231A (located south of former Buildings 371/374) sludge removal operation. The spill did not contain any detectable levels of beryllium. However, original sampling data from the 231A tank indicated levels of 0.2 to 0.3 ug/L of beryllium (K-H 2005c).
Total Chromium (Metal)	<u>Surface Soil / Subsurface Soil</u> Chromium in soil is present mainly as insoluble oxide (EPA 1984b), and is not very mobile in soil. A leachability study was conducted to study the mobility of chromium in soil. Due to different pH values, a complicated adsorption process was observed and chromium moved only slightly in soil. Chromium has a low mobility for translocation from roots to aboveground parts of plants (Cary 1982). However, depending on the geographical areas where the plants are	Chromium is a stable metal; it does not degrade in the environment. Thus it will persist indefinitely.	Chromium is defined as a surface and subsurface soil AOI in the nature and extent of soil contamination (Section 3.0), a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0), and a sediment AOI in the nature and extent of surface water and sediment contamination (Section

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	grown, the concentration of chromium in aerial parts of certain plants may differ by a factor of 2 to 3 (Cary 1982). EPA (1999) concluded that Cr(III) concentrations in soils are controlled by precipitation and dissolution (mineral solubility), and adsorption reactions are not significant in soil Cr(III) chemistry. This seems to be at odds with Rai et al. (1984), who believe that Cr(III) is sorbed by soils because several important Cr(III) species are cations. The strength of Cr(VI) sorption on soils seems to decrease (smaller K_ds) with increasing pH (EPA 1999). Manganese oxides in soil can oxidize Cr(III) to Cr(VI) yielding lower Kd values, while iron oxides can reduce Cr(VI) to Cr(III) causing precipitation and high K_ds (EPA 1999). The fate of chromium in soil is greatly dependent upon the speciation of chromium, which is a function of redox potential and the pH of the soil. In most soils, chromium will be present predominantly in the Cr(III) state. This form has very low solubility and low reactivity resulting in low mobility in the environment and low toxicity in living organisms (Barnhart 1997). Groundwater / Surface Water / Sediment Under oxidizing conditions Cr(VI) may remain dissolved as the chromate anion, and may be highly mobile in groundwater for long periods of time. A number of Cr(VI) solid phases have been detected at sites having extensive chromate contamination in groundwater, including $CaCrO_4$, $PbCrO_4$ (crocoite), K2CrO4 (tarapacaite), and $BaCrO_4$ (Palmer and Puls 1994). Cr(III) "is immobile under moderately alkaline to slightly acidic conditions" (EPA 1999, p. 5.18). Cr(VI) is sorbed by iron oxides in acidic waters and acidic soils, but is very mobile in neutral and alkaline waters (Rai et al. 1984; EPA 1999). Cr(VI) is more mobile because its aqueous species are anions which are less strongly sorbed on common minerals. Chromium speciation in groundwater depends on the redox potential and pH conditions in the aquifer. Cr(VI) predominates under highly oxidizing conditions, whereas Cr(III) predominates under reducing conditions. Oxidizing conditions are generally found in shallow aquifers, and reducing conditions generally exist in deeper groundwater. The reduction of Cr(VI) and the oxidation of Cr(III) in water have been investigated. The reduction of Cr(VI) by S^{-2} or Fe^{+2} ions under anaerobic conditions was fast, and the reduction half-life ranged from instantaneous to a few days. The reaction was generally faster under anaerobic than aerobic conditions. The reduction half-life of Cr(VI) in water with soil and sediment ranged from 4 to 140 days (Saleh et al. 1989). The fate of most chromium in rivers and lakes is believed to be deposition in sediments through precipitation and sorption processes (ATSDR 2000b).		5.0). Total (unfiltered) chromium in surface soil is distributed throughout the former IA (most notably in the former 400 and 700 Areas) at concentrations that exceed the WRW PRG. Total chromium has been identified as having contiguous, mappable plumes in the Carbon Tetrachloride Plume, the historical East Trenches, historical Ryan's Pit, and former OU 1 areas (refer to Figure 4.17 in the nature and extent of groundwater contamination). Numerous locations exist with sediment sample results above the chromium WRW PRG (28417.9 µg/kg), including locations across the former IA and in the North Walnut Creek drainage (at Ponds A-1, A-2, A-3), South Walnut Creek drainage (Pond B-4), and the Woman Creek drainage (Pond C-1). Chromium occurrences were observed in surface water background (above surface water standards) at station GS06 (Owl Branch to Woman Creek) and at SW134 (pumped water from gravel mining operations that is discharged to Rock Creek). However, it is also observed in background in surface water, suggesting that elevated chromium in surface water results from background concentrations in the soil. A portion of the chromium observed in groundwater may be attributable to stainless-steel well casings, pump parts, and well tubing stabilizers (Boylan 2004a, 2004b) (see Figure 8.7). For groundwater transport of Cr(VI) at RFETS, the K_ds measured in the pH range 6.5 to 8.5 are most applicable. At these pHs, data indicate low K_ds near 1, or in the single digits, implying that Cr(VI) should exhibit high to moderate mobility (i.e., weak retardation). A chromic acid spill from the former Building 444 basement was contained in the B-Ponds and pumped to Upper Church Ditch where it was below surface water standards. Chromium was identified in ChemRisk reports and was evaluated for potential off-site impacts; none were found (K-H 2005c).

Table 8.2
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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
Lead (Metals)	Subsurface Soil Most lead is retained strongly in soil, and very little is transported into surface water or groundwater (EPA 1986). Plants and animals may bioconcentrate lead but biomagnification has not been detected. Although the bioavailability of lead in soil to plants is limited because of the strong absorption of lead to soil organic matter, the bioavailability increases as the pH and the organic matter content of the soil are reduced. Most lead is retained strongly in soil, and very little is transported into surface water or groundwater (EPA 1986; NSF 1977). Lead is strongly sorbed to organic matter in soil, and although not subject to leaching, it may enter surface waters as a result of erosion of lead-containing soil particulates. The fate of lead in soil is affected by the specific or exchange adsorption at mineral interfaces, the precipitation of sparingly soluble solid forms of the compound, and the formation of relatively stable organic-metal complexes or chelates with soil organic matter. These processes are dependent on such factors as soil pH, soil type, particle size, organic matter content of soil, the presence of inorganic colloids and iron oxides, cation exchange capacity (CEC), and the amount of lead in soil (NSF 1977; Reddy et al. 1995; Royer et al. 1992). Surface Water A significant fraction of lead carried by river water is expected to be in a solid form, which can consist of colloidal particles or larger particles of lead carbonate, lead oxide, lead hydroxide, or other lead compounds incorporated in other components of surface particulate matter from runoff. Lead may occur either as sorbed ions or surface coatings on sediment mineral particles, or it may be carried as a part of suspended living or nonliving organic matter in water. In most surface water and groundwater, the concentration of dissolved lead is low because the lead will form compounds with anions in the water such as hydroxides, carbonates, sulfates, and phosphates that have low water solubilities and will precipitate out of the water column (Mundell et al. 1989). The chemistry of lead in aqueous solution is highly complex because this element can be found in multiple forms. Lead has a tendency to form compounds of low solubility with the major anions found in natural waters. The amount of lead in surface waters is dependent on the pH and the dissolved salt content of the water. In water, tetraalkyl lead compounds are subject to photolysis and volatilization with the more volatile compounds being lost by evaporation. Degradation proceeds from trialkyl lead to dialkyl lead to inorganic lead. Tetraethyl lead is susceptible to photolytic decomposition in water. Triethyl and trimethyl lead are more water-soluble and therefore more persistent in the aquatic environment than tetraethyl or tetramethyl lead. The degradation of trialkyl lead compounds yields small amounts of dialkyl lead compounds.	Lead is a stable metal; it does not degrade in the environment. Thus it will persist indefinitely.	Lead is defined as a subsurface soil AOI in the nature and extent of soil contamination (Section 3.0). Lead in subsurface soil at concentrations above the WRW PRG is detected in the South Walnut Creek basin (former 400 Area) and Woman Creek basin (historical Ash Pits and historical firing ranges on the north and south sides of Woman Creek). Lead was used in the former plutonium operation buildings and at the former firing ranges. It was evaluated in the ChemRisk reports for off-site impacts; none were reported. Lead was identified in soil above ALs near former Building 441 and the firing ranges (K-H 2005c). Background lead above the surface water standard is primarily found at GS06 (Owl Branch to Woman Creek) and SW134 (pumped water from gravel mining operations that is discharged to Rock Creek).
Nickel (Metals)	Groundwater Nickel in most natural waters is predominantly divalent as the Ni^{2+} cation, although nickel forms aqueous complexes with hydroxide, sulfate, and bicarbonate (ATSDR 2003b). After Ni^{2+} the ion pair $NiSO_4^0$ is an important aqueous nickel species in sulfate-rich groundwater. Under aerobic conditions, solid nickel ferrite ($NiFe_2O_4$), and under anaerobic conditions millerite (NiS), may limit the solubility of nickel to low concentrations (Rai et al. 1984). Nickel can also coprecipitate with manganese oxides and iron oxides. Nickel removed from solution by coprecipitation can be remobilized by microbial action (ATSDR 2003a). Nickel is reportedly “strongly” sorbed by alkaline soils, and this sorption may be irreversible (Rai et al. 1984). Iron and manganese oxides (e.g., goethite) appear to be the most important adsorbents of nickel, followed by clay minerals (Rai et al. 1984). Competition for adsorption sites by cations (such as Ca^{2+} and Na^+) has been shown to reduce nickel sorption by soils and clays (Rai et al. 1984). The experimentally measured K_d values for sorption of nickel on various soil compositions are often very low, less than 1 mL/g. However, higher K_ds have been measured for nickel sorption in a range of sandy sediments in the Danish Beder aquifer (Larsen and Postma 1997). Those workers found that nickel is more strongly sorbed on manganese oxides than on iron oxides in sediments, and measured K_ds of 68, 160, and 212 mL/g at pH 6.75, 7.27, and 7.44, respectively. The K_d range of 1 to 212 mL/g is very wide in terms of mobility. Surface Water Nickel is a natural constituent of soil and is transported into streams and waterways in runoff either from natural weathering or from disturbed soil. Much of this nickel is associated with particulate matter. Gravitational settling governs the removal of large particles (>5 µm), whereas smaller particles are removed by other forms of dry and wet deposition (ATSDR 2003b). The fate of heavy metals in aquatic systems depends on partitioning between soluble and particulate solid phases. Adsorption, precipitation, coprecipitation, and complexation are processes that affect partitioning. These same processes, which are influenced by pH, redox potential, the ionic strength of the water, the concentration of complexing ions, and the metal concentration and type, affect the adsorption of heavy metals to soil (Richter and Theis 1980). Nickel is strongly adsorbed at mineral surfaces such as oxides and hydrous oxides of iron, manganese, and aluminum (Evans 1989; Rai et al. 1984). Such adsorption plays an important role in controlling the concentration of nickel in natural waters.	Nickel is a stable metal; it does not degrade in the environment. Thus it will persist indefinitely.	Nickel is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of dissolved nickel are present south of the historical Ryan’s Pit and near former Building 850 (refer to Figure 4.18 in the nature and extent of groundwater contamination). Total nickel plumes are in the historical SEPs and historical Ryan’s Pit areas. Nickel plating was conducted in the 700 Area buildings. It was evaluated by ChemRisk reports. The results indicate limited use of nickel on site and the material forms are not expected to have off-site releases (K-H 2005c). Assuming that the low organic carbon contents of soils are similar to the generally low carbon soils at RFETS, nickel mobility is expected to be high to very high in UHSU groundwater. A portion of the nickel observed in groundwater may be attributable to stainless-steel well casings, pump parts, and well tubing stabilizers (Boylan 2004a, 2004b).
Vanadium (Metal)	Surface Soil Vanadium is a compound that occurs in nature as a white-to-gray metal, and is often found as crystals. Pure vanadium has no smell. It usually combines with other elements such as oxygen, sodium, sulfur, or chloride. Vanadium and vanadium compounds can be found in the earth's crust and in rocks, some iron ores, and crude petroleum deposits. Vanadium is mostly combined with other metals to make special alloys. Small amounts of vanadium are used in making rubber, plastics, ceramics, and other chemicals.	Vanadium is stable and does not degrade in the environment. Thus it will persist indefinitely.	Vanadium is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). It is also defined as a COC for surface soil/sediment in the No Name Gulch Drainage EU. Vanadium is identified as an AOI in surface soil only. Sampling locations above the WRW PRG are localized in the

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	Studies suggest that vanadium is fairly immobile in soil. A field study conducted over 30 months examined movement of vanadium added to the top 7.5 centimeters of coastal plain soil and its availability to bean plants. Less than 3 percent of applied metal moved down the soil profile. Extractable concentrations decreased over the first 18 months of the study and remained constant thereafter (Martin and Kaplan 1998). In fresh water, vanadium is transported in solution and as particulate transport (dominant process) (WHO 1988).		areas of the historical PU&D Yard and historical Oil Burn Pit No. 1. Pit construction in former Building 707 generally used plutonium, uranium, beryllium, aluminum, and stainless steel. However, in some instances more exotic materials such as vanadium were used. The metallurgical operations in former Building 865 involved the development of alloys in the 1970s, which included the use of vanadium. Vanadium was also identified as associated with metalworking in former Building 444. In former Building 447 materials handled included vanadium compounds (K-H 2005e).
PAHs: Benzo(a)anthracene Benzo(a)pyrene (SVOCs)	Surface Soil / Subsurface Soil / Sediment PAHs in soil can volatilize, undergo abiotic degradation (photolysis and oxidation), biodegrade, or accumulate in plants. PAHs in soil can also enter groundwater and be transported within an aquifer. The K_{oc} of a chemical is an indication of its potential to bind to organic carbon in soil and sediment. High-molecular-weight PAHs (such as the AOIs in RFETS surface soils) have K_{oc} values in the range of 105 to 106, which indicates stronger tendencies to adsorb to organic carbon (Southworth 1979). PAHs may volatilize from surface soil to air, although volatilization was not an important loss mechanism for benzo(b)fluoranthene, dibenz(a,h)anthracene, or benzo(a)pyrene (Park et al. 1990). Ratios of PAH concentrations in vegetation to those in soil have been reported to range from 0.001 to 0.18 for total PAHs and from 0.002 to 0.33 for benzo(a)pyrene (Edwards 1983).	Microbial metabolism is the major process for degradation of PAHs in soil environments. Photolysis, hydrolysis, and oxidation are generally unimportant processes for the degradation of PAHs in soils. Although differences exist in estimates of biodegradation half-lifes by different investigators, their results suggest the biodegradation half-lives of PAHs with more than three rings will be considerably longer (>20 days to hundreds of days) than PAHs with three or fewer rings.	Dibenz(a,h)anthracene is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0). Dibenz(a,h)anthracene is detected as an AOI in surface soil only. Results above the WRW PRG are observed throughout the former IA (most notably in the former 700 Area and the former Oil Burn Pit No. 1 area) and in the Original Landfill area. Benzo(a)pyrene is defined as a surface soil AOI in the nature and extent of soil contamination (Section 3.0) and a sediment AOI in the nature and extent of soil contamination (Section 5.0). It is also defined as a COC for surface soil/sediment in the IA, Upper Woman Drainage, and Upper Walnut Drainage EUs. Benzo(a)pyrene is present in surface soil throughout the IA OU (most notably in the former 400 and 800 areas), along the hillside north of the SID (in the former Building 881 Hillside area), and in the areas of the Present Landfill and Original Landfill. Benzo(a)pyrene exist in sediment across the former IA and in the South Walnut Creek drainage with sediment sample results above the benzo(a)pyrene WRW PRG (378.9 µg/kg). For the specific PAH AOIs identified in RFETS soils, all having more than three rings, longer biodegradation half-lives (e.g., greater than 20 days to hundreds of days) are expected (ATSDR 1995).
PCBs (Aroclors): PCB-1254 PCB-1260	Surface Soil / Subsurface Soil PCBs are strongly sorbed to soils as a result of low water solubility and high K_{ow} (6.5 and 6.8 for PCB-1254 and PCB-1260, respectively), and will not leach extensively (Sklarew and Girvin 1987). The tendency to leach will be greatest among the least chlorinated congeners and is expected to be greatest in soil with low organic carbon (Sklarew and Girvin 1987). Leaching of PCBs in most soils should not be extensive, particularly for the more highly chlorinated congeners (e.g., PCB-1254 and PCB-1260).	PCBs tend to persist in the environment with half-lives on the order of months to years (Gan and Berthouex 1994; Kohl and Rice 1998). There is no abiotic process known that significantly degrades PCBs in soil and sediment. Biodegradation has been shown to occur under both aerobic and anaerobic conditions and is a major degradation process for PCBs in soil and sediment. Aerobic biodegradation of PCBs in the environment occurs mainly in soils and surficial sediments. PCB congeners with five or more chlorines (major	PCB-1254 and PCB-1260 are both defined as surface soil AOIs in the nature and extent of soil contamination (Section 3.0). Both PCBs that are surface soil AOIs, PCB-1254 and PCB-1260, are detected above the WRW PRG in localized areas in the former IA (most notably at the former Building 771 area, east of the former SEPs, as well as near former Buildings 444, 883, and 964) and in the BZ OU (at the Original Landfill and former PU&D Yard areas). PCB-1254 is an AOI in surface soil only. PCB-1260 is an AOI in surface and subsurface soil. PCB-1260 is detected in subsurface soil above the WRW PRG in a localized portion of the former 700

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		components in PCB-1254 and PCB-1260) are not readily degraded and considered to be persistent (EPA 1979). PCBs are slowly biodegraded in anaerobic environments by reductive dechlorination resulting in the formation of less toxic congeners, which are aerobically biodegradable (EPA 1983).	Area, specifically in the area of former Building 776. PCBs are relatively nonsoluble and nonvolatile. In general, the higher the degree of chlorination, the less volatile the PCB congener. At RFETS, the Aroclors with more highly chlorinated congeners were largely used (e.g., PCB-1254 and PCB-1260). Therefore, volatilization is not likely to be significant.
2,3,7,8-TCDD TEQ (Dioxins/Furans)	Surface Soil “2,3,7,8-TCDD TEQ represents the total toxicity equivalency for the combined toxicity resulting from a mixture of dioxin-like compounds” (Kearney et al. 1971). Generally, dioxins are characterized by low vapor pressure, low aqueous solubility, and high hydrophobicity, suggesting that these compounds strongly adsorb to soil and that their vertical mobility in the terrestrial environment is low (Eduljee 1987). Because dioxins strongly adhere to soil and exhibit low solubility in water, leaching of dioxins would be unlikely if water were the only transporting medium. Instead, wind and water erosion can cause the mixing and transport of dioxin-contaminated soil. As a result of erosion, surface soil contaminated with dioxins is either blown away by wind or washed via surface water runoff into rivers, lakes, and streams, with burial in the sediments being the predominant fate of dioxins sorbed to soil (Hutzinger et al. 1985).	Degradation of dioxins in soil is relatively slow (e.g., half-lives on the order of 20 years). Measurements of 2,3,7,8-TCDD TEQ residues after 20, 40, 80, 160, and 350 days of incubation at 28 °C in foil-sealed beakers indicated a relatively slow degradation process in both soils. After 350 days, 56 percent of the initially applied 2,3,7,8-TCDD TEQ was recovered from the sandy soil, while 63 percent was recovered from the silty clay loam for all concentrations (Kearney et al. 1971).	At RFETS, the earlier soil samples identified with dioxin concentrations that exceeded the WRW PRG were located at the former incinerator, but after demolition are now buried approximately 20 ft below grade. Due to the very low mobility of dioxins, transport to other environmental media is not considered likely.
Fluoride (Water Quality Parameters)	Groundwater Fluoride is usually less abundant in natural waters than chloride. Fluoride concentrations in groundwater exist both as the uncomplexed fluoride ion (F^-), and in complexes with metals. Fluoride forms particularly strong complexes with dissolved aluminum (e.g., AlF_2^+ and AlF_3^0). These aluminum-fluoride complex ions may predominate in acid solution at pH values <5.5, while the fluoride anion dominates at neutral and alkaline pHs. The concentration of fluoride in groundwater may also be limited by the solubility of fluorite, or by coprecipitation with calcite, but no evidence of this was found in the literature. Most fluoride compounds are very soluble in water. Fluorite solubility has been shown to control fluoride concentrations in geothermal waters (Nordstrom and Jenne 1977). Fluorite is a widespread mineral in nature and it is known to precipitate in recent estuarine sediments (Krumgalz et al. 1990). The strength of fluoride sorption by soils is unclear. ATSDR (2003a, p. 215) states that “fluoride is strongly retained by soil leaching that removes only a small amount of fluorides from soils.” However, Rai et al. (1984, p. 12-1) states that “fluoride is not strongly adsorbed by soils,” but the maximum sorption takes place at pH 4 to 6.5. If the soil does not contain the mineral fluorite, then the aqueous fluoride concentration is still likely to be controlled by sorption-desorption reactions (Rai et al. 1984). The degree of sorption correlates with the Al oxide content of the soil. Maximum adsorption takes place at various pH values, which depend on the adsorbent. The greatest sorption of fluoride on goethite takes place at pH 3 to 4, while on montmorillonite clay the maximum is between pH 6 and 7 (Rai et al. 1984). The $Al(OH)_3$ mineral gibbsite has a high adsorption capacity for fluoride. The halide anions (chloride, fluoride, and iodide) share similar chemistry and may be assumed to have similar sorption behavior. In transport numerical modeling, chloride is usually treated as a conservative solute that does not undergo significant retardation. Thus chloride is assumed to have a K_d of 0.	Fluoride is quite persistent in the environment because it forms strong complexes with aluminum and its water chemistry is regulated by aluminum concentration and pH (ATSDR 2003a).	Fluoride is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Three small contiguous, mappable plumes of fluoride are observed in UHSU groundwater at locations south of former Building 707 area, at the historical OU 1, and south of historical SEP area (refer to Figure 4.21 in the nature and extent of groundwater contamination) though the data are at least 8 to 10 years old. New sources of residual fluoride are not expected at these locations and, based on the quasi-steady-state conditions found for other constituent plumes at the site, fluoride concentrations in groundwater should be currently stable or decreasing and thus are not considered a threat to surface water quality. An extensive literature search and summary of K_d values for sorption of iodide on smectite clays was performed by Lindberg and Henry (2000). Smectites are common clays with large CECs. The median K_d for iodide sorption on smectites was only 1.0 mL/g based on 41 measurements in the pH range 7 to 8.5 (similar to RFETS environment). This information implies high mobility for both iodide and fluoride in groundwater at RFETS.
Nitrate/Nitrite (as N) (Water Quality Parameters)	Groundwater / Surface Water Naturally occurring nitrates in soil, surface water, and groundwater result from the decomposition by microorganisms of organic nitrogenous material such as the protein in plants, animals, and animal excreta. The natural occurrence of nitrates and nitrites in the environment is a consequence of the nitrogen cycle. However, nitrites are generally only found in very low concentrations because most environments are oxic which favors the nitrate anion. Most nitrate-bearing salts and minerals are highly soluble in water. Therefore, nitrate concentrations in waters are generally not limited by solubility constraints (Freeze and Cherry 1979). From a transport perspective, nitrate is considered a conservative constituent, like chloride, because it is not readily sorbed (i.e., retarded) and generally migrates at the same rate as groundwater flow with little attenuation (Freeze and Cherry 1979; Fetter 1988). As a result, nitrate in soil is expected to be highly soluble and nitrate in groundwater should have very high mobility. However, in heavily vegetated areas, nitrate is taken up by plants which effectively retards	In groundwater at near-neutral pH, like at RFETS, nitrate is not typically attenuated and thus persists indefinitely unless there is a reduction in redox potential so that denitrification can occur (Canter 1997).	Nitrate/Nitrite is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of nitrate/nitrite (as N) exist in the North Walnut Creek drainage in the historical SEP area, former 700 Area Northeast Plume area, and above Pond A-1. In the South Walnut Creek drainage, contiguous, mappable plumes of nitrate/nitrite (as N) exist, at the historical 903 Pad and historical OU 1 areas (refer to

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Analyte (Analyte Group)	General Behavior Characteristics for Affected Media at RFETS	Persistence in the Environment	Rocky Flats-Specific Characteristics
	its transport in shallow groundwater (Drever 1988; Hem 1985).		Figure 4.22 in the nature and extent of groundwater contamination). Because RFETS UHSU groundwater is generally oxic (that is, well oxygenated) and nitrite is easily oxidized to nitrate, nitrate is likely the predominant dissolved nitrogen species in site waters. However, local areas of detectable nitrite may occur where the groundwater is anoxic and reducing conditions exist. It is noted that the applicable nitrate standard until December 31, 2009, is 100 mg/L, at which time the temporary modification, which applies to segment 5 only, expires and the 10-mg/L standard goes into effect.
Sulfate (Water Quality Parameters)	<u>Groundwater</u> Sulfur occurs in several oxidation states in natural groundwater systems ranging from S^{-2} to S^{+6}. Its chemical behavior is therefore strongly related to the redox properties of groundwater. The most highly oxidized form of sulfur is sulfate (SO_4^{-2}), which is the most likely aqueous sulfur species at RFETS given the highly oxygenated groundwater in the UHSU. The reduced ion, sulfide (S^{-2}), forms sulfide minerals of low solubility with most metals. Because iron is common and widely distributed, the iron sulfides have a substantial influence on sulfur geochemistry in highly reduced groundwater systems. Sulfate is a ubiquitous and important anion in natural waters. In natural waters above pH 4, it is the predominant form of aqueous sulfur (+6). Sulfate is itself a complex ion, but it displays a strong tendency to form other complex aqueous species. It forms ion pairs with many cations, such as $CaSO_4^0$, $MgSO_4^0$, $NaSO_4^-$, $FeSO_4^0$, and $AlSO_4^+$. As sulfate concentrations increase, an increasing proportion of the sulfate in solution forms ion pairs. Sulfate is very stable in oxidizing waters, although sulfate-reducing bacteria can reduce it to sulfide. However, if dissolved oxygen is present, aqueous sulfide species are not stable and are readily oxidized to sulfate. In groundwater at near-neutral pH, like at RFETS, sulfate is not typically attenuated. However, at low pH sorption becomes an important attenuation mechanism for sulfate (Rai et al. 1984). The greatest sulfate sorption is at low pH because of the positive charge on clay mineral surfaces, iron oxyhydroxides, and aluminum oxides. Chloride, nitrate and arsenite have little effect on sulfate sorption by soils under these conditions. However, fluoride, selenate, selenite, arsenate, and phosphate ions do compete with sulfate for sorption sites (Chao 1964) at low pH. Sulfate solubility-controlling solids are important in restricted environments as acid mine drainages or mine tailings impoundments. Gypsum ($CaSO_4 \cdot 2H_2O$) has typically been identified as a solubility control under oxidizing and alkaline conditions in poorly drained arid soils (Rai et al. 1984). Gypsum may also become a solubility control at sites with elevated sulfate concentrations in groundwater.	In groundwater at near-neutral pH, like at RFETS, sulfate is not typically attenuated and thus persists indefinitely unless there is a reduction in pH (Rai et al. 1984).	Sulfate is defined as a groundwater AOI in the nature and extent of groundwater contamination (Section 4.0). Contiguous, mappable plumes of sulfate in UHSU groundwater are found downgradient of the East Landfill Pond dam, the historical SEPs, and between Pond B-4 and B-5 (refer to Figure 4.23 in the nature and extent of groundwater contamination). Sulfate's chemical behavior is strongly related to the redox properties of groundwater. The most highly oxidized form of sulfur is sulfate (SO_4^{-2}), which is the most likely aqueous sulfur species at RFETS given the highly oxygenated groundwater in the UHSU. Sulfate is a ubiquitous and important anion in natural waters. In natural waters above pH 4, it is the predominant form of aqueous sulfur (+6).

Table 8.3
Surface Water - Summary of Results

Representative Surface Water Location[a]	AOI/Surface Water Standard	Number of Samples Above/Total Number of Samples[b]	Date(s) Measurements Were Above the Standard	Subsequent Samples Below the Surface Water Standard	Notes/Actions Taken to Disrupt Potential Surface Water Impacts
GS08	Americium-241/0.15 pCi/L	1/85	5/2/00	Yes	The highest results from 5/2/2000 did not result in a 30-day moving average value above 0.15 pCi/L (see Attachment 4 for the time-series graph). The 5/2/2000 sample is not identified as representative of surface water quality at GS08 (based on 1 sample out of 85 being above 0.15 pCi/L). The result can potentially be attributed to a "hot particle" captured in the sample container.
GS08	Plutonium-239/240/0.15 pCi/L	2/85	8/11/00, 7/11/03	Yes	One of the two highest results, from 8/11/00, did not result in a 30-day moving average value above 0.15 pCi/L (see Attachment 4 for the time-series graph). The 8/11/00 sample is not identified as being representative of surface water quality at GS08 (based on 1 valid result out of 85 being above 0.15 pCi/L. (The one other result above 0.15 pCi/L, on 7/11/03, was not valid, as discussed below.) The 8/11/00 result can potentially be attributed to a "hot particle" captured in the sample container. The other high result, from 7/11/03, was identified as being not valid because it and its duplicate did not meet the duplicate error ratio criteria (for further explanation, see the RFETS Automated Surface-Water Monitoring: Final WY05 Annual Report (K-H 2005d) (see Attachment 4 for the time-series graph).
GS11	Gross Beta/8 pCi/L	1/2	5/16/02	Yes	The one result above the surface water standard (9.81 pCi/L) is below the background concentration (99/99 UTL) of 15.0 pCi/L.
GS31	Gross Beta/8 pCi/L	1/4	6/25/01	Yes	The result above the surface water standard (11 pCi/L) is below the background concentration (99/99 UTL) of 15.0 pCi/L.
GS10	Americium-241/0.15 pCi/L	30/153	4/6/00 - 6/6/05	Yes	The 30 elevated americium results at GS10 (see Attachment 4 for the time-series graph) were attributed to widespread soil disturbance in the former IA due to closure activities, which were subsequently completed. The soil disturbance resulted in increased erosion, with associated increased suspended solids in surface water and transport of americium. Soil disturbance has since stopped occurring. Targeted erosion controls implemented in the former IA, including the functional channels, are effective in reducing particulate transport and associated movement of americium (K-H 2005d).

Table 8.3
Surface Water - Summary of Results

Representative Surface Water Location[a]	AOI/Surface Water Standard	Number of Samples Above/Total Number of Samples[b]	Date(s) Measurements Were Above the Standard	Subsequent Samples Below the Surface Water Standard	Notes/Actions Taken to Disrupt Potential Surface Water Impacts
GS10	Chromium/50 ug/L	1/157	3/14/05	Yes	The one elevated chromium result at GS10 dated 3/14/05 (see Attachment 4 for the time-series graph) was attributed to widespread soil disturbance in the former IA due to closure activities, which were subsequently completed. The soil disturbance resulted in increased erosion, with associated increased suspended solids in surface water and transport of chromium. Soil disturbance has since stopped occurring. Targeted erosion controls were implemented in the former IA, including the functional channels, and are effective in reducing particulate transport and associated movement of chromium (K-H 2005d). It is noted that the one elevated chromium result at GS10 (sample date 3/14/05) is not considered representative of water quality at that location (1 result out of 157).
GS10	Plutonium-239/240/0.15 pCi/L	37/157	4/6/00 - 6/6/05	Yes	The 37 elevated plutonium results at GS10 (see Attachment 4 for the time-series graph) were attributed to widespread soil disturbance in the former IA due to closure activities, which were subsequently completed. The soil disturbance resulted in increased erosion, with associated increased suspended solids in surface water and transport of plutonium. Soil disturbance has since stopped occurring. Targeted erosion controls implemented in the former IA, including the functional channels, are effective in reducing particulate transport and associated movement of plutonium (K-H 2005d).
GS10	Uranium Isotopes/10 pCi/L	4/136	5/12/05 - 7/11/05	Yes	Approximately 3 percent of uranium samples at GS10 (4 out of 136 samples collected) have uranium concentrations above the surface water standard. HR ICP/MS analyses of uranium isotope ratios indicate the uranium observed in surface water at GS10 is predominantly (approximately 2/3) from natural sources.
GS13	Nitrate/Nitrite (as N)/10 mg/L	69/87	1/6/00 - 6/15/05	No	The SPPTS was installed to decrease the nitrate/nitrite load from groundwater to surface water.
GS13	Uranium Isotopes/10 pCi/L	22/51	1/29/02 - 3/28/05	Yes	HR ICP/MS analyses of uranium isotope ratios indicate the uranium observed in surface water at GS13 is predominantly (approximately 2/3) from natural sources.

Table 8.3
Surface Water - Summary of Results

Representative Surface Water Location[a]	AOI/Surface Water Standard	Number of Samples Above/Total Number of Samples[b]	Date(s) Measurements Were Above the Standard	Subsequent Samples Below the Surface Water Standard	Notes/Actions Taken to Disrupt Potential Surface Water Impacts
GS51	Americium-241/0.15 pCi/L	22/25	5/24/02 - 4/30/05	No	Elevated americium values occurred (see Attachment 4 for the time-series graph) during the historical 903 Pad/Lip area accelerated action, when soil disturbance occurred across the GS51 watershed. Since the accelerated action was completed, erosion control measures, such as revegetation of the road, retilling of the historical 903 Pad/Lip area, and application of erosion control matting, have diminished flows and associated erosion and movement of residual americium in the soil. The station is still monitored under the IMP (K-H 2005d).
GS51	Plutonium-239/240/0.15 pCi/L	27/27	5/24/02 - 5/12/05	No	Elevated plutonium values occurred (see Attachment 4 for the time-series graph) during the historical 903 Pad/Lip area accelerated action, when soil disturbance occurred across the GS51 watershed. Since the accelerated action was completed, erosion control measures, such as revegetation of the road, retilling of the historical 903 Pad/Lip area, and application of erosion control matting, have diminished flows and associated erosion and movement of residual plutonium in the soil. The station is still monitored under the IMP (K-H 2005d).
SW018	Chromium/50 ug/L	2/31	6/2/05, 7/14/05	No	Elevated chromium at surface water station SW018 (2 results out of 31 samples collected) (see Attachment 4 for the time-series graph) was attributed to soil disturbance caused by closure activities in the former 700 Area, which have since been completed. Targeted erosion controls and the functional channels are effective in reducing particulate transport and associated elevated concentrations of plutonium in surface water (K-H 2005d).
SW018	Plutonium-239/240/0.15 pCi/L	1/30	7/14/05	No	Elevated plutonium at surface water station SW018 (1 result out of 30 samples collected) (see Attachment 4 for the time-series graph) was attributed to soil disturbance caused by closure activities in the former 700 Area, which have since been completed. Targeted erosion controls and the functional channels are effective in reducing particulate transport and associated elevated concentrations of plutonium in surface water (K-H 2005d).

Table 8.3
Surface Water - Summary of Results

Representative Surface Water Location[a]	AOI/Surface Water Standard	Number of Samples Above/Total Number of Samples[b]	Date(s) Measurements Were Above the Standard	Subsequent Samples Below the Surface Water Standard	Notes/Actions Taken to Disrupt Potential Surface Water Impacts
SW027	Americium-241/0.15 pCi/L	5/43	5/11/00 - 7/24/04	Yes	Of the five americium-241 surface water sample results detected above the standard at station SW027, four were collected during the historical 903 Pad/Lip area accelerated action, when soil was being disturbed as it was being removed. The elevated americium-241 measured at SW027 was attributed primarily to the loads from sub-basins GS51 and GS52, which flow to station SW027 and where soil disturbance related to the remediation work was occurring. The values have decreased since the retilling and application of erosion control matting in the historical 903 Pad/Lip area, and revegetation of the former road in the area (K-H 2005d). The one americium-241 sample collected at SW027 that was above the surface water standard, but was not collected during the historical 903 Pad/Lip area remediation (collected on 5/11/2000, before the Lip Area remediation), was attributed to residual americium in the soils and sediments in the SW027 drainage (see Attachment 4 for the time-series graph).
SW027	Plutonium-239/240/0.15 pCi/L	12/43	5/11/00 - 4/13/05	Yes	Of the 12 plutonium-239/240 surface water sample results detected above the standard at station SW027, 9 were collected during the historical 903 Pad/Lip area accelerated action, when soil was being disturbed as it was being removed. The elevated plutonium-239/240 measured at SW027 was attributed primarily to the loads from sub-basins GS51 and GS52, which flow to station SW027 and where soil disturbance related to the remediation work was occurring. The values have decreased since the retilling and application of erosion control matting in the historical 903 Pad/Lip area, and revegetation of the former road in the area (K-H 2005d). Of the three plutonium-239/240 samples collected at SW027 that were above the surface water standard, but not collected during the historical 903 Pad/Lip area remediation, two were collected during the remediation of the 903 Pad itself (samples from 3/24/2003 and 5/5/2003) and one was collected before any of the remediation work in that area (sample from 5/11/2000) and was attributed to residual plutonium in the soils and sediments in the SW027 drainage (see Attachment 4 for the time-series graph).

Table 8.3
Surface Water - Summary of Results

Representative Surface Water Location[a]	AOI/Surface Water Standard	Number of Samples Above/Total Number of Samples[b]	Date(s) Measurements Were Above the Standard	Subsequent Samples Below the Surface Water Standard	Notes/Actions Taken to Disrupt Potential Surface Water Impacts
SW093	Americium-241/0.15 pCi/L	19/156	4/11/04 – 12/1/04	Yes	Elevated americium at surface water station SW093 was attributed to soil disturbance caused by closure activities in the former 700 Area, which have since been completed. Targeted erosion controls and the functional channels are effective in reducing elevated concentrations of americium in surface water (K-H 2005d).
SW093	Plutonium-239/240/0.15 pCi/L	20/157	8/18/00 - 3/3/05	Yes	Elevated plutonium at surface water station SW093 (see Section 8.0 Attachment 4 for the time-series graph) was attributed to soil disturbance caused by closure activities in the former 700 area, which have since been completed. Targeted erosion controls and the functional channels are effective in reducing elevated concentrations of plutonium in surface water (K-H 2005d).
GS05	Beryllium/4 ug/L	2/7	7/16/00, 8/27/00	Yes	Background location west of RFETS
GS05	Chromium/50 ug/L	2/7	7/16/00, 8/27/00	Yes	Background location west of RFETS
GS05	Lead/50 ug/L	1/7	8/27/00	Yes	Background location west of RFETS

[a] Surface water location GS01 (Woman Creek at Indiana Street) has sample results in the data set that are above the respective surface water standards for lead (1 result [sample collected 4/11/2005] above the standard out of 15 samples) and chromium (1 result [sample collected 4/11/2005] above the standard out of 15 samples). These sample results were identified as being entered into the database improperly and were therefore excluded from the data used for this evaluation of contaminant fate and transport.

[b] Comparisons with surface water standards presented in this table are based on individual sample results; this is different than the 30-day moving average comparisons provided for specific analytes in the WY05 Surface Water Report (K-H 2005d).

Table 8.4
Evaluation of Transport Pathways - Surface Soil AOIs to Surface Water

Analyte Group	**<u>Step 1</u>** **Identify Analytes to Evaluate**	**<u>Step 2</u>** **Identify Dominant Transport Mechanism(s)**	**<u>Step 3</u>** **Is the AOI present in surface soil for potential transport in the environment?**	**<u>Step 4</u>** **Is the contaminant persistent in the surface environment?**	**<u>Step 5</u>** **Link to potential surface water impact:** **Is the AOI co-located in surface soil in the same drainage where the AOI has been detected in surface water above the standard?[a]**	**<u>Step 6</u>** **Does a complete transport pathway to surface water exist?**
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination and Table 8.4)	
Radionuclides	Americium-241	Surface (Particulate)	Yes	Yes	Yes North Walnut Creek basin - AOI in surface soil and surface water (SW093) South Walnut Creek basin - AOI in surface soil and surface water (GS10) SID basin - AOI in surface soil and surface water (GS51, SW027)	Yes
	Plutonium-239/240	Surface (Particulate)	Yes	Yes	Yes North Walnut Creek basin - AOI in surface soil and surface water (SW093) South Walnut Creek basin - AOI in surface soil and surface water (GS10) SID basin - AOI in surface soil and surface water (GS51, SW027)	Yes

Table 8.4
Evaluation of Transport Pathways - Surface Soil AOIs to Surface Water

Analyte Group	Step 1 Identify Analytes to Evaluate	Step 2 Identify Dominant Transport Mechanism(s)	Step 3 Is the AOI present in surface soil for potential transport in the environment?	Step 4 Is the contaminant persistent in the surface environment?	Step 5 Link to potential surface water impact: Is the AOI co-located in surface soil in the same drainage where the AOI has been detected in surface water above the standard?[a]	Step 6 Does a complete transport pathway to surface water exist?
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination and Table 8.4)	
	Uranium-233/234	Surface (Particulate)[b]	Yes	Yes	No South Walnut Creek basin - AOI in surface soil and surface water (GS10). However, while uranium has been detected above the surface water standard (4 out of 136 total samples above standard at GS10, all from 2005), ICP/MS analyses of isotopic ratios indicate the uranium is predominantly (approximately 2/3) from natural uranium. North Walnut Creek basin - AOI in surface soil and surface water (GS13). However, while uranium has been detected above the surface water standard (22 out of 51 total samples above standard at GS13), ICP/MS analyses of isotopic ratios indicate the uranium is predominantly (approximately 2/3) from natural uranium. Other basins - not detected above standard in surface water.	No
	Uranium-235	Surface (Particulate)[b]	Yes	Yes	See notes above regarding uranium-233/234.	No
	Uranium-238	Surface (Particulate)[b]	Yes	Yes	See notes above regarding uranium-233/234.	No
Metals	Aluminum	Surface (Particulate)	Yes	Yes	No -Not detected above surface water standard at representative surface water locations	No
	Arsenic	Surface (Particulate)	Yes, background concentrations	Yes	No -Not detected above surface water standard at representative surface water locations	No

Table 8.4
Evaluation of Transport Pathways - Surface Soil AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in surface soil for potential transport in the environment?**	**Step 4** **Is the contaminant persistent in the surface environment?**	**Step 5** **Link to potential surface water impact:** **Is the AOI co-located in surface soil in the same drainage where the AOI has been detected in surface water above the standard?[a]**	**Step 6** **Does a complete transport pathway to surface water exist?**
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination and Table 8.4)	
	Chromium	Surface (Particulate)	Yes	Yes	No South Walnut Creek - AOI in surface soil and surface water (SW018). However, chromium detections above the surface water standard (2 out of 31 total samples from SW018) were both from samples collected in 2005, during widespread soil disturbance in the former IA, and are not reflective of post-accelerated action conditions at the site. North Walnut Creek - AOI in surface soil and surface water (GS10). However, the chromium detection above the surface water standard (1 out of 157 total samples from GS10) was from a sample collected in mid-2005, during widespread soil disturbance in the former IA, and is not reflective of the post-accelerated action condition at the site. Woman Creek - AOI in surface soil and surface water (GS05). However, the chromium detections above the surface water standard (2 out of 7 total samples from GS05, both collected in 2000) are from a location on the western boundary of the site, reflective of background conditions, not from a manmade chromium contribution by RFETS historic activities.	No

Table 8.4
Evaluation of Transport Pathways - Surface Soil AOIs to Surface Water

Analyte Group	Step 1 Identify Analytes to Evaluate	Step 2 Identify Dominant Transport Mechanism(s)	Step 3 Is the AOI present in surface soil for potential transport in the environment?	Step 4 Is the contaminant persistent in the surface environment?	Step 5 Link to potential surface water impact: Is the AOI co-located in surface soil in the same drainage where the AOI has been detected in surface water above the standard?[a]	Step 6 Does a complete transport pathway to surface water exist?
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination and Table 8.4)	
	Vanadium	Surface (Particulate)	Yes	Yes	No -Not detected above surface water standard at representative surface water locations	No
SVOCs	Benzo(a)pyrene	Surface (Particulate)	Yes	No	No -Not detected above surface water standard at representative surface water locations	No
	Dibenz(a,h)anthracene	Surface (Particulate)	Yes	No	No -Not detected above surface water standard at representative surface water locations	No
PCBs[c]	PCB-1254	Surface (Particulate)	Yes	Yes	No -Not detected above surface water standard at representative surface water locations	No
	PCB-1260	Surface (Particulate)	Yes	Yes	No -Not detected above surface water standard at representative surface water locations	No
Dioxin	2,3,7,8-TCDD TEQ	Surface (Particulate)	Yes	Yes	No -Not detected above surface water standard at representative surface water locations	No

[a] Surface water quality is evaluated for this analysis at representative surface water locations across the site as depicted on Figure 8.1.

[b] Although uranium can be transported in groundwater, surface transport is identified as the dominant transport process for uranium for this surface soil table.

[c] The PCBs listed herein are equivalent to Aroclors, for example PCB-1254 is the same as Aroclor-1254.

Table 8.5
Evaluation of Transport Pathways - Sediment AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in sediment for potential transport in the environment?**	**Step 4** **Is the contaminant persistent in the surface environment?**	**Step 5** **Link to potential surface water impact:** **Is the AOI co-located in sediment in the same drainage where the AOI has been detected in surface water above the surface water standard?**[a]	**Step 6** **Does a complete transport pathway to surface water exist?**
	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination)	(Refer to Table 8.2)	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination)	(Refer to Table 8.2)	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination, and Table 8.3)	
Radionuclides	Americium-241	Surface (Particulate)	Yes (North Walnut Creek)	Yes	Yes - Sediment/surface water AOIs co-located in: North Walnut Creek basin - AOI in sediment and surface water (SW093)	Yes
	Plutonium-239/240	Surface (Particulate)	Yes (North Walnut Creek, South Walnut Creek, Woman Creek)	Yes	Yes - Sediment/surface water AOIs co-located in: North Walnut Creek basin - AOI in sediment and surface water (SW093) South Walnut Creek basin - AOI in sediment and surface water (GS10) SID basin - AOI in sediment and surface water (GS51, SW027)	Yes
Metals	Arsenic	Surface	Yes (North Walnut Creek, South Walnut Creek, Woman Creek)	Yes	Surface water data unavailable for arsenic.	No

Table 8.5
Evaluation of Transport Pathways - Sediment AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in sediment for potential transport in the environment?**	**Step 4** **Is the contaminant persistent in the surface environment?**	**Step 5** **Link to potential surface water impact:** **Is the AOI co-located in sediment in the same drainage where the AOI has been detected in surface water above the surface water standard?**[a]	**Step 6** **Does a complete transport pathway to surface water exist?**
	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination)	(Refer to Table 8.2)	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination)	(Refer to Table 8.2)	(Refer to Section 5.0, Nature and Extent of Surface Water and Sediment Contamination, and Table 8.3)	
	Chromium	Surface	Yes (throughout IA and in Ponds A-2, A-3)	Yes	No South Walnut Creek - AOI in sediment and surface water (SW018). However, chromium detections above the surface water standard (2 out of 31 total samples from SW018) were both from samples collected in 2005, during widespread soil disturbance in the former IA, and are not reflective of post-accelerated action conditions at the site. North Walnut Creek - AOI in sediment and surface water (GS10). However, the chromium detection above the surface water standard (1 out of 157 total samples from GS10) was from a sample collected in mid-2005, during widespread soil disturbance in the former IA, and is not reflective of the post-accelerated action condition at the site.	No
SVOCs	Benzo(a)pyrene	Surface	Yes (throughout IA and South Walnut Creek drainage)	Moderately short persistence	No -Representative surface water locations not sampled for benzo(a)pyrene.	No

[a] Surface water quality is evaluated for this analysis at representative surface water locations across the site as depicted on Figure 8.1.

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in subsurface soil and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
Radionuclides	Americium-241	Surface (Particulate)	No - Present, but not mobile in subsurface	Yes	No - Not analyzed in groundwater at these wells.	N/A (No modeling conducted)	No
	Plutonium-239/240	Surface (Particulate)	No - Present, but not mobile in subsurface	Yes	No - Not analyzed in groundwater at these wells.	N/A (No modeling conducted)	No
	Uranium-235	Subsurface (Dissolved)[b]	Yes	Yes	Woman Creek basin - AOI in subsurface soil (Ash Pits); AOC/Sentinel well data for uranium in that area do not exist. Other basins - Uranium-235 not a subsurface soil AOI.	N/A (No modeling conducted)	No[c]
	Uranium-238	Subsurface (Dissolved)[b]	Yes	Yes	See notes above for uranium-235.	N/A (No modeling conducted)	No[c]

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in subsurface soil and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
VOCs	Carbon Tetrachloride	Subsurface (Dissolved)	Yes	Yes	Yes[d]	Yes Areas formerly known as: - Historical East Trenches - Historical 903 Pad - Historical Ryan's Pit - Carbon Tetrachloride Plume	Yes
	Chloroform	Subsurface (Dissolved)	Yes	Yes	Yes[d]	Model results not conclusive.	Yes

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in subsurface soil and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
	Methylene Chloride	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin - AOI in subsurface soil (historical IHSS 118.1 area) and in groundwater (well 20598/20505). Other basins - Not detected above the WRW PRG in subsurface soil.	Model results not conclusive.	Yes

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in subsurface soil and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
	Tetrachloroethene	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin - AOI in subsurface soil (historical IHSS 118.1 area) and in downgradient wells (20598/20505, 1386/51605, and 37501). South Walnut Creek basin - AOI in subsurface soil (historical B991 and Mound area) and in downgradient wells (91203, 99301/99305, 00997, 15699, and 23296). Other basins - Not detected above the WRW PRG in subsurface soil.	Yes Areas known as: - Historical East Trenches - Historical 903 Pad - Historical Ryan's Pit - Carbon Tetrachloride Plume	Yes

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in subsurface soil and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
	Trichloroethene	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek - AOI in subsurface soil (historical Mound and East Trenches) and in downgradient wells (15699, 23296, and 95199). Other basins - Not detected above the WRW	Yes Areas known as: - Historical East Trenches - Historical 903 Pad - Historical Ryan's Pit - Carbon Tetrachloride Plume	Yes
	1,1,2,2-Tetrachloroethane	Subsurface (Dissolved)	Yes	Yes	No - Not detected at AOC or Sentinel wells above surface water standard.	N/A (No modeling conducted)	No

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in subsurface soil and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
Metals	Chromium	Subsurface (Dissolved)(b)	Yes	Yes	Yes South Walnut Creek - AOI in subsurface soil (historical East Trenches) and in downgradient well (23296) (2 out of 15 samples). Other basins - Not detected in AOC or Sentinel wells above surface water standard.	N/A (No modeling conducted)	No Limited extent and infrequent detections at one Sentinel well only.
	Lead	Subsurface (Dissolved)	No - Present, but limited mobility in subsurface	Yes	No - Not analyzed in groundwater at these wells.	N/A (No modeling conducted)	No
SVOCs	Benzo(a)pyrene	Surface (Particulate)	No - Present, but limited mobility in subsurface	Limited persistence	No - Not analyzed in groundwater at these wells.	N/A (No modeling conducted)	No

Table 8.6
Evaluation of Transport Pathways - Subsurface Soil AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in subsurface soil and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?
					5a) Is the subsurface soil AOI also detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the subsurface soil AOI predicted to impact surface water quality, based on models or calculated estimates?**	
	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination)	(Refer to Table 8.2)	(Refer to Section 3.0, Nature and Extent of Soil Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)	
PCBs[e]	PCB-1260	Surface (Particulate)	No - Present, but limited mobility in subsurface	Yes	No - Not analyzed in groundwater at these wells.	N/A (No modeling conducted)	No

[a] Representative groundwater locations are defined for this evaluation as AOC and Sentinel wells, which are indicative of potential groundwater impacts to surface water.

[b] Although uranium and chromium can also be transported as a particle via surface processes, only the subsurface transport pathway for these AOIs is addressed for this evaluation of subsurface soil AOIs.

[c] The one area where uranium is identified as an AOI in subsurface soil (historical Ash Pits) is not conclusively associated with elevated uranium in groundwater. Therefore, based on that observation, uranium in subsurface soil is identified as having a limited transport pathway to surface water. However, in groundwater, uranium is identified as having a complete pathway to surface water.

[d] Carbon tetrachloride and chloroform are identified as subsurface soil AOIs based on soil samples above the WRW PRG concentrations in the historical IHSS 118.1 area. Groundwater samples from AOC and Sentinel wells in that area are not above the respective surface water standards for these AOIs. Therefore, based strictly on the criteria for Step 5a, there are no complete pathways to surface water for these AOIs. However, subsurface soil samples in several other areas (for example, historical Mound, historical 903 Pad, and historical East Trenches areas) are above background for these AOIs, and in those areas these AOIs are detected in downgradient AOC and Sentinel wells, thereby indicating complete pathways are present from subsurface soil to surface water for carbon tetrachloride and chloroform.

Table 8.7
Summary of Groundwater Data at AOC Wells

Groundwater Plume Area	AOC Well(s)	Does it meet surface water standard for each AOI?	Description/Explanation
Carbon Tetrachloride Plume (Historical IHSS 118.1) South of the Former Building 771	10594	Yes	Trichloroethene was observed in one sample (out of seven total results) above the surface water standard and laboratory PQL. Subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (99% UTL) (the surface water standard is lower than background). These data are from 1995 and 1996, and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; based upon results from HR ICP/MS or TIMS analyses, the uranium is from natural sources. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.
Historical East Trenches	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
Historical SEP	10594	Yes	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (the surface water standard is lower than background). These data are from 1995 and 1996 and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; it was deemed to be from natural sources using HR ICP/MS or TIMS analyses. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.
Former 700 Area Northeast Plume	10594	Yes	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (the surface water standard is lower than background). These data are from 1995 and 1996 and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; it was deemed to be from natural sources using HR ICP/MS or TIMS analyses. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.

Table 8.7
Summary of Groundwater Data at AOC Wells

Groundwater Plume Area	AOC Well(s)	Does it meet surface water standard for each AOI?	Description/Explanation
Historical Mound Site (Historical IHSS 113)	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
Historical Oil Burn Pit No. 2	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
Historical 903 Pad (Historical IHSS 112)	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
	10304	Yes	All AOIs are nondetect, below the surface water standard, or less than or equal to the PQL
	00193	Yes	Arsenic was observed in one sample (out of four total results) above the surface water standard and PQL (no background available); this measurement is from 1995 and subsequent data are below the PQL.
Historical Ryan's Pit (Historical IHSS 109)	10304	Yes	All AOIs are nondetect or below the surface water standard.
	00193	No	Arsenic was observed in one sample (out of four total results) above the surface water standard and PQL (no background available); this measurement is from 1995 and subsequent data are below the PQL. Sulfate was detected in two samples (out of two total results) above background (99% UTL) (background is greater than the surface water standard).

Table 8.7
Summary of Groundwater Data at AOC Wells

Groundwater Plume Area	AOC Well(s)	Does it meet surface water standard for each AOI?	Description/Explanation
Historical IHSS 119.1 (Historical OU 1)	89104	N/A	The data (one sample date) are nondetect or below the standard, background (99% UTL), and PQL.
Former IA Plume Sources	10594	Yes	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (99% UTL) (the surface water standard is lower than background). These data are from 1995 and 1996 and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; it was deemed to be from natural sources using HR ICP/MS or TIMS analyses. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.
	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
Historical PU&D Yard	10594	Yes	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (99% UTL), which is higher than the surface water standard. These data are from 1995 and 1996 and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; it was deemed to be from natural sources using HR ICP/MS or TIMS analyses. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.
Historical Oil Burn Pit No. 1	10594	Yes	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect. Sulfate was detected in three samples (out of four total results) above background (99% UTL) (the surface water standard is lower than background). These data are from 1995 and 1996 and there are no subsequent data. Uranium was also detected twice (out of two total results) at this AOC well; it was deemed to be from natural sources using HR ICP/MS or TIMS analyses. No nitrate/nitrite (as N) has been detected above the surface water standard at this AOC well.

Table 8.7
Summary of Groundwater Data at AOC Wells

Groundwater Plume Area	AOC Well(s)	Does it meet surface water standard for each AOI?	Description/Explanation
Former Building 444	89104	N/A	The data (one sample date) are nondetect or below the standard, background, and less than or equal to the PQL.
	11104	Yes	The data (three sample dates) are nondetect or below the standard, background (99% UTL), and less than or equal to the PQL.
Former Building 443	None	N/A	No applicable AOC well
Former Building 991	00997	Yes	Arsenic was detected in 1 sample (out of 14 total results) above the standard and PQL (no background value available); subsequent samples were below. Tetrachloroethene was observed in 1 sample (out of 17 total results) above the surface water standard and PQL. This value was measured in 1997, and all 16 subsequent values are nondetect. Uranium was noted in one sample (out of two total results) above the surface water standard but below background (99% UTL). It was also deemed to be almost entirely from natural sources using the HR ICP/MS or TIMS analyses.
Present Landfill	None	N/A	No applicable AOC well. (There are two Sentinel wells downgradient of the Present Landfill, per the IMP.)
Original Landfill	11104	Yes	The data (three sample dates) are nondetect or below the standard, background (99% UTL), and PQL.

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
Carbon Tetrachloride Plume (Historical IHSS 118.1) South of Former Building 771 and North of Former Building 771	52505 (1986)	No	Benzene and trichloroethene were detected in 1 sample (out of 33 total results) above the surface water standard and the PQL. These were detected in 1999 and 1998, respectively, and subsequent data are below the standard or PQL. Arsenic (filtered) was observed in 16 samples (out of 25 total results) above the surface water standard and PQL (no background available); the S-K trending analysis indicated there is not a statistically significant trend of the data. Nickel (filtered) was measured in 1 sample (out of 27 total results) above the surface water standard, PQL, and background (99 %UTL); subsequent data have been below the standard and background (99% UTL).	Partial soil and free product removal (to the extent practicable) and insertion of HRC® at historical IHSS 118.1 (Carbon Tetrachloride Spill). Also, disruption of the former Building 771 footing and foundation drains. Arsenic is believed to be due to background levels.
	20205 (20298)	Yes	Trichloroethene was detected in one sample (out of eight total results) above the surface water standard and PQL; subsequent samples are nondetect. The S-K analysis did not show a statistically significant trend. Arsenic (filtered) was detected once (out of one total result) above the surface water standard and PQL (no background available).	Partial soil and free product removal (to the extent practicable) and insertion of HRC® at historical IHSS 118.1 (Carbon Tetrachloride Spill). Also, disruption of the former Building 771 footing and foundation drains.
	20505 (20598)	No	1,1-Dichloroethene, methylene chloride, and tetrachloroethene were observed in one sample (out of five total results) above the surface water standard and the PQL; the latest data are nondetect. Vinyl chloride was detected in five samples (out of five total results) above the surface water standard and the PQL. Trichloroethene was detected in three samples (out of six total results) above the surface water standard and the PQL.	Partial soil and free product removal (to the extent practicable) and insertion of HRC® at historical IHSS 118.1 (Carbon Tetrachloride Spill). Also, disruption of the former Building 771 footing and foundation drains.
	20705 (20798)	Yes	Arsenic (filtered) was observed in six samples (out of seven total results) above the surface water standard and PQL (no background available).	

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
Historical East Trenches	95099	Yes	Tetrachloroethene was observed in 1 sample (out of 14 total results) above the surface water standard and the PQL; all the other samples (including the subsequent samples) are nondetect or below the PQL.	Soil removal at historical Trenches T-3 and T-4, installation of 1,200-ft-long groundwater treatment system (ETPTS), and use of phytoremediation technologies in the Walnut Creek drainage (between Ponds B-2 and B-3).
	95199	No	Methylene chloride was observed in 2 samples (out of 14 total results) above the surface water standard and the PQL; subsequent samples are nondetect. Tetrachloroethene was observed in 13 samples (out of 14 total results) above the surface water standard and the PQL. Trichloroethene was observed in 14 samples (out of 14 total results) above the surface water standard and the PQL. All of these AOIs showed a statistically insignificant trend from the S-K analysis.	Soil removal at historical Trenches T-3 and T-4, installation of 1,200-ft-long groundwater treatment system (ETPTS), and use of phytoremediation technologies in the Walnut Creek drainage (between Ponds B-2 and B-3).
	95299	N/A	No sample results (well is dry).	
	23296	No	Carbon tetrachloride was observed in 22 samples (out of 27 total results), cis-1,2-dichloroethene was observed in 16 samples (out of 27 total results), chloroform was observed in 21 samples (out of 27 total results), methylene chloride was detected in 4 samples (out of 27 total results), and trichloroethene and tetrachloroethene were noted in 27 samples (out of 27 total results) above their respective surface water standard and PQL. Nickel (total) was observed in 1 sample (out of 15 total results). Chromium was detected twice (out of 12 total results); subsequent samples are below the surface water standard or nondetects. All of these AOIs have a decreasing or statistically insignificant trend based on the S-K analysis. Uranium (sum of isotopes) was noted in 12 samples (out of 12 total results) above the surface water standard, PQL, and background. Approximately 90 percent of the uranium is from natural sources (based on HR ICP/MS and TIMS analyses).	Soil removal at historical Trenches T-3 and T-4, installation of 1,200-ft-long groundwater treatment system (ETPTS), and use of phytoremediation technologies in the Walnut Creek drainage near well 23296 (between Ponds B-2 and B-3).

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
	TH046992	Yes	All AOIs are nondetect or below the surface water standard, background (99% UTL), or PQL.	
	04091	No	Carbon tetrachloride was detected in 21 samples (out of 32 total results), tetrachloroethene was detected in 1 sample (out of 32 total results), and trichloroethene was noted in 2 samples (out of 32 total results) above the surface water standard and PQL. Using the S-K trending analysis, a decreasing trend is observed.	A decreasing trend of the VOC data was calculated, and the results are near the surface water standards. In addition, the results of VOC modeling indicate that the VOC concentrations are below surface water standards at groundwater discharge locations (see Table 8.10 for details).
Historical SEP	P210089	No	Nitrate (total) was detected in 22 samples (out of 22 total results) above the surface water standard, PQL, and background. A nitrate plume does exist in the former SEP and the area surrounding well P210089, and the S-K analysis shows an increasing trend. Nickel (total and filtered) was detected in one sample (out of three total results for total nickel and out of 11 total results for dissolved nickel) above the surface water standard, PQL, and background (99% UTL). Sulfate was observed in 19 samples (out of 20 total results) above background (99% UTL), which is higher than the surface water standard with a decreasing S-K trend.	Removal of sludge, closure of the historical SEP, installation of a 1,100-ft-long groundwater treatment system (SPPTS), and use of phytoremediation technologies at the discharge gallery of the treatment system.
	70299	Yes	Uranium was detected above the surface water standard in 4 samples (out of 10 total results), but they were all below background (99% UTL).	
	51605 (1386)	No	Nickel (total) was detected in one sample (out of three total results) and nickel (dissolved) was detected in 29 samples (out of 34 total results) above the surface water standard, PQL, and background (99% UTL) with an increasing S-K trend. Tetrachloroethene was observed in 1 sample (out of 36 total results) above the surface water standard and the PQL. Uranium (sum of isotopes) was detected in 15 samples (out of 15 total results) above the surface water standard, PQL, and background (99% UTL); based on HR ICP/MS or TIMS results, the uranium is from natural sources.	Well 1386 (replaced by 51605) was constructed with a stainless-steel casing, which is recognized to cause misleading elevated results for nickel (see Table 8.12 for details). Removal of sludge, closure of the historical SEP, installation of a 1,100-ft-long groundwater treatment system (SPPTS), and use of phytoremediation technologies at the discharge gallery of the treatment system.

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
Former 700 Area Northeast Plume	P210089	No	Nitrate was detected in 22 samples (out of 22 total results) above the surface water standard, PQL, and background (99% UTL) with an increasing S-K trend. Nickel (total and filtered) was detected in one sample (out of three total results for total nickel and out of 11 total results for dissolved nickel) above the surface water standard, PQL, and background (99% UTL).	Hydrologic modeling results indicate that groundwater from the 700 Area Northeast Plume is capture by the SPPTS.
	70299	Yes	Uranium was detected in 4 samples (out of 10 total results), but they were all below background (99% UTL).	
Historical Mound Site (Historical IHSS 113)	15699	No	Several VOCs are above their respective surface water standards and PQL concentrations, including 1,1-dichloroethene (10 samples out of 11 total results), 1,2-dichloroethane (4 samples out of 10 total results), cis-1,2-dichloroethene and chloroform (9 samples out of 11 total results), tetrachloroethene and trichloroethene (11 samples out of 11 total results), methylene chloride (7 samples out of 11 total results), and carbon tetrachloride (1 sample out of 11 total results). Based upon the S-K analysis, a decreasing or statistically insignificant trend was observed for all of these analytes, except for 1,2-dichloroethane, which had insufficient data to run the S-K analysis. Uranium (sum of isotopes) was detected in three samples (out of 3 total results) above the surface water standard and PQL but below background (99% UTL).	Soil removal and installation of a 220-ft-long groundwater treatment system (MSPTS). See also actions taken at the historical Oil Burn Pit No. 2.
Historical Oil Burn Pit No. 2	91203	No	Carbon tetrachloride, chloroform, and tetrachloroethene were detected in five samples (out of five total results) above their respective surface water standards and PQLs. Trichloroethene was detected in one sample (out of five total results) above the surface water standard and PQL.	Soil and free product source removal (to the extent practicable) and insertion of HRC® at the historical Oil Burn Pit No. 2. Also, hydrologic modeling of the historical Oil Burn Pit No. 2 indicates that the contaminated groundwater is captured by a French drain that goes to the MSPTS (see Figure 8.5 for its location).

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
	91305 (2187)	No	Methylene chloride was detected in 1 sample (out of 20 total results) above the surface water standard and PQL. This measurement is from 1995, and subsequent data are nondetect. In replacement well 91305, vinyl chloride was detected in one sample (out of one total results). Sulfate was observed in 16 samples (out of 16 total results) above background (99% UTL) which is higher than the surface water standard (with a decreasing S-K trend).	Soil and free product source removal (to the extent practicable) and insertion of HRC® at the historical Oil Burn Pit No. 2. Also, hydrologic modeling of the historical Oil Burn Pit No. 2 indicates that the contaminated groundwater is captured by a French drain that goes to the MSPTS (see Figure 8.5 for its location).
Historical 903 Pad (Historical IHSS 112)	95099	Yes	Tetrachloroethene was observed in 1 sample (out of 14 total results) above the surface water standard and the PQL; all the other samples (including the subsequent samples) are nondetect or less than the PQL.	Soil removal at the historical 903 Pad/Lip area and the insertion of HRC® at boring locations in the historical 903 Pad area.
	95199	No	Methylene chloride was observed in 2 samples (out of 14 total results) above the surface water standard and the PQL; subsequent samples are nondetect. Tetrachloroethene was observed in 13 samples (out of 14 total results) above the surface water standard and the PQL. Trichloroethene was observed in 14 samples (out of 14 total results) above the surface water standard and the PQL. None of these AOIs had a statistically significant trend based on the S-K trending analysis.	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.
	95299	N/A	The well is dry, and thus AOI data are unavailable.	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.
	23296	No	Carbon tetrachloride was observed in 22 samples (out of 27 total results), cis-1,2-dichloroethene was observed in 16 samples (out of 27 total results), chloroform was observed in 21 samples (out of 27 total results), methylene chloride was detected in 4 samples (out of 27 total results), and trichloroethene and tetrachloroethene were noted in 27 samples (out of 27 total results) above their respective surface water standard and PQL. Nickel (total) was observed in 1 sample (out of 15 total results). Chromium was detected twice (out of 12 total results); subsequent samples are below the surface water standard or nondetects. All of these AOIs had a decreasing or statistically insignificant trend based on the S-K trending analysis.	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
			Uranium (sum of isotopes) was noted in 12 samples (out of 12 total results) above the surface water standard, PQL, and background. Approximately 90 percent of the uranium is from natural sources according to results from HR ICP/MS and TIMS analyses.	
	TH046992	Yes	All AOIs are nondetect or below the surface water standard, background, or PQL.	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.
	90299	No	Several VOCS have been observed above their respective surface water standards and PQLs, including carbon tetrachloride (3 samples out of 11 total results, subsequent data are below the standard), chloroform (5 samples out of 11 total results), and trichloroethene (6 samples out of 11 total samples). None of these AOIs had a statistically significant trend based on the S-K analysis. Arsenic (filtered) was observed in one sample (out of five total results).	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.
	90399	No	Several VOCS were observed above their respective surface water standards and PQL concentrations, including carbon tetrachloride, chloroform (15 samples out of 15 total results), methylene chloride (3 samples out of 15 total results), trichloroethene (15 samples out of 15 total results), tetrachloroethene (14 samples out of 15 total results). All of these AOIs show a decreasing S-K trend.	Soil removal at the historical 903 Pad/Lip Area and the insertion of HRC® at boring locations in the historical 903 Pad area.
Historical Ryan's Pit (Historical IHSS 109)	90299	No	Several VOCs have been observed above their respective surface water standards and PQLs, including carbon tetrachloride (3 samples out of 11 total results, subsequent data are below the standard), chloroform (5 samples out of 11 total results), and trichloroethene (6 samples out of 11 total samples). Arsenic (filtered) was observed in one sample (out of five total results). All of these AOIs had a statistically insignificant trend based on the S-K analysis.	Soil removal of the historical Ryan's Pit and insertion of HRC® into well 07391.

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
	90399	No	Several VOCS were observed above their respective surface water standards and PQL concentrations, including carbon tetrachloride, chloroform, (15 samples out of 15 total results), methylene chloride (3 samples out of 15 total results), trichloroethene (15 samples out of 15 total results), and tetrachloroethene (14 samples out of 15 total results). However, a decreasing S-K trend was calculated for all of these AOIs.	Soil removal of the historical Ryan's Pit and insertion of HRC® into well 07391.
Historical IHSS 119.1 (Historical OU 1)	none	N/A	Data unavailable.	The treatment system previously installed in this area is no longer required and was decommissioned in accordance with the OU 1 CAD/ROD.
Former IA Plume Sources	52505 (1986)	Yes	Benzene and trichloroethene were detected in 1 sample (out of 33 total results) above the surface water standard and the PQL. These were detected in 1998 and 1999, respectively, and subsequent data are below the standard or PQL. Arsenic was observed in 16 samples (out of 25 total results) above the surface water standard and PQL (no background available). The S-K trending analysis for arsenic did not show a statistically significant trend. Nickel (filtered) was measured in 1 sample (out of 27 total results) above the surface water standard, PQL, and background (99%UTL); subsequent data have been below the standard and background.	
	20205 (20298)	Yes	Trichloroethene was detected in one sample (out of eight total results) above the surface water standard and PQL; subsequent samples are nondetect and do not have a statistically significant S-K trend. Arsenic (filtered) was detected once (out of one total result) above the surface water standard and PQL (no background available).	
	20505 (20598)	No	1,1-Dichloroethene, methylene chloride, and tetrachloroethene were observed in one sample (out of five total results) above the surface water standard and the PQL; the latest data are nondetect. Vinyl chloride was detected in five samples (out of five total results) above the surface water standard and the PQL. Trichloroethene was detected in three samples (out of six total results) above the surface water standard and the PQL.	

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
	20705 (20798)	Yes	Arsenic (filtered) was observed in six samples (out of seven total results) above the surface water standard and PQL (no background available).	
Historical PU&D Yard	30002	Yes	All AOIs are nondetect or below the surface water standard.	
Historical Oil Burn Pit No. 1	33703	Yes	All AOIs are nondetect or below the surface water standard.	
Former Building 444	00797	Yes	Uranium was detected in two samples (out of two total results), but they were all below background (99% UTL).	
	11502	Yes	Tetrachloroethene was detected in one sample (out of two total results) above the surface water standard and PQL.	
	40305 (40399)	Yes	All AOIs are nondetect or below the surface water standard, background, or less than or equal to the PQL.	
	88104 (88101)	N/A	Trichloroethene was detected in one sample (out of seven total results) above the surface water standard and PQL; subsequent samples are nondetect.	
Former Building 443	None	N/A	Fuel oil constituents (from storage tanks) were not observed in wells downgradient.	Storage tanks and associated soil removed.
Former Building 991	99305 (99301)	No	Trichloroethene was detected in nine samples (out of nine total results) above the surface water standard and PQL. Tetrachloroethene was detected in seven samples (out of nine total results) above the surface water standard and PQL. The S-K analysis for these two VOCs showed a statistically insignificant trend. Arsenic (filtered) was detected once (out of seven total results) above the surface water standard and PQL (no background available).	No contiguous plumes of tetrachloroethene or trichloroethene exist in the former Building 991 or well 99301 areas; these AOIs are not widespread in this area and are unlikely to impact surface water quality.
	99405 (99401)	No	Carbon tetrachloride was detected in one sample (out of seven total results) above the surface water standard and PQL. Arsenic (filtered) was detected once (out of six total results) above the surface water standard and PQL (no background available). There were insufficient data for an S-K analysis.	
	91305 (2187)	No	Methylene chloride was detected in 1 sample (out of 20 total results) above the surface water standard and PQL. This measurement is from 1995, and subsequent data are nondetect.	

Table 8.8
Summary of Groundwater Data at Sentinel Wells

Groundwater Plume Area	Sentinel Well(s) Number/ (Former Well Number)	Does it meet the surface water standard for each AOI?	Description/Explanation	Notes/Actions Taken to Disrupt Pathway
			In replacement well 91305, vinyl chloride was detected in one sample (out of one total result).	
Present Landfill	4087	No	Fluoride was detected in 8 samples (out of 22 total results) above surface water standard, PQL, and background (99% UTL). However, no contiguous plume of fluoride exists in the Present Landfill area, and there is a statistically insignificant S-K trend. Sulfate was observed in 6 samples (out of 23 total results) above the background (99% UTL) (background is higher than the surface water standard), with a statistically insignificant S-K trend.	Fluoride was not observed in the area surrounding well 4087, located downgradient (east of the landfill). Hence, fluoride is not widespread and is unlikely to impact surface water quality.
	B206989	No	Nitrate/nitrite was detected in 31 samples (out of 32 total results) above the surface water standard, PQL, and background (99% UTL). There is a statistically insignificant S-K trend for nitrate/nitrite. Arsenic (filtered) was observed in 4 samples (out of 19 total results) above the surface water standard (no background available) with an increasing trend. Sulfate was observed in 12 samples (out of 12 total results) above background (99% UTL), which is higher than the surface water standard (with a statistically insignificant S-K trend). Uranium (sum of isotopes) was observed in two samples (out of two samples) above the surface water standard, but below background. Based on HR ICP/MS or TIMS analysis, the uranium is from natural sources.	No contiguous plume of nitrate exists in the Present Landfill area, nor in the area surrounding well B206989, located downgradient (east of the landfill). Nitrate is not widespread and is unlikely to impact surface water quality.
Original Landfill	N/A	N/A		

Table 8.9
Summary of S-K Trending Analysis at AOC and Sentinel Wells

Station	Filtered	Analyte	S-K Trend	Z Value	Sen's Slope	85th Percentile	Unit	No. of Data Points
51605(1386)	Yes	Nickel	Increasing Trend	5.376	54.39	941	µg/L	34
B206989	Yes	Arsenic	Increasing Trend	2.004	0.6902	9	µg/L	19
B206989	No	Nitrate/Nitrite	Not Significant	-1.791	-985	54100	µg/L	32
P210089	No	Nitrate/Nitrite	Increasing Trend	2.456	5678	200000	µg/L	22
04091	No	Carbon Tetrachloride	Decreasing Trend	-6.078	-0.1944	3	µg/L	32
15699	No	1,1-Dichloroethene	Not Significant	-1.284	-7.837	120	µg/L	11
15699	No	Chloroform	Decreasing Trend	-2.121	-3.661	29	µg/L	11
15699	No	cis-1,2-Dichloroethene	Not Significant	-1.273	-30.63	410	µg/L	11
15699	No	Methylene Chloride	Not Significant	-1.439	-6.205	330	µg/L	11
15699	No	Tetrachloroethene	Not Significant	0	-16.49	920	µg/L	11
15699	No	Trichloroethene	Not Significant	-1.838	-188.2	1900	µg/L	11
20205(20298)	No	Trichloroethene	Not Significant	0	0	8.5	µg/L	9
23296	No	Carbon Tetrachloride	Not Significant	0	0	24.8	µg/L	27
23296	No	Chloroform	Not Significant	-0.3245	-0.09842	24	µg/L	27
23296	No	Chromium	Not Significant	0.4903	0.1287	92	µg/L	15
23296	No	cis-1,2-Dichloroethene	Not Significant	1.013	4.125	150	µg/L	27
23296	No	Methylene Chloride	Decreasing Trend	-2.041	-0.4276	14	µg/L	27
23296	No	Nickel	Not Significant	1.863	7.211	77.3	µg/L	15
23296	No	Tetrachloroethene	Not Significant	-0.3654	-0.1363	19.6	µg/L	27
23296	No	Trichloroethene	Not Significant	-0.649	-9.614	628	µg/L	27
4087	No	Fluoride	Not Significant	1.355	41.66	2800	µg/L	22
52505(1986)	Yes	Arsenic	Not Significant	-0.4071	-0.06501	9	µg/L	25
70693	No	1,1-Dichloroethene	Decreasing Trend	-4.756	-6.028	77	µg/L	21
70693	No	Carbon Tetrachloride	Decreasing Trend	-4.559	-0.4442	6	µg/L	21
70693	No	Chromium	Insufficient Data	-----	-----	179	µg/L	9
70693	No	Nickel	Insufficient Data	-----	-----	190	µg/L	9
70693	No	Tetrachloroethene	Decreasing Trend	-4.185	-0.4141	7	µg/L	21
70693	No	Trichloroethene	Decreasing Trend	-4.689	-2.25	31	µg/L	21
88104(88101)	No	Tetrachloroethene	Insufficient Data	-----	-----	2.46	µg/L	8
90299	No	Carbon Tetrachloride	Not Significant	-0.4359	-0.04716	1.7	µg/L	11
90299	No	Chloroform	Not Significant	0	-0.02332	5	µg/L	11
90299	No	Trichloroethene	Not Significant	-1.141	-0.4409	4.2	µg/L	11
90399	No	Carbon Tetrachloride	Decreasing Trend	-2.638	-43.98	380	µg/L	15
90399	No	Chloroform	Decreasing Trend	-2.334	-5.115	59	µg/L	15

Table 8.9
Summary of S-K Trending Analysis at AOC and Sentinel Wells

Station	Filtered	Analyte	S-K Trend	Z Value	Sen's Slope	85th Percentile	Unit	No. of Data Points
90399	No	Methylene Chloride	Decreasing Trend	-2.677	-0.9103	15	µg/L	15
90399	No	Tetrachloroethene	Decreasing Trend	-2.334	-1.365	12	µg/L	15
90399	No	Trichloroethene	Decreasing Trend	-2.166	-17.99	330	µg/L	15
95199	No	Methylene Chloride	Not Significant	-1.084	0	5	µg/L	14
95199	No	Tetrachloroethene	Not Significant	1.324	0.02723	3.07	µg/L	14
95199	No	Trichloroethene	Not Significant	1.611	4.581	85.1	µg/L	14
99305(99301)	No	Tetrachloroethene	Not Significant	0	0.2219	7.18	µg/L	9
99305(99301)	No	Trichloroethene	Not Significant	0	1.751	58.9	µg/L	9
99405(99401)	No	Carbon Tetrachloride	Insufficient Data	-----	-----	21.7	µg/L	8

Table 8.10
Summary of Groundwater VOC Transport Model Analyses

Groundwater Contaminant Area	Location of Groundwater Discharge to Surface Water	Model PSA[a]	Are the model results conclusive[b]?	Conclusive model results above surface water standard?
Carbon Tetrachloride Plume (Historical IHSS 118.1)	Tributary between former Buildings 371 and 771	14	Yes	Yes (carbon tetrachloride, tetrachloroethene, and trichloroethene)
Historical East Trenches	South Walnut Creek	6,7	Yes	Yes (carbon tetrachloride, tetrachloroethene, and trichloroethene)
Historical SEP	North Walnut Creek	N/A – No VOC sources modeled	N/A	N/A
North Side of Former Building 771[c]	North Walnut Creek	B771(North)	Yes for vinyl chloride	No
Former 700 Area Northeast Plume[d]	North Walnut Creed	15	Inconclusive	No
Historical Mound Site (Historical IHSS 113[c])	South Walnut Creek	5	Yes	No
Historical Oil Burn Pit No. 2	South Walnut Creek	5	Yes	Yes
Historical 903 Pad (Historical IHSS 112)	South Walnut Creek and SID	2S	Yes	Yes (carbon tetrachloride, tetrachloroethene, trichloroethene)
Historical Ryan's Pit (Historical IHSS 109)	South	2S	Yes	Yes (carbon tetrachloride, tetrachloroethene, trichloroethene)
Historical IHSS 119.1 (Historical OU 1)	Woman Creek	9	Inconclusive	No
Former IA Plume Sources	Tributary between former Buildings 371 and 771	12	Inconclusive	No
Historical PU&D Yard	North Walnut Creek and No Name Gulch	PU&D	Yes	No
Historical Oil Burn Pit No. 1	Tributary between former Buildings 371 and 771	13	Yes	No
Former Building 444	SID	10	Inconclusive	No
Former Building 443	South Walnut Creek (near the former Central Avenue)	11	Inconclusive	No
Former Building 991	South Walnut Creek	Area not modeled	N/A	N/A
Mesa top east of the Historical East Trenches	South Walnut Creek	E	Yes	No
Present Landfill	No Name Gulch	PU&D	Yes	No
Original Landfill	Woman Creek	OLF	Yes	No

[a] The results of the modeling are provided in Appendix J of the Groundwater IM/IRA (DOE 2005a) and the Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at the Rocky Flats Environmental Technology Site (K-H 2005b).

[b] Modeling results are conclusive if all 10 to 16 modeling sensitivity runs (less for the Original Landfill) predict results all above or all below the surface water standard. Modeling results are inconclusive if there are sensitivity run results that are above and below the standard. Further details are provided in the Groundwater IM/IRA (DOE 2005a).

[c] See the Modeling Summary Report (K-H 2005b) for details on the modeling results.

[d] This plume is captured by the SPPTS.

[e] The historical Oil Burn Pit No. 2 plume is captured by the Mound French drain and the MSPTS (see Figure 8.5 for its location).

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	Step 1 Identify Analytes to Evaluate	Step 2 Identify Dominant Transport Mechanism(s)	Step 3 Is the AOI present in groundwater and mobile in the subsurface environment?	Step 4 Is the contaminant persistent in the environment?	Step 5 Link to potential surface water impact:		Step 6 Does a complete subsurface transport pathway to surface water exist?	Have actions been taken to disrupt the pathway?
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
Radionuclides	Uranium (sum of isotopes)	Subsurface (Dissolved)[b]	Yes	Yes	Yes North Walnut Creek basin 10594, 1386/51605 South Walnut Creek basin 00997, 15699, 23296 Woman Creek basin 00797	N/A (No modeling conducted)	Yes	Yes SPPTS (North Walnut Creek)
VOCs	cis-1,2-Dichloroethene	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 70299 South Walnut Creek basin 15699, 23296 Woman Creek basin 90399 No Name Gulch basin 4087, B206989	N/A (No modeling conducted)	Yes	Yes MSPTS (South Walnut Creek)

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:** **5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?**[a]	**Step 5** **5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**	**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	1,2-Dichloroethane	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek basin 15699	N/A (No modeling conducted)	No - Limited extent in groundwater. Also, not a surface water AOI.	No action needed for this AOI.
	1,1-Dichloroethene	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek basin 15699	N/A (No modeling conducted)	No - Limited extent in groundwater. Also, not a surface water AOI.	No action needed for this AOI.

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in groundwater and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?	Have actions been taken to disrupt the pathway?
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Benzene	Subsurface (Dissolved)	Yes	Limited persistence	Yes North Walnut Creek basin 1986	N/A (No modeling conducted)	No - Limited extent. Also, not a surface water AOI.	Present Landfill Seep Treatment System
	Carbon Tetrachloride	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek basin 15699, 23296, 91203, 99401 Woman Creek basin 90299, 90399	Yes Areas historically known as: - East Trenches - 903 Pad - Ryan's Pit - Carbon Tetrachloride Plume	Yes	Yes MSPTS ETPTS

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Chloroform	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek basin 15699, 23296, 91203 Woman Creek basin 90299, 90399	- Model results inconclusive	Yes	Yes MSPTS ETPTS
	Chloromethane	Subsurface (Dissolved)	Yes	Yes	Not above surface water standard in AOC or Sentinel wells	- Model results inconclusive	No - Not a surface water AOI	No action needed for this AOI.
	Methylene Chloride	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 20598/20505 South Walnut Creek basin 15699, 23296, 2187/91305, 95199 Woman Creek basin 90399	- Model results inconclusive	Yes	Yes MSPTS ETPTS

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Tetrachloroethene	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 20598/20505, 1386/51605, 37501/37505 South Walnut Creek basin 00997, 04091, 15699, 23296, 91203, 95099, 95199, 99301/99305 Woman Creek basin 11502, 88101/88104, 90399	Yes Areas historically known as: - East Trenches - 903 Pad - Ryan's Pit - Carbon Tetrachloride Plume	Yes	Yes MSPTS ETPTS

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Trichloroethene	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 20598/20505, 10594, 1986/52505, 20298/20205 South Walnut Creek basin 04091, 15699, 23296, 91203, 95199, 99301/99305 Woman Creek basin 90299, 90399	Yes Areas historically known as: - East Trenches - 903 Pad - Ryan's Pit - Carbon Tetrachloride Plume	Yes	Yes MSPTS ETPTS

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Vinyl chloride	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 20598/20505 South Walnut Creek basin 2187/91305	No. - Modeling did not indicate impact to surface water for area north of former Building 771. Other areas not modeled for vinyl chloride.	Yes	No

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in groundwater and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact:		**Step 6** Does a complete subsurface transport pathway to surface water exist?	Have actions been taken to disrupt the pathway?
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
Metals	Arsenic (dissolved)	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 1986/52505, 20298/20205, 20798/20705, 37501 South Walnut Creek basin 00997, 99301/99305, 99401 Woman Creek basin 00193, 90299 No Name Gulch basin B206989	N/A (No modeling conducted)	No - Limited extent in groundwater. Also, not a surface water AOI.	No action needed for this AOI.
	Chromium (total)	Subsurface (Dissolved)	Yes	Yes	Yes South Walnut Creek basin 23296	N/A (No modeling conducted)	No - Limited extent in groundwater, infrequently detected at one Sentinel well.	No action needed for this AOI.

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** Identify Analytes to Evaluate	**Step 2** Identify Dominant Transport Mechanism(s)	**Step 3** Is the AOI present in groundwater and mobile in the subsurface environment?	**Step 4** Is the contaminant persistent in the environment?	**Step 5** Link to potential surface water impact: 5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**Step 5** Link to potential surface water impact: 5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?	**Step 6** Does a complete subsurface transport pathway to surface water exist?	Have actions been taken to disrupt the pathway?
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Nickel (dissolved)	Subsurface (Dissolved)	Yes	Yes	Yes No Name Gulch basin 4087	N/A (No modeling conducted)	No	No action needed for this AOI.
	Nickel (total)	Subsurface (Dissolved)	Yes	Yes	Yes North Walnut Creek basin 1386/51605, 1986/52505, P210089 South Walnut Creek basin 23296	N/A (No modeling conducted)	No	No action needed for this AOI.
Water Quality Parameters	Fluoride	Subsurface (Dissolved)	Yes	Yes	Yes No Name Gulch basin 4087	N/A (No modeling conducted)	No	No action needed for this AOI.

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Nitrate/Nitrite	Subsurface (Dissolved)	Yes	Yes	Yes N. Walnut Creek basin 37501, P210089 No Name Gulch basin B206989	N/A (No modeling conducted)	Yes	Yes. SPPTS (North Walnut Creek) and removal of the historical Bowman's Pond.

Table 8.11
Evaluation of Transport Pathways - Groundwater AOIs to Surface Water

Analyte Group	**Step 1** **Identify Analytes to Evaluate**	**Step 2** **Identify Dominant Transport Mechanism(s)**	**Step 3** **Is the AOI present in groundwater and mobile in the subsurface environment?**	**Step 4** **Is the contaminant persistent in the environment?**	**Step 5** **Link to potential surface water impact:**		**Step 6** **Does a complete subsurface transport pathway to surface water exist?**	**Have actions been taken to disrupt the pathway?**
					5a) Is the groundwater AOI detected above the surface water standard at representative groundwater locations (AOC and Sentinel wells) that suggest a potential impact to surface water?[a]	**5b) Is the groundwater AOI predicted to impact surface water quality, based on models or calculated estimates?**		
	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination)	(Refer to Table 8.2)	(Refer to Section 4.0, Nature and Extent of Groundwater Contamination, and Tables 8.7, 8.8)	(Refer to Table 8.10)		
	Sulfate	Subsurface (Dissolved)	Yes	Yes	Yes N. Walnut Creek basin 10594, P210089 S. Walnut Creek basin 04091, 91305 Woman Creek basin 00193, 00797 No Name Creek basin 4087, B206989	N/A (No modeling conducted)	Yes	No

Table 8.12
Groundwater Monitoring Locations With Stainless-Steel Well Construction and/or Sampling Equipment

Groundwater Sampling Location	Location Type	Chromium AOI	Nickel AOI	Steel Casing	Steel Pump	Abandoned
1187	Monitoring Well	Yes	Yes	Stainless	No	Yes
0271	Monitoring Well	Yes	No	Unknown Steel	No	Yes
0587	Monitoring Well	Yes	No	Stainless	No	Yes
1287	Monitoring Well	Yes	No	Stainless	No	Yes
2587	Monitoring Well	Yes	No	Stainless	No	Yes
4387	Monitoring Well	Yes	No	Stainless	No	Yes
4887[b]	Monitoring Well	Yes	No	Stainless	No	No
5786	Monitoring Well	Yes	No	Stainless	No	Yes
02695	Borehole	Yes	No	No	No	Yes
02995	Borehole	Yes	No	No	No	Yes
12191	Monitoring Well	Yes	No	No	No	Yes
13491	Monitoring Well	Yes	No	No	No	Yes
58693	Borehole	Yes	No	No	No	Yes
60893	Well Point	Yes	No	No	No	Yes
B771UBC01401	Borehole	Yes	No	No	No	Yes
B771UBC01601	Borehole	Yes	No	No	No	Yes
0187	Monitoring Well	No	Yes	Stainless	No	Yes
6386	Monitoring Well	No	Yes	Stainless	No	Yes
6486	Monitoring Well	No	Yes	Stainless	No	Yes
57994	Well Point	No	Yes	No	No	Yes
58194	Well Point	No	Yes	No	No	Yes
58494	Well Point	No	Yes	No	No	Yes
P313589	Monitoring Well	No	Yes	No	No	Yes
P314289	Monitoring Well	No	Yes	No	No	Yes

[a] These groundwater sampling locations are shown on Figure 8.7.

[b] Well 4887 is being retained, in accordance with the FY2005 IMP, Revision 1, for groundwater monitoring of the post-accelerated action condition.

Table 8.13
Summary of Air Emission Sources of Historical Interest and Current Status

Historic Source of Airborne Emissions[a]	Primary Pollutants Emitted	Nature of Emissions	Status/Conclusions	Ongoing Emission Source?
Radionuclide processing/operations and waste handling/storage	Plutonium, americium, uranium	Point source emissions from stacks and vents	No potential sources remain following completion of accelerated actions	No
Radionuclide surface soil contamination (resuspension by wind)	Plutonium, americium, uranium	Fugitive emissions	Minor continuing emissions from residual soil contamination below RSALs	Yes
Tritium	Tritium	Primarily point source emissions from stacks and vents	No potential sources remain (since at least 2000)	No
Beryllium processing/operations and waste handling/storage	Berillium	Point source emissions from stacks and vents	No potential sources remain following completion of accelerated actions	No
Environmental restoration	Plutonium, americium, uranium VOCs PM/PM_{10} CO, NO_x, SO_2, VOCs, PM_{10} (from construction equipment and traffic)	Fugitive and tailpipe emissions	No potential sources remain following completion of accelerated actions	No
Decommissioning/building demolition	Plutonium, americium, uranium PM/PM_{10} CO, NO_x, SO_2, VOCs, PM_{10} (from construction equipment and traffic)	Fugitive and tailpipe emissions	No potential sources remain following completion of accelerated actions	No
Landfills	VOCs, HAPs Landfill gas (methane and CO_2)	Fugitive emissions	Minor continuing emissions; below regulated levels	Yes

Table 8.13
Summary of Air Emission Sources of Historical Interest and Current Status

Historic Source of Airborne Emissions[a]	Primary Pollutants Emitted	Nature of Emissions	Status/Conclusions	Ongoing Emission Source?
VOC soil contamination	VOCs, HAPs	Fugitive emissions	Minor continuing emissions from residual contamination below ALs; past sampling during period of higher potential emissions shows ambient levels below levels of concern	Yes
Uncontaminated fugitive dust sources (traffic, soil disturbances, stockpiles, street sanding, and so forth)	PM/PM_{10}	Fugitive emissions	No potentially significant sources remain following completion of accelerated actions; assuming no significant soil-disturbing activities in future	Possible at low level if soil is mechanically disturbed, or from vehicle operations
Fuel combustion, gasoline dispensing, paint spray booths, tanks, refrigerant leaks, open burning, and so forth	CO, NO_x, SO_2, PM_{10}, VOCs, HAPs, ODS	Both point source and fugitive emissions	No regulated sources/sources requiring permits or APENs remain following completion of accelerated actions	No

[a] Environmental restoration did not remove all contamination, only that above the accelerated ALs. Those areas where contaminant levels did not exceed these levels were not removed.

FIGURES

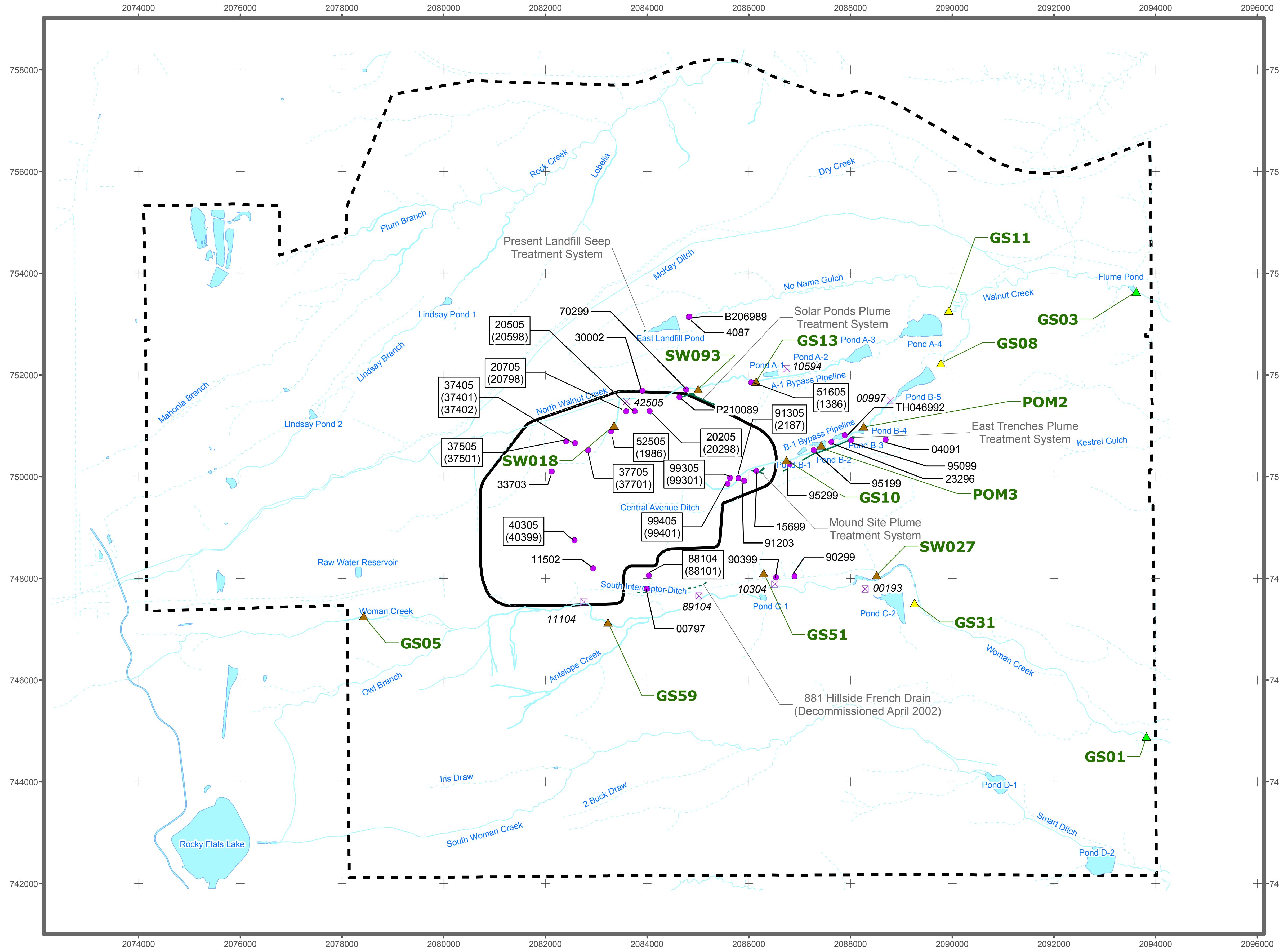

Figure 8.1

Representative Groundwater and Surface Water Monitoring Locations

KEY

- ☒ Area of concern well
- ● Sentinel well
- — Groundwater treatment system
- - - - Decommissioned French drain
- △ Surface water monitoring location representing segment 5
- ▲ Surface water monitoring location representing segments 4a and 4b
- ▲ Surface water monitoring location representing water quality upstream of the terminal ponds

Notes:
1) Groundwater monitoring in the Present Landfill and Original Landfill areas is defined in corresponding RFCA Decision Documents. This is defined and shown in the FY05 IMP.
2) Well identification number in parentheses is the former well number.
3) Sentinel well 45605 was not included on map because it was installed after 8/1/2005.
4) Sentinel well 95299 does not have any data because it has been historically dry.

Standard Map Features

- ▭ IA OU boundary
- 🟦 Pond
- - - Site boundary
- — Perennial stream
- — Intermittent stream
- ···· Ephemeral stream

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Scale 1:24,000

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

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Rocky Flats Environmental
Technology Site

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Figure 8.2
Fate and Transport of Contaminants at RFETS - General Conceptual Model

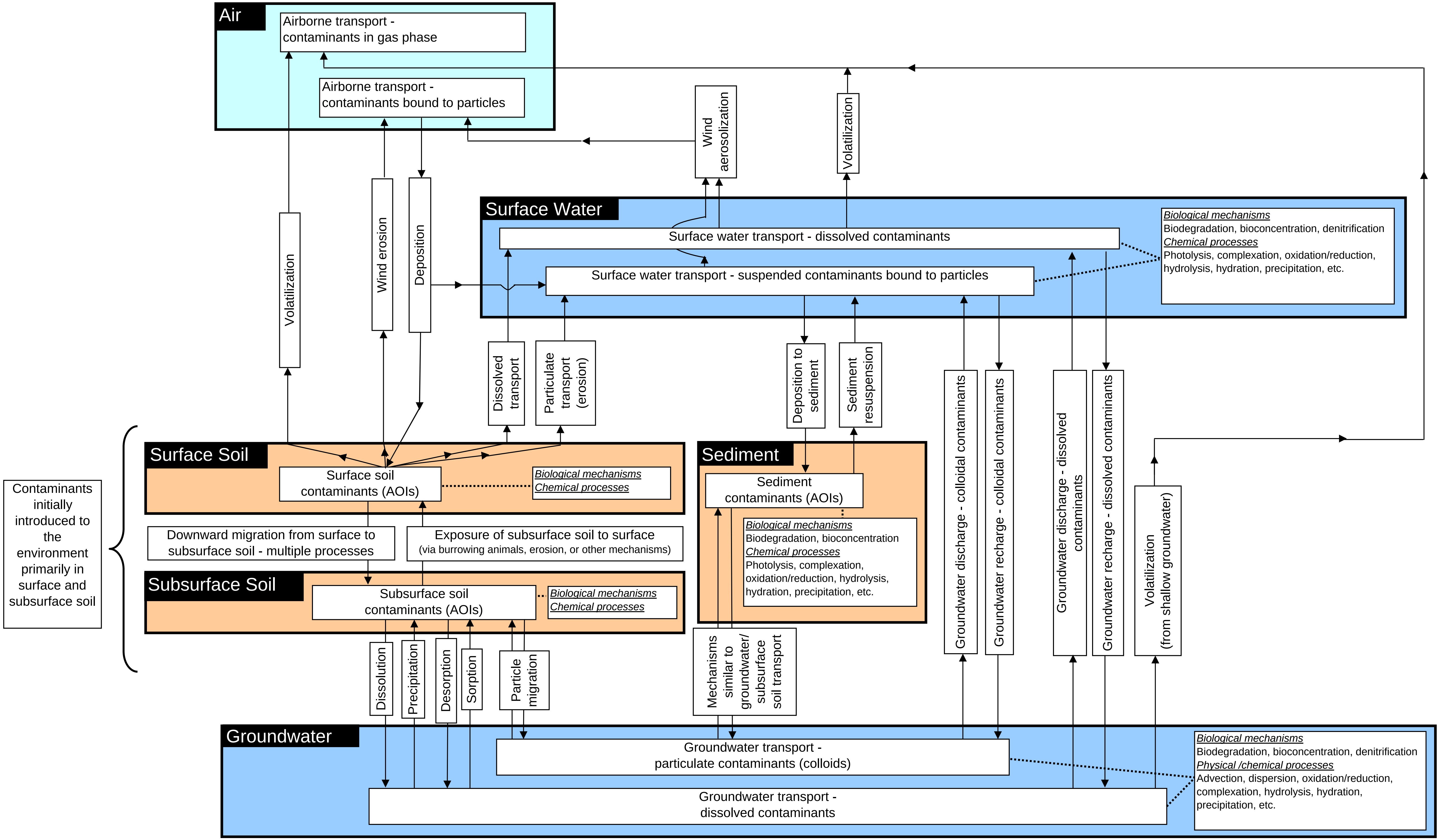
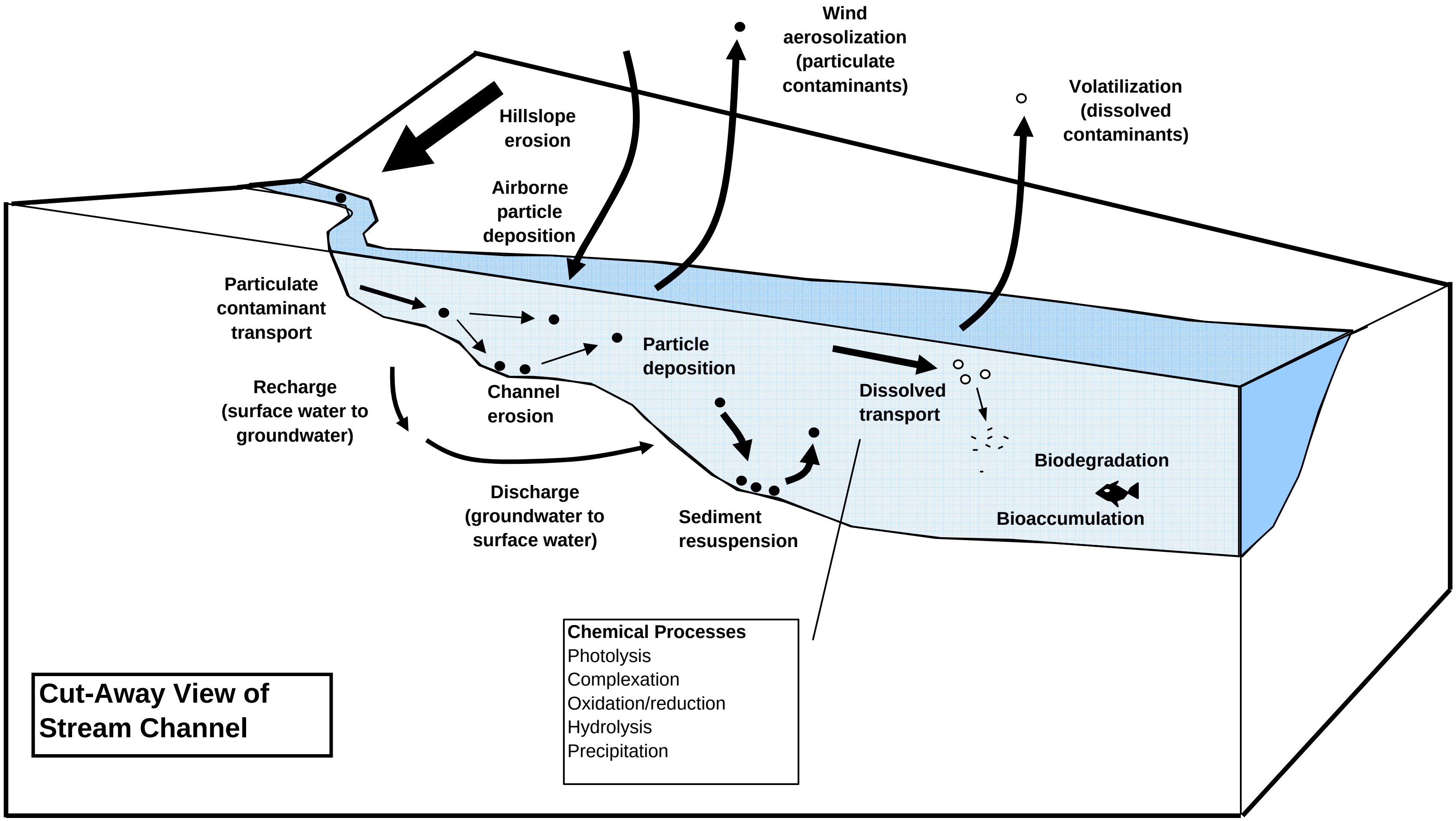
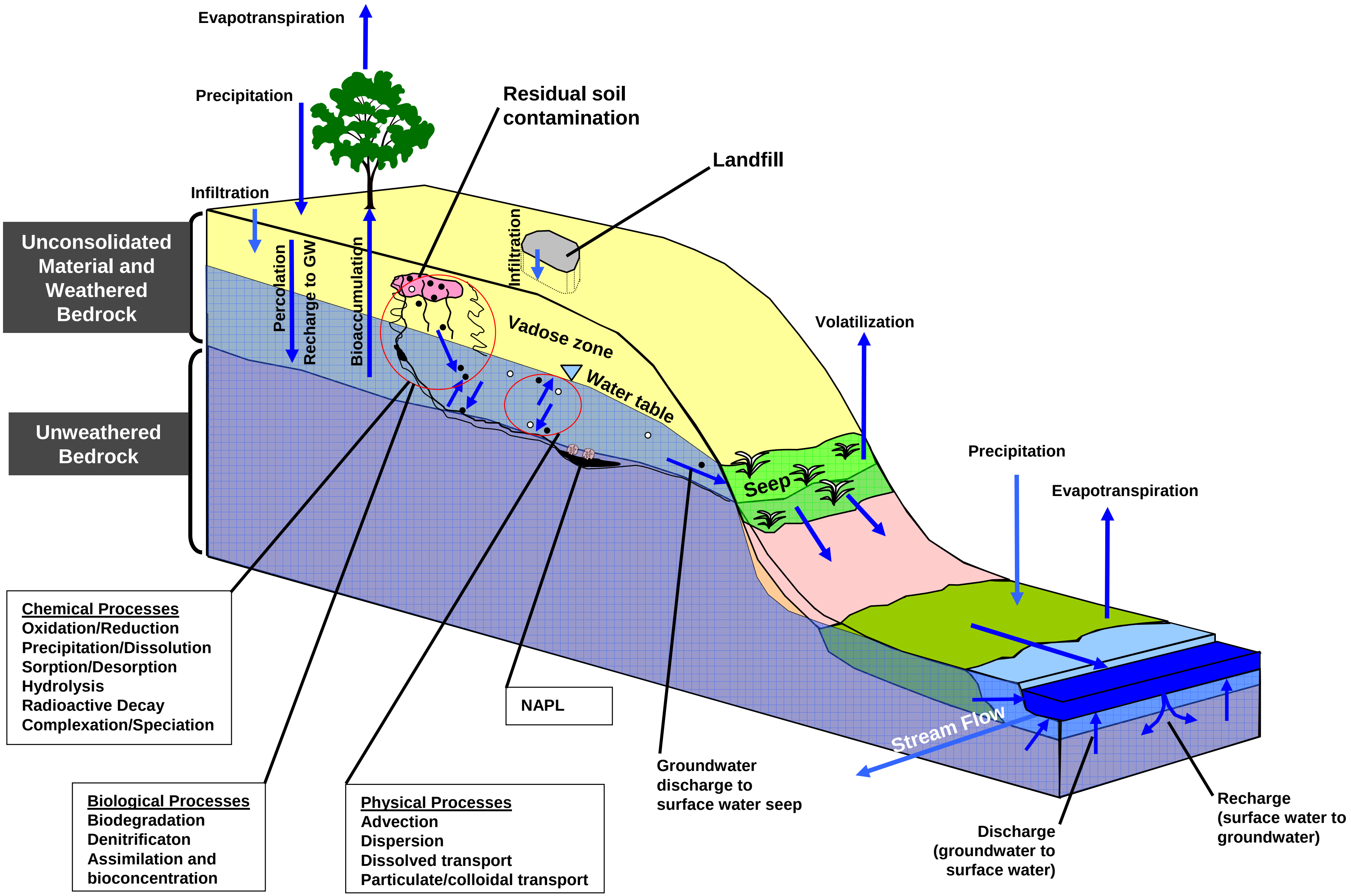


Figure 8.3
Surface Water - Conceptual Model of General Fate and Transport Mechanisms



Chemical Processes
Photolysis
Complexation
Oxidation/reduction
Hydrolysis
Precipitation

Figure 8.4
Groundwater - Conceptual Model of Contaminant Fate and Transport Mechanisms



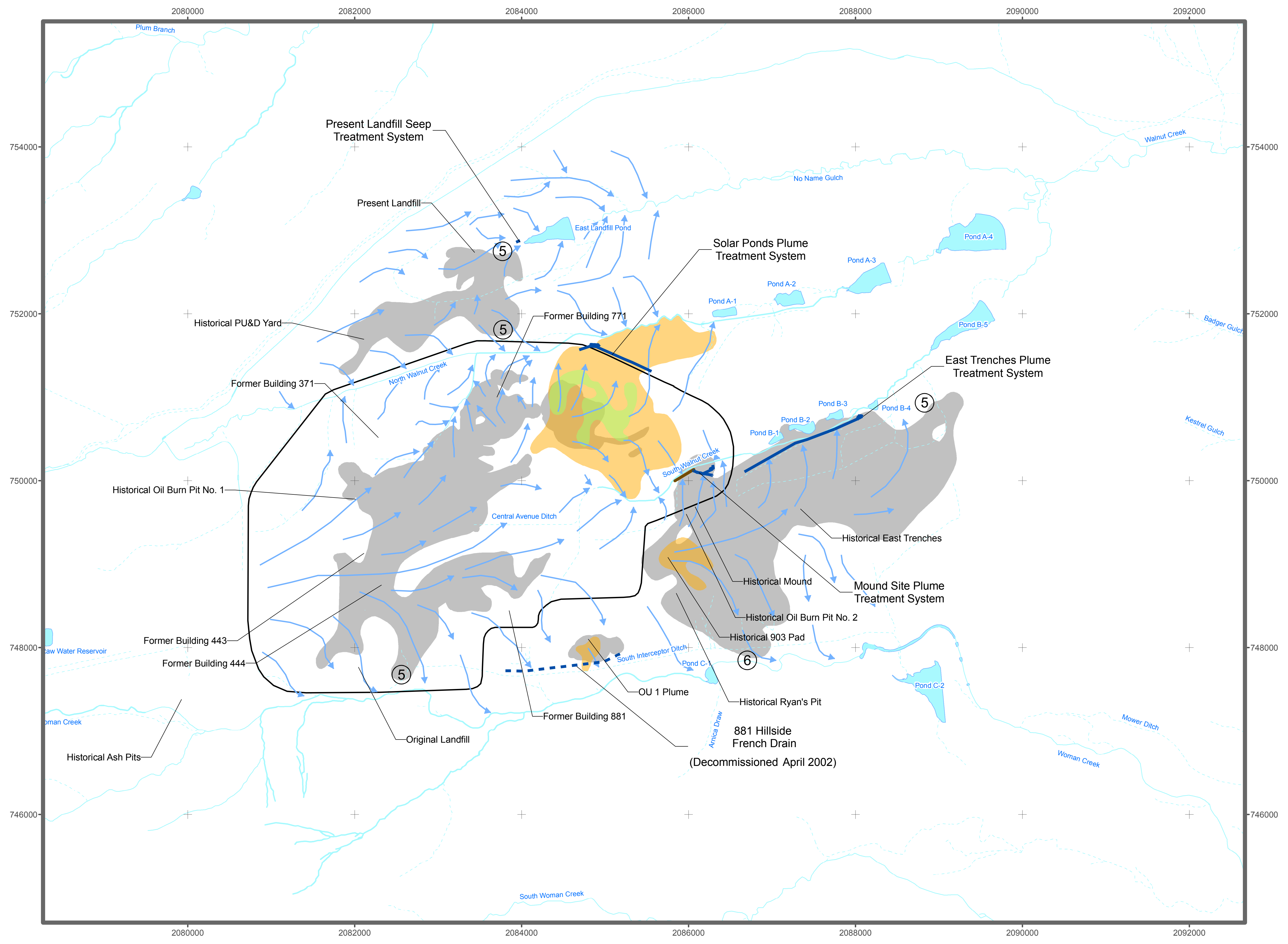


Figure 8.5

Composite Plume Map[1]

KEY

- → Predicted groundwater flow direction (from figure 2.18)[2]
- ━ Groundwater treatment system
- ╍ 881 Hillside French drain
- ━ Mound French drain
- 🟧 Nitrate exceeds the surface water standard
- 🟩 Uranium (unfiltered) exceeds the surface water standard[3]
- ▩ VOC composite plume[4]

Notes:

1) No metals or flouride were included because of their dissimilar transport characteristics.
2) The length of the arrow does not correspond to the groundwater velocity.
3) There is no radionuclide filtered uranium standard and thus it has not been represented on the map. (Uranium that exceeded the metal filtered uranium standard is less than 1% of the data and is also not represented.)
4) The VOC composite plume is all VOC AOIs that exceed the surface water standard.
5) Modeling results indicate that groundwater discharge concentrations will be below surface water standards at these locations.
6) Groundwater in the area is in weathered bedrock and is only saturated during wet years, thus AOI transport is limited to wet years (high groundwater levels). See the Groundwater IM/IRA for details.

Standard Map Features

- ☐ IA OU boundary
- 🟦 Pond
- Perennial stream
- Intermittent stream
- Ephemeral stream

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Scale 1:14,400

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

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Technology Site

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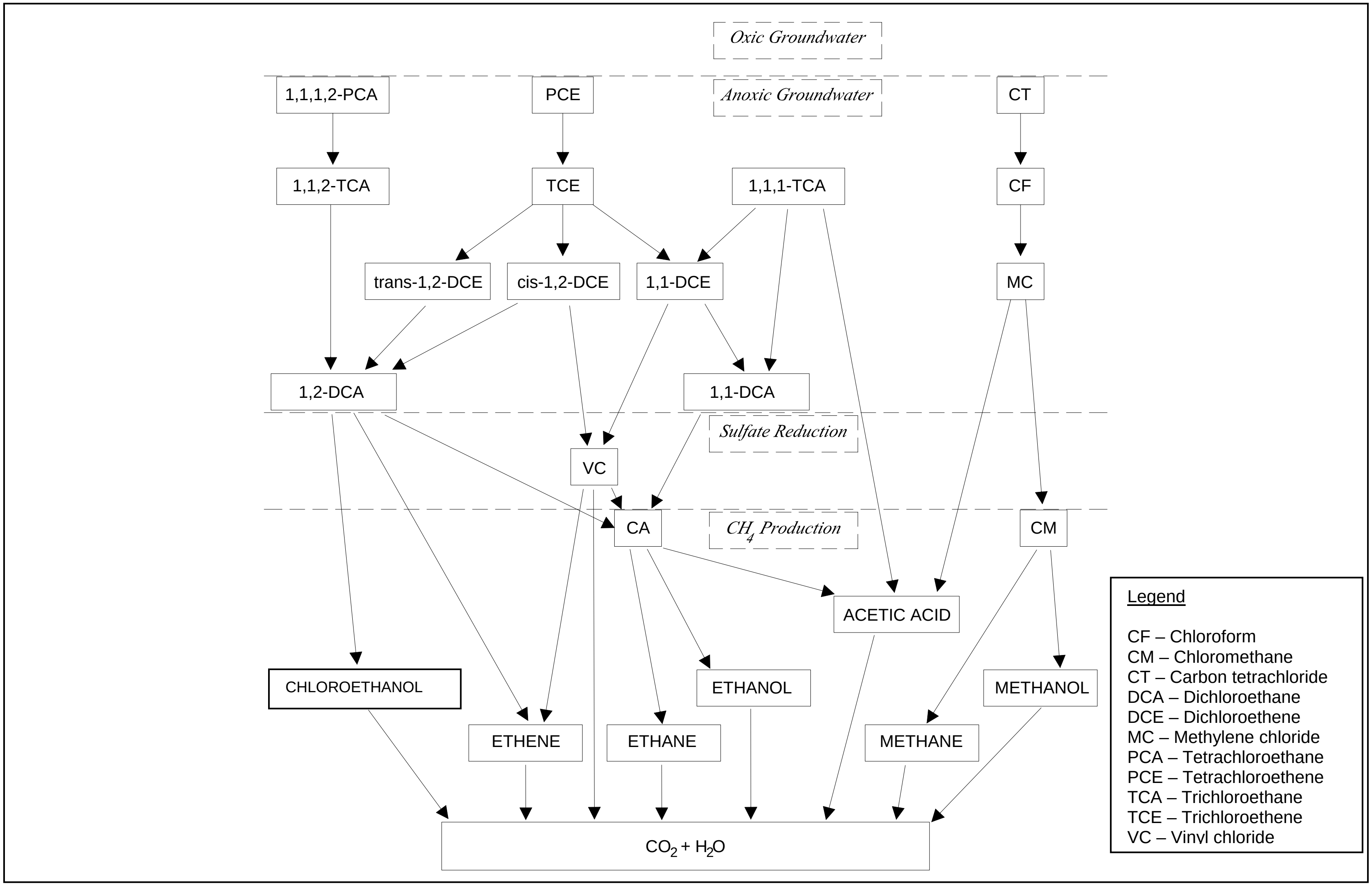
Figure 8.6
Degradation Pathways of Chlorinated Aliphatic Hydrocarbons



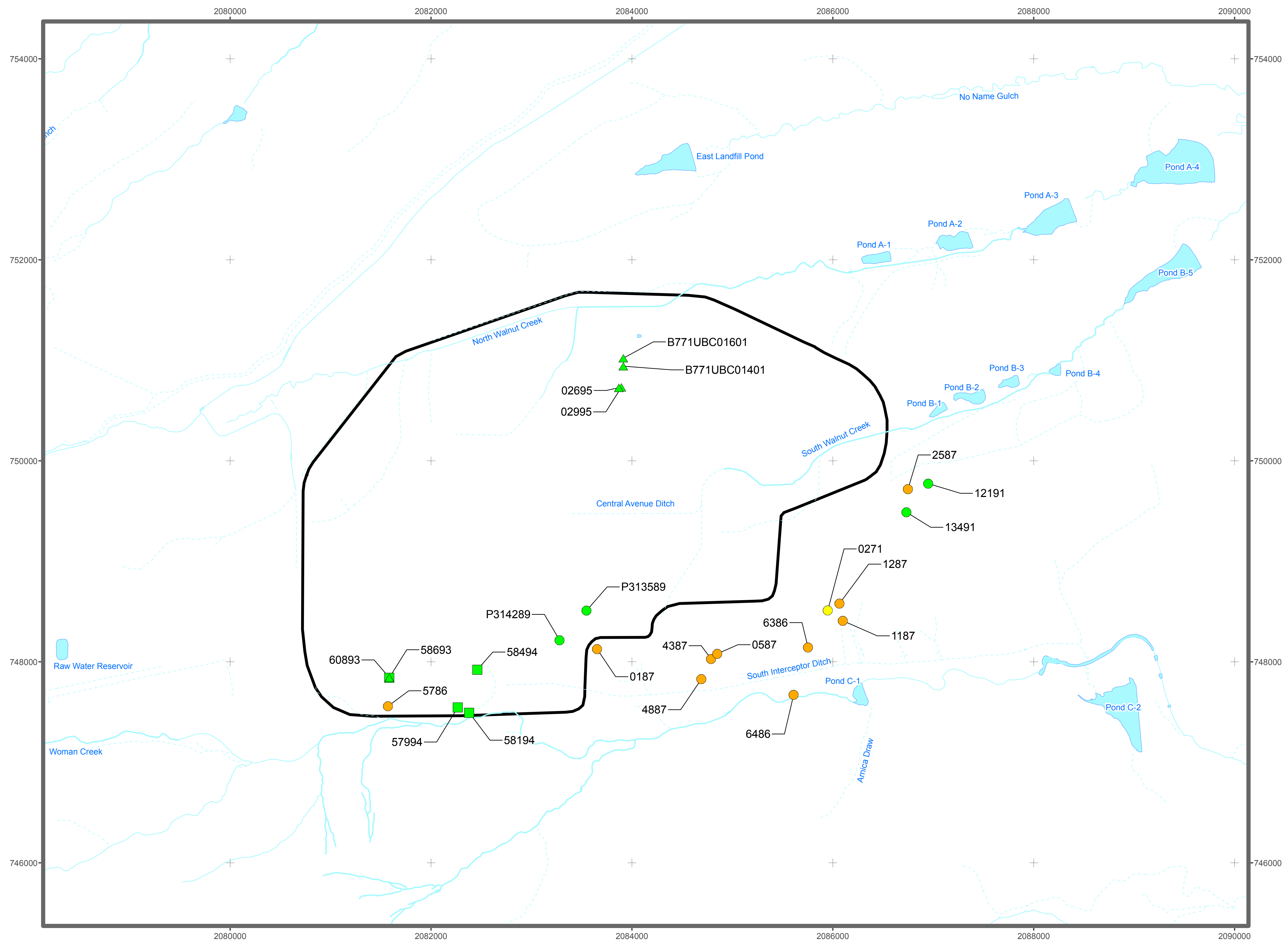


Figure 8.7

Groundwater Monitoring Locations with Stainless-Steel Construction or Sampling Equipment

KEY

Stainless-Steel Well Locations

- ▲ Borehole
- ● Monitoring well
- ● Monitoring well, stainless casing
- ● Monitoring well, unknown steel casing
- ■ Well point

Notes:

1) Groundwater monitoring in the Present Landfill and Original Landfill areas is defined in corresponding RFCA Decision Documents. This is defined and shown in the FY05 IMP.
2) Well identification number in parentheses is the former well number.
3) Sentinel well 45605 was not included on map because it was installed after 8/1/2005.
4) Sentinel well 95299 does not have any data because it has been historically dry.

Standard Map Features

- ▭ IA OU boundary
- ▨ Pond
- ╌ Site boundary
- ─ Perennial stream
- ─ Intermittent stream
- ┄ Ephemeral stream

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State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

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Figure 8.8
Air - Conceptual Model of Contaminant Fate and Transport Mechanisms

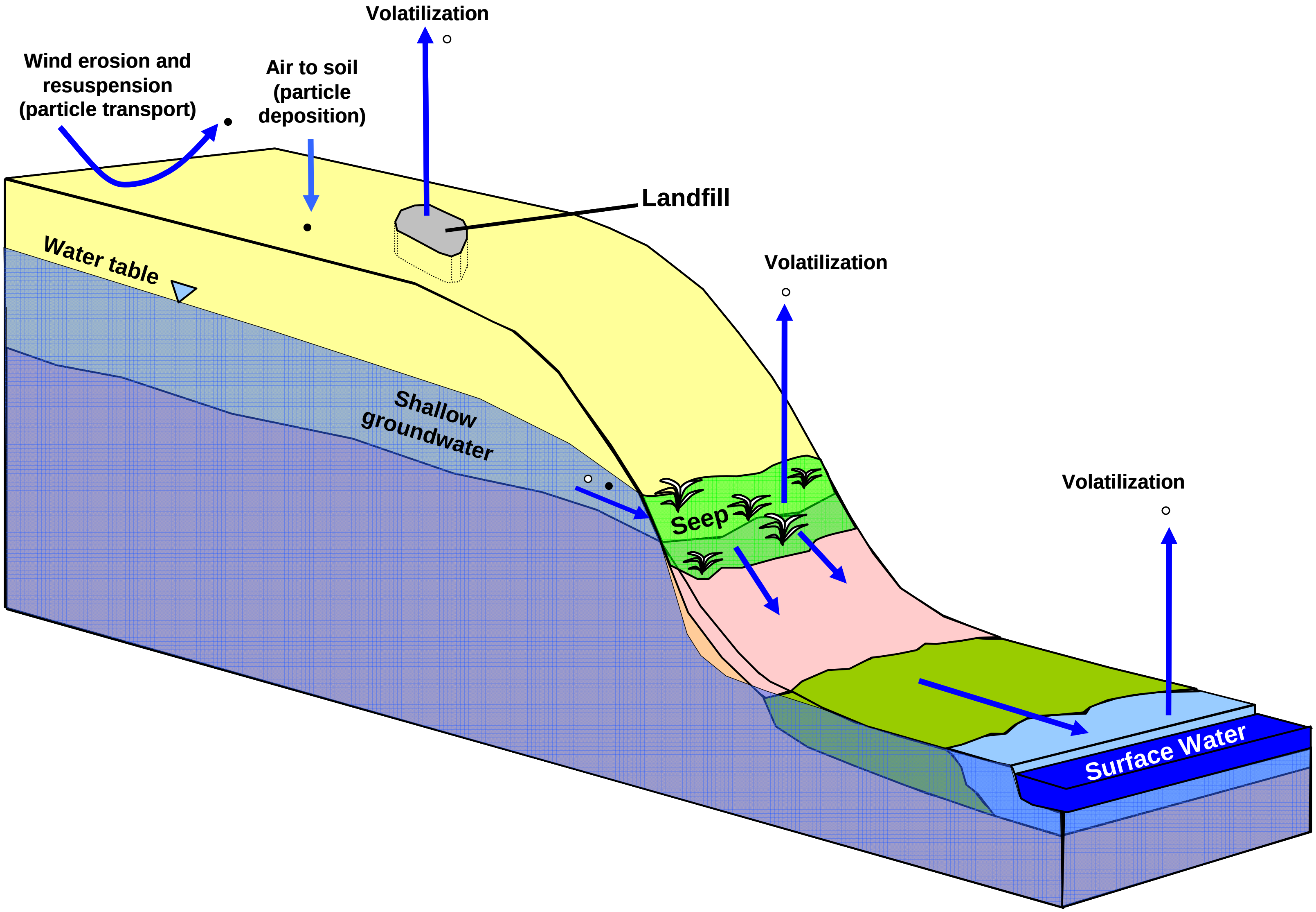
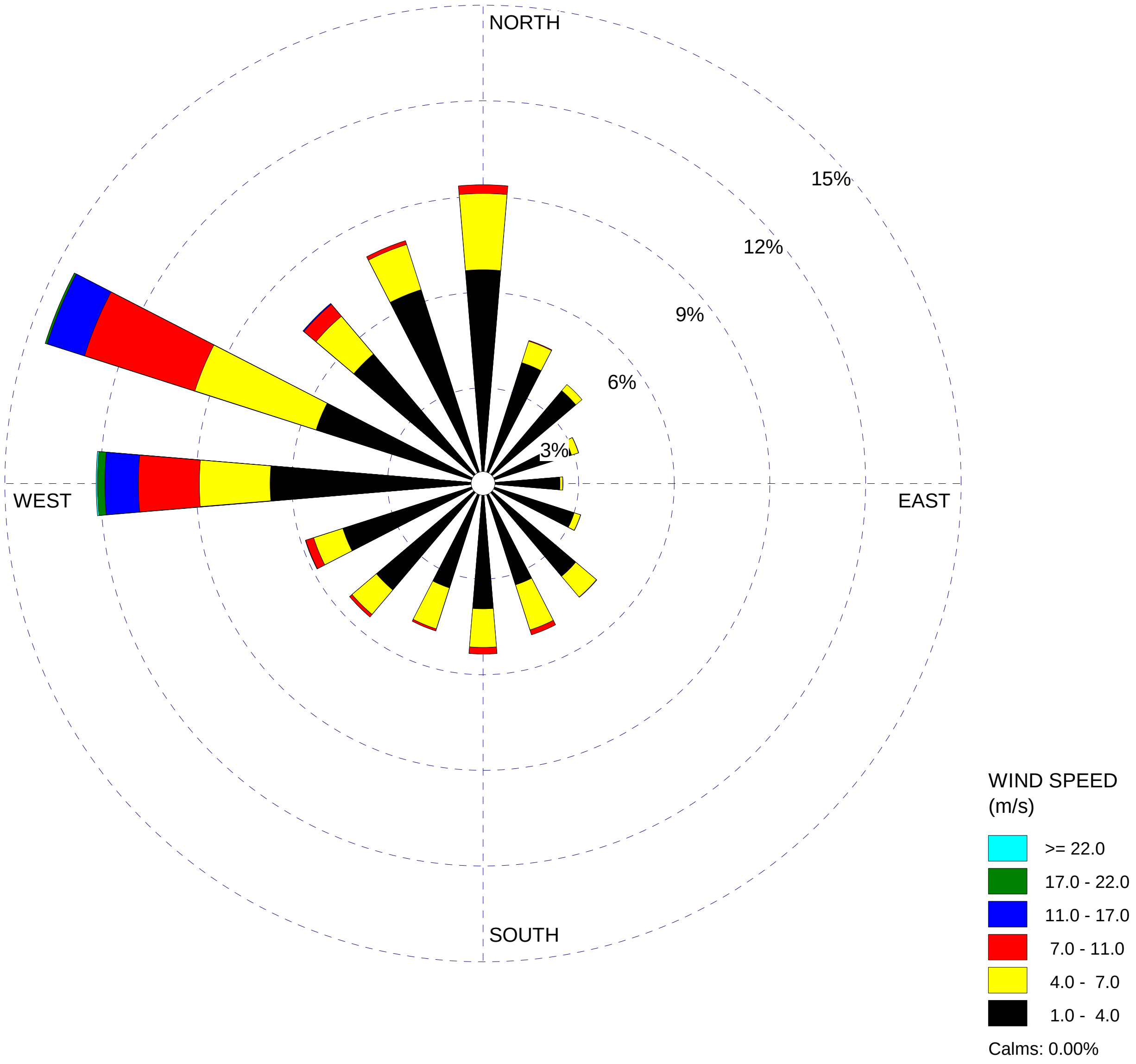


Figure 8.9
2004 RFETS Wind Rose



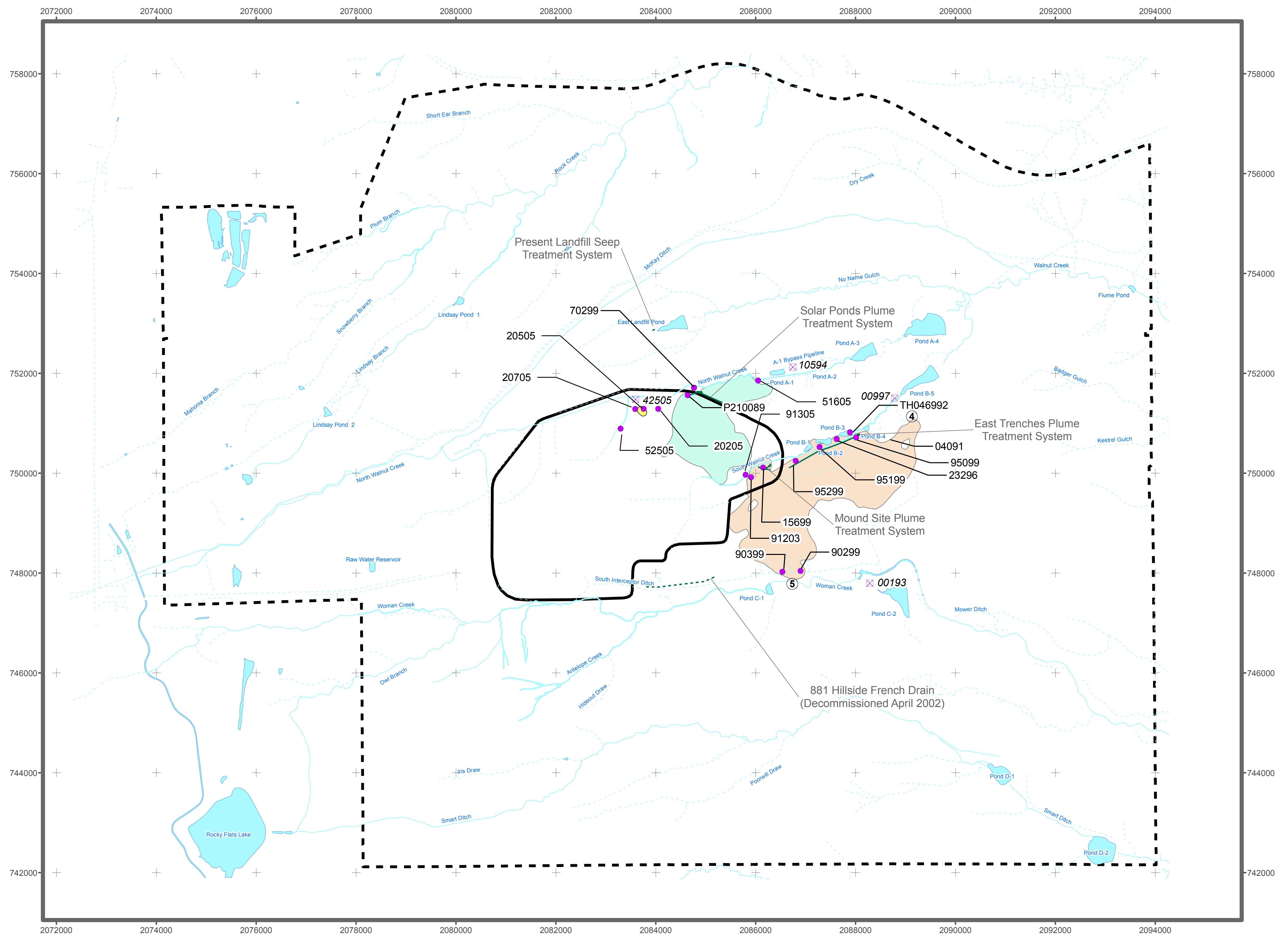


Figure 8.10

Groundwater Areas with Sentinel Wells Above the Higher of the Surface Water Standard, Background, or PQL

KEY

☒	Area of concern well
●	Sentinel well
—	Groundwater treatment system
- - -	Decommissioned French drain
🟨	North of Former Building 771[1]
▭	Historical Solar Ponds Area and former 700 Area Northeast Plume[2]
▭	-Historical East Trenches -Historical 903 Pad/Ryan's Pit -Historical Mound/Oil Burn Pit No. 2[3]

Notes:

1) AOI associated with the area north of former Building 771: trichloroethene.
2) AOIs associated with the historical Solar Ponds area: nitrate/nitrite, sulfate, and uranium. AOI associated with the former 700 Area Northeast Plume: nitrate/nitrite.
3) AOIs associated with the historical East Trenches: carbon tetrachloride, chloroform, tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene. AOIs associated with the historical 903 Pad/Ryan's Pit area (both northern and southern flow paths): carbon tetrachloride, chloroform, tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene. AOIs associated with the historical Mound/Oil Burn Pit No. 2: chloroform, trichloroethene, cis-1,2-dichloroethene, 1,1-dichloroethene, methylene chloride, sulfate, carbon tetrachloride, and tetrachloroethene.
4) Modeling results indicate that groundwater discharge concentrations will be below surface water standards at these locations.
5) Groundwater in the area is in weathered bedrock and is only saturated during wet years, thus AOI transport is limited to wet years (high groundwater levels). See the Groundwater IM/IRA for details.

Standard Map Features

▭	IA OU boundary
▭	Pond
- -	Site boundary
—	Perennial stream
—	Intermittent stream
- -	Ephemeral stream

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Scale 1:24,000

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD 27

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RCRA FACILITY INVESTIGATION-REMEDIAL INVESTIGATION/ CORRECTIVE MEASURES STUDY-FEASIBILITY STUDY REPORT

CONTAMINANT FATE AND TRANSPORT

SECTION 8.0: ATTACHMENT 1

CD ROM, Physical, Chemical, and Biological Processes That Influence Contaminant Transport and Persistence in the Environment

June 2006

RCRA FACILITY INVESTIGATION-REMEDIAL INVESTIGATION/ CORRECTIVE MEASURES STUDY-FEASIBILITY STUDY REPORT

CONTAMINANT FATE AND TRANSPORT

SECTION 8.0: ATTACHMENT 2

CD ROM, Projections of Future Conditions – Groundwater and Air

June 2006

RCRA FACILITY INVESTIGATION – REMEDIAL INVESTIGATION/ CORRECTIVE MEASURES STUDY – FEASIBILITY STUDY REPORT

CONTAMINANT FATE AND TRANSPORT

SECTION 8.0: ATTACHMENT 3

CD ROM, Quantitative Evaluation of Mixture Components in
RFETS Uranium Isotopic Analyses
June 2006

RCRA FACILITY INVESTIGATION – REMEDIAL INVESTIGATION/
CORRECTIVE MEASURES STUDY – FEASIBILITY STUDY REPORT

CONTAMINANT FATE AND TRANSPORT

SECTION 8.0: ATTACHMENT 4

CD ROM, Surface Water AOIs Time-Series Data Plots
Groundwater AOIs Time-Series Data Plots
Air Modeling Methodology and Results

June 2006