ACTINIDE MIGRATION EVALUATION PATHWAY ANALYSIS REPORT TECHNICAL APPENDIX

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ACTINIDE MIGRATION EVALUATION
PATHWAY ANALYSIS REPORT

TECHNICAL APPENDIX

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TA-1 INTRODUCTION AND BACKGROUND

TA-1.1 PURPOSE OF THE PATHWAY REPORT

The purpose of the Actinide Migration Evaluation (AME) Pathway Report is to provide a quantified analysis of the processes that impact movement of actinides in the environment at the Rocky Flats Environmental Technology Site (RFETS or Site). Actinides, for the purposes of this study, refer to plutonium (Pu), americium (Am) and uranium (U).

Evaluation of remedial alternatives for actinide contamination at RFETS must consider migration and mobility along available environmental pathways. Major transport pathways addressed in this study include air, surface water, groundwater and biota. The analysis investigates the physical and chemical interactions between the pathways as well as processes involving surrounding environmental media, including surface soils, sub-surface soils and sediments. The ultimate objective of the study is to quantitatively compare and rank the various pathways in terms of total actinide loads transported off-Site for a given time period.

This report expands upon the pathway analysis work addressed by the AME Conceptual Model document written in 1998 (Kaiser-Hill, 1998; see Section TA-1.4). The Conceptual Model was developed to address the AME goals outlined in Section TA-1.3 with the understanding it would be revised and formally updated as new data are obtained by the AME Group.

TA-1.2 REPORT ORGANIZATION

The Pathway Report is presented in two documents, a Summary Report and a Technical Appendix. The Summary Report provides a condensed review of the major topics and findings presented in the Technical Appendix. The Technical Appendix presents detailed discussions, calculations and literature references to support subjects addressed in the Summary Report.

Technical Appendix headings, table and figure numbers are all preceded with a "TA" to clarify the organization of the Pathway Report. The Technical Appendix is organized in the following manner:

- Section TA-1 presents background information on the development of the Pathway Report, pertinent regulatory issues and general information on the physical characteristics of the Site;
- Section TA-2 presents measured actinide data for RFETS environmental media. Data are presented on related "background" actinide levels in the environment and regulatory limits for different media. Section TA-2 is a presentation of measured Site data without interpretation;
- Section TA-3 addresses Pu, Am and U geochemical transport processes;
- Section TA-4 provides an analysis of actinide transport pathways using measured data *only*;
- Section TA-5 provides an analysis of actinide transport pathways using measured data combined with modeled data. Models provide data for actinide transport pathways where measured data are not available;
- Section TA-6 provides model results of actinide transport for hypothetical extreme environmental conditions;
- Section TA-7 presents the summary, conclusions and implications for Site closure.

TA-1.3 ACTINIDE MIGRATION EVALUATION PROGRAM

The AME group was established in 1996 to provide guidance at RFETS on issues of actinide behavior and mobility in surface water, groundwater, air, soil and biota (Kaiser-Hill, 2000a). The AME activity at RFETS brings together investigations, management and external advisory personnel to facilitate integration and review of RFETS remediation, D&D, monitoring and

project planning. Where appropriate, the external advisory team identifies research, techniques and approaches that can be used to solve short- and long-term issues. The external advisory team covers a broad range of relevant expertise and the advisors are explicitly independent of RFETS-funded projects on AME. Knowledge garnered by the AME group is used to help characterize current RFETS environmental conditions and to recommend a path forward for long-term protection of surface water quality during and after Site closure. Long-term protection of surface water quality at the Site is specified in the Rocky Flats Cleanup Agreement (RFCA)(see Section TA-1.5). Specifically, the goals of the AME are to answer the following questions in the order of urgency shown (Kaiser-Hill, 2000a):

- Urgent: What are the important actinide migration sources and migration processes that account for surface water quality standard exceedances?

- Near-term: What would be the impacts of planned remedial actions on actinide migration? To what level do sources need to be remediated to protect surface water from exceeding action levels for actinides?

- Long-term: How will actinide residual contamination and migration affect surface water quality and Site stewardship after closure?

TA-1.4 CONCEPTUAL MODEL FOR ACTINIDE TRANSPORT

The *Conceptual Model for Actinide Migration Studies at the Rocky Flats Environmental Technology Site* report was written as an initial effort to provide a qualitative understanding of the relationship between actinide sources and transport pathways at RFETS (Kaiser-Hill, 1998). Physical aspects of the Site, including surface and subsurface geology, soils, hydrology and meteorology were discussed in terms of their impact on actinide fate and transport.

As noted in the Conceptual Model report, the transport of actinides in the environment involves complex chemical and physical processes dependent on the type and source of the actinide as well as the influence of the surrounding environmental media. To facilitate understanding the potential routes for actinide transport at RFETS, a graphic depiction of the multiple potential actinide transport pathways was included in the Conceptual Model Diagram (see Figure TA-1-1). Further detail on suspected major and minor pathways and their variability with different actinides was also diagrammed in the Conceptual Model. These more detailed conceptual pathway schematics are presented in Section TA-4. They provide an initial model to be tested and expanded upon by the pathway analysis described in this report.

TA-1.5 REGULATORY FRAMEWORK

The RFCA Action Level Framework (ALF) sets forth standards and action levels for environmental media (DOE, 1996). These standards and action levels incorporate the RFCA vision and land- and water-use controls in the RFETS cleanup. Surface water action levels for Point of Evaluation (POE) monitoring locations and standards for Point of Compliance (POC) monitoring locations, are 0.15 picoCuries per liter (pCi/L) for both Pu and Am. These standards and action levels are based upon human health risk based on ingestion of surface water over a 30-year period.

The Site's surface water quality standard for total U is currently set at 10 pCi/L for Walnut Creek and 11 pCi/L for Woman Creek based on ambient levels in Site surface waters. In comparison, the Environmental Protection Agency (EPA) promulgated a total U Maximum Contaminant Level (MCL) of 30 micrograms per liter (μg/L) for drinking water on December 7, 2000 (Federal Register, 2000). The ruling noted that treating drinking water to below 20 μg/L was not considered feasible. Converting mass to activity, the 30 μg/L total U MCL corresponds to a total U activity of approximately 20 pCi/L using the isotopic proportions typically found in surface water at RFETS. Measured total U concentrations in surface water at RFETS from Water Years

1997 through 1999, at POE and POC monitoring stations, averaged approximately 2 to 5 μg/L or roughly one order of magnitude less than the recently established MCL for drinking water.

The RFCA soil action levels (Section TA-3.3.2) do not take into account the transport of soil containing actinides to surface water. This is because it was assumed, when the soil action levels were calculated, that there would be no consumption of groundwater or surface water (Rocky Mountain Remediation Services [RMRS], 1997). The soil radionuclide action levels must be assessed for long-term protectiveness of surface water. The RFCA states "protection of surface water uses with respect to the long-term Site condition will be the basis for making soil and groundwater remediation and management decisions and that additional groundwater or soil remediation or management may be required for the protection of surface water quality or ecological resources (DOE, 1996)."

TA-1.6 BACKGROUND SITE DESCRIPTION

TA-1.6.1 General Site Description

RFETS is located 16 miles northwest of Denver in Jefferson County, Colorado. Owned by the United States Department of Energy (DOE), the former nuclear weapons facility encompasses approximately 6,550 acres of federally owned land (Figure TA-1-2). Major plant structures, including all former production buildings, are located within a centralized 385-acre Industrial Area that is surrounded by a 6,165-acre Buffer Zone (EG&G, 1993a). From its first construction in 1951, the Site evolved into a complex of over 440 permanent and temporary structures used as manufacturing, chemical processing, laboratory, support and administrative facilities (DOE, 1995). Production operations occurred from 1952 until 1989, at which time RFETS was added to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) National Priorities List for environmental cleanup. Site-specific regulatory requirements for remediation and closure were established in 1995 when RFCA was signed by the DOE, EPA and Colorado Department of Public Health and Environment (CDPHE) (DOE, 1996).

The plant produced components for nuclear weapons made from Pu, U, beryllium and stainless steel. Other production activities included chemical recovery and purification of recyclable transuranic radionuclides, metal fabrication and assembly and related quality control functions. The plant conducted research and development programs in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry and physics. Parts manufactured at the Site were shipped to other locations for final assembly.

Site operations generated solid and liquid nonhazardous, hazardous, radioactive and mixed (hazardous and radioactive) waste streams. These wastes have been handled and disposed of in a variety of ways. Solid nonhazardous and nonradioactive wastes are recycled, stored on Site, or shipped off Site for recycling, treatment or disposal.

TA-1.6.2 Climate

Basic climatological information, including general descriptions of precipitation, temperature and wind patterns, is pertinent to understanding the hydrologic setting and actinide migration potential of environmental media at RFETS (RMRS, 1997). For example, precipitation amount, frequency, intensity and seasonality (combined with air temperatures, humidity and wind conditions) influence the erosion potential due to wind and water, groundwater recharge and evapotranspiration.

The RFETS climate is temperate and semiarid, characteristic of Colorado's Front Range. The dry atmosphere of the Site at 1,830 meters (m) (6,000 foot [ft]) elevation above mean sea level (MSL) often causes wide temperature fluctuations between daytime and nighttime. Summer high temperatures are typically in the upper-20 degrees Centigrade (°C)(equivalent to mid-80 degrees Fahrenheit [°F]), with nighttime lows falling to approximately 16°C (60°F) (EG&G, 1993b). During the winter, temperatures typically range from 4°C to 7°C (40°F to 45°F) during the day and -9°C to -4°C (15°F to 25°F) at night. Arctic and Siberian air masses occasionally

bring frigid air during the winter when low temperatures may drop to between -21°C and -24°C (-5°F and -12°F) (EG&G, 1993b).

Precipitation

The average annual precipitation based on 30 years of record is approximately 368 millimeters (mm) (14.5 inches [in]) (DOE, 1995). Roughly half of the precipitation occurs as rain and half as snow, with precipitation falling primarily as snow from late October through early April and as rain during the remaining months (RMRS, 1997). Annual snowfall averages approximately 1,778 mm (70 in), with the highest monthly snowfall average (approximately 406 mm [16 in]) occurring in March (EG&G, 1993b). Rainfall is highest from April through June, with nearly 42 % of the average annual precipitation occurring during those months (EG&G, 1993b). The average monthly distribution of precipitation, based on data collected at the Site 61-meter meteorological tower from 1993 through 1999, is shown in Figure TA-1-3.

These precipitation data cover the time frame, from Water Year 1997 through 1999 (October 1996 through September 1999), during which the surface water actinide data presented in Section TA-2 were collected. This precipitation record was also used to calculate estimated erosion rates, presented in Section TA-5, to predict actinide transport in surface water runoff.

Analysis of Precipitation for Water Years 1997 Through 1999

Surface water actinide data from Water Years 1997 through 1999 are analyzed later in this report because similar sampling protocols were used at multiple locations throughout the Site during this time frame. This allowed for reasonable comparison of data from different sampling locations. To determine whether this three-year period of study was relatively wet or dry compared to normal, an analysis was performed to compare RFETS precipitation data with other precipitation gages in the region that have longer historical precipitation records.

Monthly total precipitation data were obtained from two sources, the Colorado Climate Center (CCC) and the National Climate Data Center (NCDC), for five National Oceanic and Atmospheric Administration (NOAA) monitoring stations (CCC, 2001 and NCDC, 2001). These stations, their NOAA station numbers and their data sources are listed in Table TA-1-1. These stations were chosen based on their proximity to RFETS, the available period of record and, in the case of the Fort Collins station, because previous RFETS studies had used the station for comparison.

Table TA-1-1. NOAA Precipitation Stations Used to Compare with RFETS Data

Station	NOAA Station #	Data Source
Boulder	50848	Colorado Climate Center
Denver	52220	National Climate Data Center
Fort Collins	53005	National Climate Data Center
Lakewood	54762	National Climate Data Center
Ralston	56816	Colorado Climate Center

Monthly precipitation records from each of the stations for Water Years 1997 through 1999 were plotted against the corresponding monthly precipitation depth measured at RFETS (Figure TA-1-4). The Boulder station has the best correlation with the RFETS data ($R^2 = 0.79$), followed by the Ralston Reservoir and Lakewood stations. During Water Years 1997 through 1999, the Boulder, Lakewood and Fort Collins stations contain a complete data set, while the Ralston Reservoir and Denver stations have missing months in their data sets.

The Boulder station was used as the reference to compare with the RFETS record because it had the best correlation with the RFETS precipitation data. The difference in monthly precipitation for Water Years 1997 through 1999 with the normal precipitation at the Boulder station was plotted (Figure TA-1-5). Normal monthly precipitation depths for the Boulder station are based

on a period of record from 1961-1990. Both the Boulder and RFETS stations followed the same trend with Water Year 1999 having the greatest amount of precipitation followed by Water Years 1997 and 1998. Precipitation at the Boulder station for Water Years 1997-1999 exceeded the normal by approximately 490 mm (19.3 in) over the three-year period as shown in Figure TA-1-5. The Boulder station record provides a better historical basis than the more limited RFETS record to indicate that the three-year period of study, from Water Years 1997 through 1999, received above-normal precipitation.

Evapotranspiration

Evapotranspiration averages over 400 mm (16 in) per year, creating a water deficit in most years (Wright Water Engineers, Inc. [WWE], 1995). Much of the runoff feeding the Site's drainages occurs rapidly, originating from the mainly impervious Industrial Area surfaces (RMRS, 1998). RFETS is located in a semi-arid environment. For perspective, evapotranspiration in a humid environment, such as Florida, can average over 890 mm (35 in) per year (Hanson et al., 1991).

Winds

Winds at RFETS are predominantly from the northwest toward the southeast. This wind pattern reflects the influence of local terrain combined with prevailing winds from west to east. Winds at RFETS average approximately 4 meters per second (m/s) (9 miles per hour [mph]), with a range from zero (calm) to sustained winds over 18 m/s (40 mph), with gusts to over 45 m/s (100 mph). Figure TA-1-6 shows the joint wind speed and direction distribution (wind rose) for 1999. Wind speed data for 1997, 1998 and 1999 were used to develop models, presented in Section TA-5 that forecast actinide transport via the air pathway.

RFETS is noted for the periodic occurrence of strong, gusty winds, which can be an important factor in the resuspension of soil and actinides. Higher wind speeds may be associated with thunderstorms and the passage of weather fronts, while the highest wind speeds typically occur with storms from the west called Chinooks (EG&G, 1993b). These windstorms occur from late

November into April, but reach their height around January in most years. Chinook winds occur when air masses are forced over the Continental Divide. The air masses warm and dry out, as they compress on the eastern side of the mountains. The steep-sided canyons along the Front Range tend to channel the airflow, which also contributes to high wind speeds.

Other flow patterns also occur at RFETS. Moderately strong winds from the north or from the south are common in winter and summer, respectively. During periods of atmospheric stability, when regional flow patterns are weak, thermally driven upslope and downslope flow predominates, with downslope flow at night and upslope during the day. Winds from the east can also occur following frontal passages. These upslope events may be associated with heavy snowfall or other precipitation. A more detailed summary of the climatology and meteorology at the Site is provided in the *RFETS Historical Data Summary* (Aerovironment, 1995).

TA-1.6.3 Geology

The Site is situated approximately two miles east of the Front Range of Colorado, on the western margin of the Colorado Piedmont section of the Great Plains Physiographic Province (Spencer, 1961). Geologic units at RFETS can be grouped into two general categories: unconsolidated surficial deposits and underlying consolidated bedrock (RMRS, 1999a). The surficial geologic unit has a relatively shallow agricultural soil horizon that developed by *in situ* weathering processes and/or erosion of the geologic units. Soils information is important for understanding actinide transport based on microbiologic processes, water balances, vegetation, erosion, infiltration and runoff all of which impact actinide transport and vary with different soil environments. An understanding of the Site geology is necessary when discussing contaminant transport because of the sub-surface pathways that may exist. General descriptions of the soils and major geologic units at RFETS are provided in the following sections.

Soils

The United States Department of Agriculture (USDA) Soil Conservation Service (SCS) developed map unit models on aerial photographs to reasonably predict the types of soils that have formed near the surface on the geologic units in the area. The boundaries of the soil map units were refined and the map unit models were tested by digging test pits and recording the characteristics of the soil profiles (EG&G, 1995b). A soils map for the Site is presented in Figure TA-1-7.

The RFETS geologic map units are described in the *Geologic Characterization Report for the Rocky Flats Environmental Technology Site, Final Report, Volume I of the Sitewide Geoscience Characterization Study* (EG&G, 1995b). The geologic map units are shown in Figure TA-1-8. A comparison between the agricultural soils map (Figure TA-1-7) and the geologic map (Figure TA-1-8) illustrates the relationship between agricultural soils and geologic map units. Generally, there are four agricultural soil types at RFETS that are associated with the geologic units as follows:

- Pediment (flat upland areas) soils are located on the broad, dissected, eastward-sloping pediment surface in the western portion of the Site. These soils are associated with the Rocky Flats Alluvium (Qrf) geologic map unit;

- Valley slope soils are located in the stream-cut valleys of the intermittent Rock Creek, Walnut Creek and Woman Creek drainages. These are associated with the Laramie Formation (KI), Arapahoe Formation (Ka) and Landslide (Qls) geologic map units;

- Hilltop soils of the eastern third of RFETS are similar to valley slope soils and are associated with the Laramie (KI) and Arapahoe (Ka) Formations. Localized areas on hill summits are associated with Terrace Alluvium (Qta); and

- Drainage bottom soils form in recent alluvium (Qa) along drainage bottoms.

Unconsolidated Surficial Deposits

Approximately 99 % of the Site is covered with surficial deposits that include artificial fill, colluvial, landslide and alluvial deposits. A generalized stratigraphic cross-section, including unconsolidated and consolidated layers, shows the vertical sequence of geologic units (Figure TA- 1-9).

Surficial deposits range in thickness from zero to 30.5 meters (0 to 100 feet) (EG&G, 1995b). The unconsolidated surficial deposits, combined with the weathered portion of subcropping bedrock formations, have the greatest importance regarding groundwater flow and contaminant transport at the Site (Rocky Mountain Remediation Services [RMRS], 1999). Further detail on the various types of surficial deposits found at RFETS is provided below.

Artificial Fill Materials

These materials are present across the Site including road and railroad embankments, earth dams and other engineered fills, as well as compacted and uncompacted landfills and spoil piles along some of the irrigation ditches. The artificial deposits are commonly less than 3.05 meters (10 feet) thick, although some of the earth dams and landfills are greater than 9.1 meters (30 feet) thick. Most of these deposits are relatively impermeable and restrict groundwater flow (EG&G, 1995c).

Colluvial Deposits

This material covers the steep hill slopes in the incised stream drainages (EG&G, 1995b). These middle Pleistocene to Holocene deposits were derived from older alluvial units and bedrock and were deposited by sheet wash and soil creep. Colluvial deposits range in thickness from 0.9 to 4.6 meters (3 to 15 feet). Lithologically, the colluvium consists of silty sand, sandy silt, clayey silt and silty clay with pebbles and cobbles. These deposits are typically poorly sorted and

poorly stratified. Colluvial deposits are variably saturated and colluvial groundwater tends to flow downslope following paleogullies developed on the bedrock surface.

Landslide Deposits

These deposits are present along the steep hill slopes in the incised drainages (EG&G, 1995c). These middle Pleistocene to Holocene deposits include earth flows, earth slumps, debris flows, debris slumps, rock-block slides and complex landslides. These deposits range in thickness from 3 to 30.5 meters (10 to 100 feet). Landslide scarps are present in all of the drainages in the map area and are most numerous in the Rock Creek drainage (EG&G, 1995b). Landslides are commonly located downgradient from alluvial or bedrock groundwater discharge areas. Groundwater discharge increases the saturation within downgradient soils, leading to failure of the material.

Alluvial Deposits

Alluvial deposits have been mapped in floodplains, stream channels and terraces along the drainages across the Site and include valley-fill alluvium, undifferentiated alluvium and Rocky Flats Alluvium. Valley-fill alluvium includes the Pleistocene Louviers, Broadway and pre-Piney Creek Alluvium and the Holocene Piney Creek and post-Piney Creek alluvial units. Valley-fill alluvium consists of channel and terrace deposits in and along most of the ephemeral streams that cross the Site (EG&G, 1995b).

Valley-fill alluvium ranges in thickness from 3 to 12.2 meters (10 to 40 feet) and is variably saturated. The valley-fill alluvium is permeable and may provide preferential pathways for groundwater migration. Undifferentiated alluvial deposits include the Pleistocene Slocum Alluvium and Verdos Alluvium of Shroba and Carrara (1994). These units form small remnants of pediment or terrace deposits primarily in the southeastern portion of the RFETS. The undifferentiated alluvial deposits range in thickness from 1.5 to 6.1 meters (5 to 20 feet), but this unit is not a significant component of the hydrologic system on the Site (EG&G, 1995c).

The Rocky Flats Alluvium caps the pediment at the Site. These Pleistocene sediments were deposited as alluvial fans along the eastern edge of the Front Range. The deposit diminishes from west to east with thicknesses ranging from approximately 30.5 to less than 0.3 meters (100 to less than 1 foot). In the central portion of the Site the deposit is approximately 35.1 to 7.6 meters (15 to 25 feet) thick (RMRS, 1999). Thicker deposits correspond to paleoscours and thinner deposits occur along the crests of paleoridges. Groundwater flow within the Rocky Flats Alluvium is influenced by the topography of the underlying bedrock surface (paleotopography), the geometry and lithology of alluvial lithofacies and the regional hydraulic gradient.

Consolidated Bedrock Deposits

Bedrock from the Arapahoe, Laramie, Fox Hills and uppermost Cretaceous Pierre Formations are present at RFETS (Figure TA- 1-9) (EG&G, 1995c). Further detail on these bedrock deposits is provided below.

Arapahoe Formation

The Arapahoe Formation is composed of claystone and silty claystone with lenticular sandstone in the basal portion of the formation. The Arapahoe Formation is generally less than 7.6 meters (25 feet) thick at the Site, occurring as erosional remnants of fine-grained sandstone above the Laramie Formation at various locations on the Site (EG&G, 1995c). This basal Arapahoe Formation sandstone, which is currently defined as the No. 1 Sandstone, is of concern as a potential contamination pathway, especially where it subcrops beneath the alluvial/bedrock unconformity.

Laramie and Fox Hills Sandstone Formations

The Laramie Formation is approximately 180 to 245 meters (590 to 800 feet) thick and is composed of a lower sandstone/claystone/coal interval and an upper, thick claystone interval. Within the upper claystone interval, thin, lenticular sandstone lenses occur (EG&G, 1991). The discontinuous nature of these sandstone lenses coupled with the large claystone layer that

encloses them mitigates their potential for transmitting groundwater contamination in both horizontal and vertical directions.

The Fox Hills sandstone is primarily fine-grained sandstone with thin siltstone and claystone interbeds and an approximate thickness of between 20 and 40 meters (65 and 130 feet) contamination (Figure TA- 1-9). The Fox Hills sandstone crops out and subcrops along a narrow, north-south trending pattern in the extreme western part of the Site, upgradient from known sources of (EG&G, 1995b).

The regionally-important Laramie-Fox Hills aquifer is composed of the permeable lower unit of the Laramie Formation and the underlying Fox Hills Sandstone (Robson, 1983). This aquifer system is an important water source in the South Platte River Basin and is the sole water supply for some residents in the RFETS area (Rocky Mountain Remediation Services, 1999a). This aquifer lies approximately 180 to 275 meters (590 to 900 feet) below the Industrial Area and is protected from Site contamination by the intervening Laramie Formation claystones (EG&G, 1995b).

Pierre Formation

The Pierre Formation is a 7,500-foot thick, dark gray, silty bentonitic shale that acts as a lower confining layer for the Laramie-Fox Hills aquifer in the Denver Basin. This thick marine shale unit subcrops only in the extreme western part of the Site (RMRS, 1999).

Structural Features

The Site is located along the western margin of the Denver Basin, an asymmetric basin with a steeply east-dipping western flank and a gentle eastern flank. The interpretation of the subsurface structure is generalized in the west-east generalized geological cross section of the Site area presented in Figure TA-1-10. A monoclinal fold limb exposed west of the Site is the most significant surficial structural feature in the Site area. Along the west limb of the fold, an

angular unconformity exists between the Upper Cretaceous bedrock and the base of the Quaternary Rocky Flats Alluvium.

No active faults have been identified at the Site. Several high-angle bedrock faults have been inferred to exist in the Industrial Area based on various stratigraphic and borehole correlation criteria. These faults appear to have only a limited hydrologic significance with regard to vertical groundwater movement and contaminant transport (RMRS, 1996).

TA-1.6.4 Hydrogeology and Geochemistry

Hydrostratigraphy and Hydraulic Conductivities

Shallow groundwater flow systems at RFETS have been categorized into two hydrostratigraphic units based on contrasts observed between groundwater geochemistry, core logging and hydraulic conductivity determinations (EG&G, 1995b). These are generally referred to as the upper hydrostratigraphic unit (UHSU) and lower hydrostratigraphic unit (LHSU) and are described in detail in the Hydrogeologic Characterization Report for RFETS (EG&G, 1995b). General descriptions of the UHSU and LHSU are provided in the following subsections.

Upper Hydrostratigraphic Unit

UHSU Hydrostratigraphy. The UHSU has many subunits, of which two are primarily important: the surficial deposits (unconsolidated materials) and the weathered bedrock in hydraulic connection with the overlying unconsolidated surficial deposits or with the ground surface. The degree of hydraulic communication between the UHSU subunits varies with the permeability of the units. The relative amount of hydraulic communication between the UHSU subunits is much greater than that between the UHSU and LHSU, which is the basis for including portions of the weathered bedrock in the UHSU (EG&G, 1995b).

The UHSU is comprised of several distinct lithostratigraphic units. These include the alluvium (including Rocky Flats Alluvium), colluvium and landslide deposits; weathered portions of the

Cretaceous Arapahoe and Laramie Formations; and all sandstones within the Arapahoe and Laramie Formations that are in hydraulic connection with the overlying, surficial deposits or the ground surface (EG&G, 1995c). On the west side of the Site, the UHSU may also include weathered portions of the Cretaceous Pierre Shale and Fox Hills Sandstone.

UHSU Hydraulic Conductivities. The UHSU at the Site has a relatively low to moderate hydraulic conductivity that typically yields small amounts of water to groundwater monitoring wells. The UHSU exhibits a wide range of hydraulic conductivities because of the diverse nature of the individual geologic units that comprise this unit.

The relative ranking of individual UHSU units are listed in Table TA-1-2 in order of decreasing geometric mean hydraulic conductivity (RMRS, 1999):

Table TA-1-2. Hydraulic Conductivity of UHSU Units

UHSU Unit	Hydraulic Conductivity in centimeters per second (cm/sec)	Hydraulic Conductivity in meters per year (m/year)
Valley-fill Alluvium	2.5×10^{-3}	789
Arapahoe No. 1 Sandstone	7.9×10^{-4}	249
Rocky Flats Alluvium	2.1×10^{-4}	66
Colluvium	93×10^{-5}	29
Weathered Laramie	3.9×10^{-5}	12
Weathered Laramie	8.8×10^{-7}	0.3

Lower Hydrostratigraphic Unit

LHSU Hydrostratigraphy. The LHSU is comprised of all lithostratigraphic units in the unweathered portions of the Arapahoe and upper Laramie Formations, except for subcropping sandstones at the alluvial/bedrock unconformity (EG&G, 1995b). In general, saturated

sandstones that lie within unweathered claystones and siltstones of the Arapahoe or Laramie Formations are confined units. These sandstone units are not interpreted as being directly interconnected and each may act as an isolated hydrostratigraphic unit. In addition, recharge to these units occurs through the confining claystone and siltstone units. Therefore, all unweathered bedrock is considered part of the LHSU (EG&G, 1994 and 1995b). The LHSU forms a thick (over 100 meters (several hundred feet)), regionally extensive confining layer that serves to isolate shallow groundwater from the underlying Laramie-Fox Hills aquifer (RMRS, 1996).

LHSU Hydraulic Conductivities. Hydraulic conductivities for LHSU materials are generally significantly lower than those of the overlying unit with geometric mean values for individual lithologic groups ranging from 1.6×10^{-7} to 5.8×10^{-7} cm/sec (EG&G, 1995c). The low permeability and +180-meter (+590-foot) thickness of the upper Laramie Formation claystones act as effective aquitards that restrict downward vertical groundwater flow and contaminant transport to the Laramie-Fox Hills aquifer (RMRS, 1999).

Groundwater Occurrence and Flow Conditions

Groundwater Occurrence

The Site is located in a regional groundwater recharge area (EG&G, 1991). Groundwater is found in all geologic units present at RFETS, although not always in predictable amounts and availability. Groundwater recharge occurs from the infiltration of precipitation and from stream, ditch and pond seepage. Much of the groundwater that discharges from the UHSU to streams and seeps evaporates as it is being discharged. Limited investigation of the former Operable Unit 2 (OU 2) area during the period of July through October 1993 indicated that the precipitation component of recharge was lost to evapotranspiration demands (EG&G, 1993c).

In the western part of the Site, where the thickness of the Rocky Flats Alluvium reaches 30.5 meters (100 feet), the depth to the water table is 15 to 21 meters (50 to 70 feet) below the

surface. The depth to water generally becomes shallower from west to east, as the alluvial material thins and the confining claystones are closer to the ground surface. At the head of stream drainages and along valley sides, seeps are common at the base of the Rocky Flats Alluvium where it is in contact with claystones of the Arapahoe/Laramie Formations and where the Arapahoe Formation sandstone crops out. In general, the unconsolidated surficial materials are thicker in the western, higher elevations at the Site. Accordingly, the saturated thickness of these materials also thins eastward. The potentiometric surface of groundwater in unconsolidated surficial deposits was mapped and is shown in Figure TA-1-11 for the second quarter of 1998, a time of year when static water levels are expected to be high. Areas of unsaturated and seasonally unsaturated alluvium and colluvium are indicated east and northeast of the Industrial Area.

Groundwater in the Arapahoe Formation sandstone units, which subcrop beneath the alluvial material, is not confined when in contact with the surficial materials. In this setting, a hydraulic connection exists between the bedrock sandstone and the alluvial material allowing the bedrock groundwater to exist under unconfined conditions as part of the UHSU. The subcropping Arapahoe Formation No. 1 sandstone, located in the eastern portion of the Industrial Area and in the area between South Walnut Creek and Woman Creek, is part of the UHSU (EG&G 1991). The upper discontinuous sandstones of the Laramie Formation also subcrop beneath alluvium and colluvium but in limited areas in the valleys and along valley slopes. Groundwater in the lenticular sandstone units of the Laramie Formation occurs under confined conditions over scattered areas of the Site.

Groundwater levels in UHSU wells fluctuate in response to seasonal recharge events. Approximately 15 % of the groundwater monitoring wells are commonly dry during at least one of the quarterly sampling events. Of the remaining wells, approximately half cannot yield sufficient water volume (4.5 gallons) necessary for a full suite of laboratory samples. Sampling crews must return later, after wells have recovered, to obtain additional sample volumes.

The Arapahoe aquifer is one of the primary aquifers in the Denver Basin east of the Site. Existing evidence indicates that the Arapahoe Formation at RFETS is not in communication with the regional Arapahoe aquifer in the Denver Basin (EG&G, 1995b).

The Arapahoe Formation is present only at the top of the Rocky Flats pediment and is breached by modern streams along the valley slopes. Consequently, the channel deposits within the formation are cut off and do not extend eastward into the Denver Basin. The groundwater within the channel deposits discharge via springs and seeps along the hillsides. Therefore, the sandstones of the Arapahoe Formation are not considered primary pathways for off-Site groundwater migration. A thorough discussion of the hydrogeologic characteristics of the UHSU is included in the *Hydrogeologic Characterization Report* (EG&G, 1995d).

The Laramie/Fox Hills aquifer is present at greater depth (approximately 180 to 275 meters (590 to 900 feet)) below the Site (Robson, 1983). This deeper hydrostratigraphic unit is composed of the lower unit of the Laramie Formation and the underlying Fox Hills Sandstone. These units subcrop beneath the Rocky Flats alluvium and are locally exposed in gravel quarries near the western boundary of the Site. Recharge to the aquifer occurs along this subcrop zone. Claystones of the Laramie Formation have very low hydraulic conductivities. In a study of Site hydrology, the United States Geological Survey (USGS) concluded the low hydraulic conductivities in the Laramie Formation would prevent Site operations from impacting the underlying Laramie-Fox Hills aquifer (Hurr, 1976).

Groundwater Flow Conditions

A conceptual description of unconfined groundwater flow was developed for the Site as part of the *Well Evaluation Report* (EG&G, 1994). That report described three general zones where the characteristics of groundwater flow are distinctive. These zones occupy the western, central and eastern portions of the Site.

A relatively unbroken topographic slope formed on the Rocky Flats Alluvium characterizes the western zone. In this zone, alluvial thickness is greatest, water-level fluctuations are minor and the alluvium is rarely, if ever, completely unsaturated. Groundwater in the UHSU flows generally east, with slight variations in flow direction occurring along the top of the bedrock surface. The predominantly claystone bedrock impedes downward vertical migration of groundwater and directs flow laterally.

The central zone has a gently eastward-sloping topographic surface that is incised by east-west-trending drainages. Topographic highs are capped by thick alluvial deposits and flanked by colluvium. Water flowing through the capping alluvium follows the bedrock surface and emerges at seeps, drains into hillside colluvium, or migrates vertically into lower lithostratigraphic units (weathered or unweathered bedrock). The potentiometric surface of groundwater in the UHSU generally resembles the ground surface and paleotopographic (bedrock) surface. The potentiometric surface slopes gently to the east and more steeply north-northeast and south-southeast along hillslopes of the incised drainage valleys. Groundwater flows from broad areas of recharge located upgradient and on nearby topographic highs, toward the erosional limit of alluvium and then directly toward creeks in incised drainages. Groundwater and surface water are in direct connection at seeps and in some alluvial deposits along these drainages. In areas of relatively steep topography, baseflow to creeks may occur. The paleotopographic surface also plays a role in directing groundwater flow and in the development of unsaturated zones in unconsolidated surficial deposits. Channels and depressions on the top-of-bedrock surface may act as conduits, or even small basins, for groundwater. Surficial deposits on either side of these channels can be drained, or dewatered, by flow toward the channel.

The eastern zone is characterized by relatively flat surface topography, the absence of thick alluvial deposits (Rocky Flats Alluvium) and more widespread valley-fill deposits. Thin deposits of colluvium generally cover the ground surface. The hydraulic gradients are relatively low and groundwater in unconsolidated deposits may not flow directly toward the axes of stream

valleys. Baseflow to creeks is probably also diminished relative to the central zone because of the lower hydraulic gradients.

In summary, the direction of groundwater flow in the UHSU is largely controlled by the topography of the ground surface and bedrock surface. Both surfaces slope gently to the east and are incised by stream valleys. Groundwater generally flows from west to east across the Site following the regional topography. The incised valleys in the central area of the Site have formed east-west-trending ridges and east-draining valleys. Groundwater in the UHSU generally flows to the east along the ridge tops, flows north and south along the valley sides and flows east in the valley bottoms (EG&G, 1994 and EG&G, 1995d). The permeability of bedrock units, composed primarily of claystone with lesser amounts of siltstone and sandstone, is typically several orders of magnitude less than for unconsolidated surficial deposits. The 180+ meters (590+ feet) of unweathered bedrock between the shallow groundwater flow system and deep regional Laramie-Fox Hills aquifer provide an effective barrier to vertical groundwater and contaminant movement.

Groundwater Interaction With Surface Waters and Soils

The pattern of seep distribution confirms that seep occurrence is controlled by local geologic conditions. Hillside seeps at RFETS are common along the eastern extent of the Rocky Flats Alluvium at the contact between the Rocky Flats Alluvium and underlying claystone subcrops. In general, seeps occur in greater number and areal extent along the north side of the pediment ridges, as observed along South Walnut Creek and Rock Creek. Most seeps are ephemeral in nature and only discharge at the ground surface in the spring. Perennial seeps are relatively rare, with most located in the Rock Creek drainage. Groundwater seepage also occurs along segments of Woman Creek's stream channel, particularly above the Woman Creek's stream diversion structure at Pond C-2, as determined from a stream gain/loss study (Fedors and Warner, 1993). The stream channels of North and South Walnut Creeks are so extensively interrupted by impoundments that channel seepage measurements have not been made (RMRS, 1997).

Seep flow data are generally unavailable due to difficulties inherent with measuring broad, diffuse sources of discharge. The results of an incomplete seepage inventory conducted after the 1995 spring recharge event in portions of the Woman, Walnut and Rock Creek's watersheds revealed that, of over 200 potential seep areas indicated by wetland vegetation, only 32 had a measurable flow and, of these, 14 had flows of one gallon per minute or less (EG&G, 1995d and RMRS, 1997). The remaining sites were moist to wet at the ground surface with little or no evidence of surface flow. Given the magnitude of the spring recharge event as reflected by Site-wide high water table conditions, it is likely that seep flows measured during this time were at or near maximum levels. It was commonly observed during this survey that surface flow from many ephemeral hillside seeps percolate back into the soil below the discharge point before entering a surface water body. Direct contact with surface water may occur during exceptionally wet periods because of increased seep flow caused by abnormal water table rises or by mixing with surface runoff.

The most common type of seep develops at the contact between the Rocky Flats Alluvium and underlying bedrock claystones. These seeps are thought to be related to preferential flow channels in bedrock surface topography and/or alluvial stratigraphy (high hydraulic conductivity zones) (EG&G, 1995b). In the 903 Pad and East Trenches areas, some seep occurrences have been attributed to discharge from the subcropping Arapahoe Formation sandstone, which receives recharge from the overlying surficial deposits (EG&G, 1995b). The most notable sandstone seeps in this area include a grouping of seeps situated above the B-1 pond in the South Walnut Creek drainage and the 903 Pad hillside seep (Figure TA-1-2).

Along the north slope of Woman Creek from the 903 Pad eastward to Indiana Street, evidence of present-day seep activity is limited primarily to the 903 Pad hillside seep and potentially a few scattered small seeps. Periodic activation of a series of presumably old seepage sites located east of the 903 Pad have occurred from historic spray evaporation operations conducted at the South Spray field; however, these sites have since returned to a dry state following cessation of spray field operations. Sites for groundwater interaction with surficial soils and surface water are both

limited in extent and predictable based on the high degree of hydrologic control exerted by the local geology (RMRS, 1997).

Groundwater discharge to surface water is presumed to occur along major stream channels, although relatively little information is available to evaluate the significance of this interaction. Stream gain/loss studies conducted along Woman Creek (EG&G, 1995d) have indicated that the flow regime in the upper reaches of the creek (west of the confluence with Antelope Springs Creek) tend to be predominantly gaining, while the lower reaches (east of Antelope Springs Creek) tend to be predominantly losing. The presence of gaining segments found just upstream of Ponds C-1 and C-2 suggests that these impoundments exert a local influence on groundwater discharge to surface water in the alluvium. Similar relationships are suspected to occur in the Walnut Creek drainage but to an unknown degree because gain/loss stream flow data are lacking in this area. It can be assumed, however, that groundwater/surface water interactions are potentially more complex in North and South Walnut Creeks because of the influence of plant discharges and a more extensive pond system and other stream channel modifications. These interactions are potentially meaningful in terms of actinide transport, though it is important to recognize the interactions involve only the upper hydrostratigraphic unit and surface water. Hydraulic communication from the upper to the lower hydrostratigraphic units is limited (EG&G, 1995d).

Groundwater Geochemistry

A comprehensive evaluation of groundwater geochemistry at the Site is presented in the *Groundwater Geochemistry Report* (EG&G, 1995c). The study identified four probable groundwater flow paths after a review of the potentiometric surface contours for the UHSU (EG&G, 1995c). Selection of each flow path was made with the assumption that groundwater flow is perpendicular to the contours of the potentiometric surface. Major cations and anions in the UHSU groundwater are presented using stiff diagrams, based on data collected from 1990 through 1994, for the Rock Creek flow path (Figure TA-1-12), Industrial Area flow path (Figure

TA-1-13), Woman Creek flow path (Figure TA-1-14) and the Southern Area flow path (Figure TA-1-15). The four flow paths selected, from northernmost to southernmost and the distinguishing geochemical characteristics of each path are summarized below.

Rock Creek Flow Path – The Rock Creek Drainage covers the northern portion of the Site's Buffer Zone. This northern Buffer Zone flow path begins northwest of the Industrial Area and flows northeast along Rock Creek to the northern boundary of the Site. The flow path length is approximately 5 kilometers (km) (3 miles (mi)). Flat areas to the west, several small stock ponds within the creek bed and multiple steep gullies and stream channels to the east characterize the drainage channel. This basin is hydrologically isolated from the developed areas.

The Rock Creek flow path is considered to be largely unaffected by historic activities at the Site and clearly shows the results of water/rock interaction (EG&G, 1995c). Bicarbonate is the dominant ion in groundwater along this path. Wells along the Rock Creek flow path exhibit the least amount of variability in major ion chemistry (i.e., exhibit the tightest clustering of points of the four flow paths). Major ion concentrations at the upstream wells range from approximately 10 milligrams per liter (mg/L) or less for sulfate, chloride, calcium and sodium up to 100 mg/L for bicarbonate. From flow path beginning to end, the concentrations of many major ions increase by approximately one order of magnitude. Total Dissolved Solids (TDS) concentrations vary from 144 mg/L at the initial well to approximately 1160 mg/L at the most downgradient well on the path.

Industrial Area Flow Path – The Industrial Area flow path begins in the West Spray Fields, directly west of the Industrial Area and flows eastward through the center of the Industrial Area, down South Walnut Creek through the B-Series ponds and on to the Site boundary at Indiana Street. The flow path length is approximately 7 km (4 mi). Major ion concentrations at the upstream wells range from approximately 10 mg/L or less for sulfate, chloride, calcium and sodium up to 100 mg/L for bicarbonate. Similar to Rock Creek, the magnitude of overall increase in elemental concentrations is approximately one order of magnitude from the initial to

the final wells. Groundwater within the central Industrial Area shows increases in the concentrations of some major ions for certain wells. However, groundwater samples from the beginning to end of the Industrial Area flow path indicate only equal or less of an increase in ion concentrations than were observed along the shorter Rock Creek flow path (EG&G, 1995c).

The major-ion composition of UHSU groundwater also undergoes a change along this flow path. Groundwater changes from a calcium-bicarbonate water within the Industrial Area to a mixed sodium-bicarbonate/sodium-sulfate water along South Walnut Creek. At the end of the Industrial Area flow path, the groundwater is again a calcium-bicarbonate water. The observed major-ion variations thus have a limited extent and may reflect inputs from contaminant sources in the Industrial Area or along Walnut Creek (EG&G, 1995c). TDS shows the highest variability within and immediately downgradient of the Industrial Area and varies from 138 mg/L at the initial well to approximately 455 mg/L at the most downgradient well on the path.

Woman Creek Flow Path – The regional Woman Creek flow path extends eastward from the base of the foothills near Coal Creek Canyon to Standley Lake. On-Site, Woman Creek flows through the southwest Buffer Zone, through Pond C-1, to the Site boundary at Indiana Street. The flow path length is approximately 6 km (4 mi). Similar to the Industrial Area flow path, groundwater along the Industrial Area and Woman Creek flow paths shows local increases in the relative proportions of chloride and sulfate. Major ion concentrations at the upstream wells range from approximately 10 mg/L or less for sulfate, chloride, calcium and sodium up to approximately 60 mg/L for bicarbonate. Major ion concentrations show an upgradient-to-downgradient increase of approximately one order of magnitude. This is similar to the increases observed in the Industrial and Rock Creek flow paths. The impact of Site activities is potentially suggested in wells located along Woman Creek on the southeast corner of the Industrial Area (EG&G, 1995c). TDS concentrations vary from 140 mg/L at the initial well to approximately 500 mg/L at the most downgradient well on the path.

Southern Flow Path – The southern flow path begins in the south Buffer Zone just east of Rocky Flats Lake. It continues eastward to the ponds in the southeast corner of the Site and on to the Site boundary. The flow path length is approximately 7 km (4 mi). Similar to the Rock Creek flow path, bicarbonate is the dominant ion in groundwater along the southern flow path. Major ion concentrations at the upstream wells range from approximately 10 mg/L or less for sulfate, chloride and sodium up to approximately 100 mg/L for calcium and bicarbonate. Major ion concentrations show an upgradient-to-downgradient one order of magnitude increase similar to that observed in the Industrial and Rock Creek flow paths. TDS concentrations vary from 331 mg/L at the initial well to approximately 500 mg/L at the most downgradient well on the path.

As noted in the *Groundwater Geochemistry Report*, the major-ion chemistry of the UHSU and LHSU groundwater generally supports the current definition of the two hydrostratigraphic units. The major-ion composition of groundwater is much less variable in the UHSU than in the LHSU. Groundwater in the UHSU is generally distinct in composition from groundwater in the LHSU, although groundwater in the two hydrostratigraphic units can be similar. These observations are consistent with hydrologic evidence for two distinct hydrostratigraphic units that have only limited hydraulic communication with each other (EG&G, 1995c).

TA-1.6.5 Surface Water Features

Streams and seeps at RFETS are largely ephemeral, with stream reaches gaining or losing flow, depending on the season and precipitation amounts. Surface water flow across RFETS is primarily from west to east, with three major drainages traversing the Site. A total of 14 detention ponds (plus several small stock ponds) collect surface water runoff, although only ten ponds are actively managed. The Site drainages and detention ponds, including their respective interest to this report, are described below and shown in Figure TA-1-2.

Walnut Creek

Walnut Creek drains the central third of RFETS, including the majority of the Industrial Area. It consists of several tributaries (North Walnut Creek, South Walnut Creek and No Name Gulch) that join prior to Walnut Creek flowing off RFETS at the eastern boundary (Indiana Street). East of Indiana Street, Walnut Creek is diverted by the Broomfield Diversion Ditch to the south of Great Western Reservoir and into Big Dry Creek. The Walnut Creek tributaries, from north to south, are described below.

McKay Ditch

The McKay Ditch was formerly a tributary to Walnut Creek within the RFETS boundaries but was diverted in July 1999 into a new pipeline to keep McKay Ditch water from co-mingling with RFETS water in Walnut Creek. Although no longer a contributor to Walnut Creek, the McKay Ditch drainage is described here to clarify water routing at the Site. The new configuration allows the City of Broomfield to transport water from the South Boulder Diversion Canal, across the northern RFETS Buffer Zone and directly into Great Western Reservoir (east of the Site) without contacting Walnut Creek water from the Site's stormwater detention ponds.

No-Name Gulch

This drainage is located downstream from the former Site landfill. Runoff from the Industrial Area does not flow into this basin.

North Walnut Creek

Runoff from the northern portion of the Industrial Area flows into this drainage, which has four detention ponds (Ponds A-1, A-2, A-3 and A-4). The combined capacity of the A-series ponds is approximately 197,000 cubic meters (m^3) (50 million gallons [160 acre-feet]). Ponds A-1 and A-2 are kept off-line and maintained for emergency spill control; evaporation or transfer controls water levels in these ponds. Pond A-1 also receives water pumped from the Landfill Pond

roughly once per year. North Walnut Creek flow is diverted around Ponds A-1 and A-2 to Pond A-3, where water is held and settling of solids occurs. Pond A-3 is transferred in batches to the A-series "terminal pond," Pond A-4. After filling to a predesignated level (typically approximately 50 % of capacity). Pond A-4 water is isolated, sampled and released if water quality standards are met. These off-Site discharges, each averaging approximately 63,000 m^3 (17 million gallons [50 acre-feet]), typically occur 2 to 4 times per year.

The average annual discharge to North Walnut Creek at the east perimeter of the Industrial Area (at station SW093) is approximately 148,000 m^3 (40 million gallons [120 acre-feet]). The average mean daily flow rate at station SW093, from October 1992 through April 1997, was 0.005 cubic meters per second (m^3/s) (0.16 cubic feet per second [cfs]). The maximum mean daily flow rate during this period was approximately 0.25 m^3/s (9 cfs).

South Walnut Creek

Runoff from the central portion of the Industrial Area flows into this drainage, which has five detention ponds (Ponds B-1, B-2, B-3, B-4 and B-5). The combined capacity of the South Walnut Creek detention ponds (B-series ponds) is approximately 102,000 m^3 (30 million gallons [85 acre-feet]). Ponds B-1 and B-2 are kept off-line and maintained for emergency spill control; evaporation or transfer controls water levels in these ponds. Pond B-3 receives effluent from the Site's wastewater treatment plant (WWTP) and flows into Pond B-4. South Walnut Creek flow is diverted around Ponds B-1, B-2 and B-3, into Pond B-4, which flows continuously into "terminal pond" Pond B-5. After filling to a pre-designated level, Pond B-5 is released in batches of approximately 54,000 m^3 (15 million gallons [45 acre-feet]) to South Walnut Creek. Pond B-5 discharges typically occur 6 to 8 times per year.

The average annual discharge to South Walnut Creek, including effluent from the Site's WWTP, is approximately 318,000 m^3 (85 million gallons [260 acre-feet]). The average mean daily flow rate measured in South Walnut Creek (at station GS10), from October 1992 through April 1997,

was 0.003 m^3/s (0.12 cfs) and the maximum mean daily flow rate during this period was approximately 0.142 m^3/s (5 cfs).

South Interceptor Ditch

South of the Industrial Area is the South Interceptor Ditch (SID)/Woman Creek system. Although it is tributary to Woman Creek, the SID warrants more thorough discussion than other comparable tributaries at the Site because it captures runoff from the southern portion of the Industrial Area, a drainage basin that includes the 903 Pad. The 903 Pad, located on the southeast corner of the Industrial Area, has some of the highest known levels of actinides in surface soils on the Site as shown in Section TA-3.

Surface water runoff from the southern portion of the Industrial Area is captured by the SID, which flows from west to east into Pond C-2. Water from Pond C-2 is sampled and, if surface water quality criteria are met, pump discharged into Woman Creek that flows to the Woman Creek Reservoir. Off-Site discharges from Pond C-2, averaging approximately 46,900 m^3 (13 million gallons [40 acre-feet]), typically occur once per year.

There is frequently no flow in the SID. The average mean daily flow rate (at station SW027), from October 1994 through April 1997 and including the periods of no flow, was 0.001 m^3/s (0.05 cfs). The maximum mean daily flow rate during this period was approximately 0.170 m^3/s (6 cfs).

Woman Creek

South of the SID is Woman Creek, which flows through Pond C-1 and off-Site at Indiana Street. The Woman Creek drainage basin extends eastward from the base of the foothills, near Coal Creek Canyon, to Standley Lake. Woman Creek currently flows into the Woman Creek Reservoir, where it is held until it is pump transferred to Big Dry Creek. The average annual yield of the basin is approximately 420,000 m^3 (110 million gallons [340 acre-feet]). The

average mean daily flow rate in Woman Creek (at Indiana Street) was 0.010 m^3/s (0.47 cfs) and the maximum mean daily flow rate during this period was approximately 2.150 m^3/s (76 cfs).

Other Drainages

The largest major drainage at the Site, other than Walnut and Woman Creeks, is Rock Creek. The Rock Creek drainage covers the northern portion of the Site's Buffer Zone. Flat areas to the west, several small stock ponds within the creek bed and multiple steep gullies and stream channels to the east characterize the drainage channel. This basin is hydrologically-isolated from the developed areas. It receives no runoff from the Industrial Area and contaminant transport by surface (or subsurface) processes is not indicated or suspected based on data presented in the *Background Geochemical Characterization Report* (EG&G, 1993a). Analytical data for Rock Creek are not presented in this report.

Smart Ditch, located south of Woman Creek, is also hydrologically-isolated from the RFETS Industrial Area. The D-series Ponds (D-1 and D-2) are located on Smart Ditch. This drainage and these ponds are not discussed in this report.

TA-1.6.6 Biological and Ecological Resources

The Buffer Zone provides habitat for a wide range of plant and animal species. Background information on the plants and wildlife found at the Site is provided below as a reference for the biological transport pathway analysis presented later in this report.

Vegetation

The topography and close proximity of the Site to the mountains provides for a diverse mixture of prairie and foothills plant communities in the Site's Buffer Zone. Currently, over 585 species of plants are reported to exist at the Site (Kaiser-Hill, 2000b). Plant communities at RFETS range from xeric (dry) grassland communities to more hydric (wet) communities, such as wet meadows and marshes. The plant communities of greatest ecological significance on Site are the

xeric tallgrass prairie, the Great Plains riparian community, the tall upland shrubland community and wetlands (Kaiser-Hill, 1996) (Figure TA-1-16).

The xeric tallgrass prairie occurs on the cobbly alluvium found on pediments and ridges at the Site and is a part of what is classified as xeric mixed grassland. This prairie is distinguished by such tallgrass plant species as big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), prairie dropseed (*Sporobolus heterolepis*) and switchgrass (*Panicum virgatum*).

The Great Plains riparian community is found along streams at the Site. Examples of this community are found in the Rock Creek, Walnut Creek, Woman Creek and Smart Ditch drainages (Figure TA-1-2). Cottonwood trees and willows predominate in this community. Another unusual shrub community, dominated by leadplant, is also often found in association with the Great Plains riparian community at the Site. These communities provide important habitat for many of the bird and mammal species found here, including the Preble's meadow jumping mouse (*Zapus hudsonius preblei*).

The tall upland shrubland community is found on north-facing slopes primarily in the Rock Creek drainage and commonly occurs just above wetlands and seeps. The dominant tall shrubs are hawthorne and chokecherry, which are associated with other shrubs and plants common in the foothills to the west of the Site. This community is used by many animals throughout the year for cover, including several rare bird species during the breeding season and is used preferentially during the spring by mule deer for fawning areas.

Wildlife

RFETS provides habitat for a large variety of wildlife, ranging from big-game species to small mammals, bird species, fish and reptiles. Descriptions of commonly observed animal species, with information on their preferred habitat at the Site, is provided here as a reference for understanding potential actinide transport mechanisms related to wildlife. Details on wildlife observed at the Site can be found in the *2000 Annual Wildlife Report for the Rocky Flats*

Environmental Technology Site (Kaiser-Hill, 2001). Information is provided on data collection and analysis methods, survey results, species density analysis and other survey data.

At the end of the 2000 field season, 253 terrestrial vertebrate species had been verified as using the Site's ecosystems. This compares to the 322 terrestrial vertebrate species found at the Rocky Mountain National Park, an area 98 % larger than RFETS. The Site's diversity includes 189 species of birds, 20 of which are raptors; 3 big game species; 12 species of carnivores; 3 lagomorphs (rabbits and hares); 6 large rodents; 19 small mammal species, including the federally listed Preble's meadow jumping mouse; 6 bats, 11 reptiles; and 7 amphibians recorded since 1991 (Kaiser-Hill, 2001).

The dominant big game species at the Site is the mule deer (*Odocoileus hemionus*). The current population at the Site is estimated to be 130 to 150 individuals (Murdock, 2002). White-tailed deer (*Odocoileus virginianus*) numbers have increased and it is probable that more than a dozen of this species regularly use the Site. Elk (*Cervas elephas*) continue to be in the vicinity during spring and, during spring 2001, a herd of 80 to 100 elk has been observed in the grasslands west of the Site. South-facing mesic hillsides are used extensively by deer as feeding areas during the late fall, winter and spring. Shrublands, particularly tall upland shrublands are critical areas for mule deer fawning in spring and as wind-break sites during the winter months. Tall upland shrubland and Great Plains riparian habitats are heavily used for shade cover during the summer. Xeric mixed grassland, which is found on the flat uplands, is important to the deer during the breeding season, second only to mesic mixed grasslands of the hillsides. Mountain lions (*Felis concolor*) are uncommon visitors to the Site, but are reported in various habitats every year (Kaiser-Hill, 1996).

The most frequently observed carnivore species at the Site is the coyote (*Canis latrans*) and the next is the raccoon (*Procyon lotor*). Coyotes, which are active both diurnally and nocturnally, were found in all habitats. Both species are common in most habitats, with coyotes favoring grasslands and raccoons preferring areas around ponds and creeks.

Muskrats (*Ondatra zibethicu*s) have been recorded in ponds in the Woman Creek, Walnut Creek and Rock Creek drainages. They are also present in the SID. Physical signs continue to confirm the occasional presence of striped skunks (*Mephitis mephitis*) around water and badgers (*Taxidea taxus*) in grasslands, though neither species is abundant at the Site. Bobcats (*Lynx rufus*) and red fox (*Vulpes vulpes*) are seldom seen but have been recorded at the Site. Beavers have been observed sporadically.

Small game mammals include desert cottontail rabbits (*Sylvilagus audubonii*), two species of jackrabbits (*Lepus californicus* and *Lepus townsendii*) and fox squirrels (*Sciurus niger*). The rabbits inhabit disturbed areas, scrap storage areas, riprap areas and other areas affording cover. Fox squirrels are usually found in shrublands and woodlands, although they have been recorded in the developed areas of the Site as well. Other large rodents include black-tailed prairie dogs (*Cynomys ludovicianus*) and porcupines (*Erethizon dorsatum*). Porcupines prefer tall upland shrubland habitat and the scattered ponderosa pines on the Site. Long-tailed weasels (*Mustela frunata*) are recorded infrequently, usually around heavy shrub cover, or along creeks. Gray fox (*Urocyon cinereoargenteus*) and mink (*Mustela vison*) have been observed once each since 1991. Preble's meadow jumping mice (*Zapus hudsonius preblei*) live in the riparian areas and around ponds. This species is seldom found far from tall vegetation and water (Kaiser-Hill, 1996).

During 2000, 85 bird species were recorded on migratory bird surveys alone. This compares to 153 species that have been recorded along bird survey transects at the Site since bird surveys were initiated in 1991. Trends over the last seven years indicate bird diversity in wetlands appears to be gradually increasing in winter while diversity appears to be steadily decreasing in grasslands in spring. No other trends are discernible (Kaiser-Hill, 2001).

Songbird density and diversity numbers indicate little change in songbird use of all habitats at the Site over the past decade. Completing an accurate census of migratory waterfowl is more difficult, but surveys conducted in 2000 indicate these species continue to be observed in

numbers similar to past years (Kaiser-Hill, 2001). Raptor species exhibited their normal species richness and seasonal species assemblages. As in past years, red-tailed hawks (*Buteo jamaicensis*), Swainson's hawks (*Buteo swainsoni*), American kestrels (*Falco sparverius*) and Great Horned Owls (*Bubo virginianus*) nested at the Site, demonstrating that the habitat continues to provide the necessary resources for these raptors.

TA-1.6.7 Microbiology

Microbial Ecology of Contaminated Sites

Microbial ecology is the relationship between microbial populations and their biotic and abiotic environments. Because microorganisms can tolerate, adsorb, reduce (or oxidize) and precipitate metals, microbial populations potentially can modify trace metal geochemistry. Conversely, microbial population structure and dynamics (species, abundance, diversity and activity) may be subject to environmental changes in metal chemistry. Thus, the geochemical and microbial characteristics of contaminated sites are interrelated and interdependent. Moreover, it is only recently that the interactions between indigenous microbial populations and metal contaminants have been investigated adequately. Part of the problem has been the lack of accurate tools to assess the species, numbers, diversity and activity of an indigenous population. Recent applications of molecular tools, such as polymerase chain reaction (PCR) amplification and advanced DNA sequencing techniques have advanced our understanding of native microbial populations. In the past few years, dozens of new microbial kingdoms have been identified, attesting to our past lack of understanding of native microbial populations.

It is possible, however, to make a few general statements taken from past studies about the interdependency of microorganisms and contaminants. The effects of toxic metals on microbial ecology vary with several environmental parameters such as nutrients, temperature, pH, salinity, water, light and oxygen. It is believed that only a subset of the organisms present in the environment has the ability to adapt to environments highly modified by metal pollution. Toxic

metal contaminants are believed to reduce cell abundance and species diversity by selecting for metal resistant subsets of the population (Duxbury, 1986; Babich, 1985). In general, prokaryotes (e.g., bacteria) are more sensitive than eukaryotes (fungi, algae, etc.) to heavy metal pollution in soils, due perhaps to their higher surface area per unit volume than other life forms. Finally, it is widely recognized that Gram negative bacteria are more metal-tolerant than are gram positive microorganisms (the Gram reaction divides microorganisms into categories based on their cell wall characteristics).

It can be difficult to separate the effects from metals from the effects of other environmental components. However, the microbial ecology of high U environments has been studied using both traditional microbiological and newer molecular techniques (Suzuki; Bafield, 1999). Generally, these studies reveal the presence of microorganisms in these contaminated environments. For example, 16S-rRNA gene sequencing methods were used by Puers and Selensks-Pobell (Puers, 1998). To assess bacterial diversity in a U mining waste pile having elevated U concentrations up to 58 mg/L revealed that microorganisms related to *Proteobacteria* (24 %), green-non-sulfur bacteria (41 %) and *Fibrio*/*Acidobacteria* subdivisions (19 %) were the most prevalent. Only 5 % of the clones were Gram-positive, confirming the dominance of Gram negative species over Gram positive with respect of metal tolerance.

Microbial Ecology and Geomicrobiology at RFETS

Unfortunately, Site-specific data on the microbial ecology of RFETS do not exist, nor have studies been performed detailing specific geomicrobiological processes in the surface soils, subsurface material or surface waters. While it is tempting to extrapolate this information from studies conducted at nearby locations along the Front Range (e.g., Pawnee National Grasslands), such attempts would provide little in the way of irrefutable and defensible evidence regarding the role of microorganisms in actinide transport. Certainly, to develop a more complete description of transport pathways, a fundamental need of this program will be to perform a minimum assessment of the microbial ecology in both contaminated and uncontaminated locations at the

Site. The recent merging of molecular biology with microbial ecology has provided new and exciting techniques to probe the microbial complexity of soil and aquatic environments. They are now being used with ever increasing resolution to understand the relatedness of contaminants and indigenous populations.

TA-1.7 TECHNICAL APPENDIX SECTION TA-1 REFERENCES

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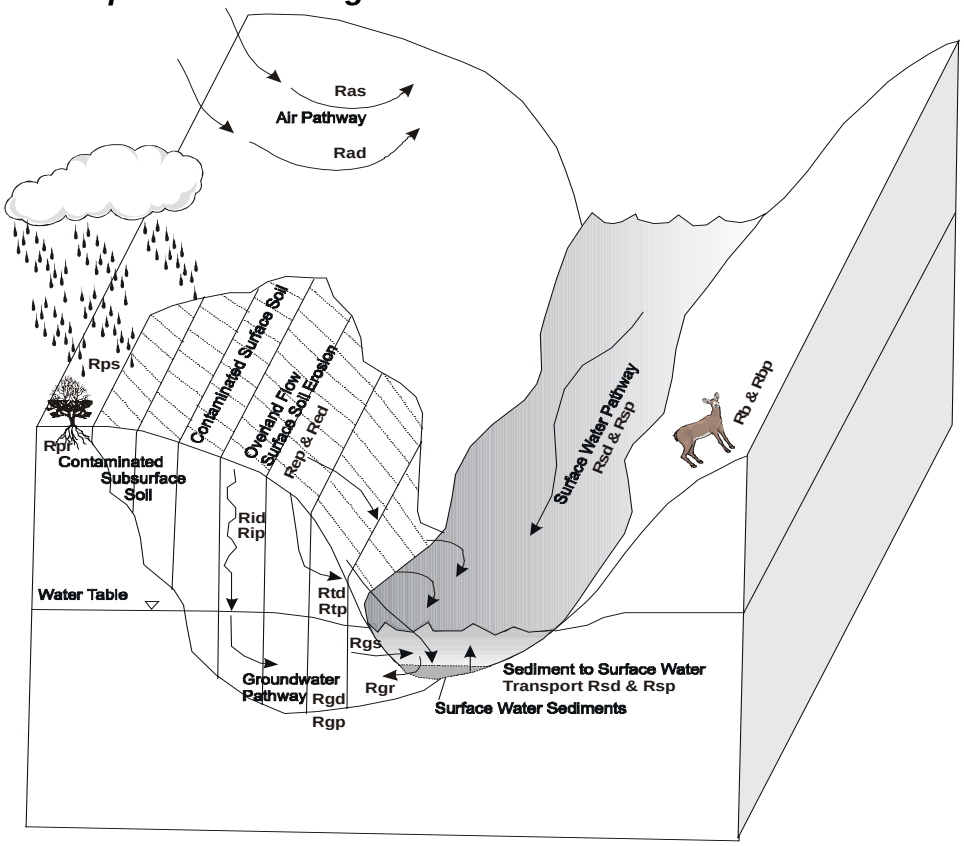
Figure TA-1-1. Potential Actinide Transport Pathways at RFETS – Conceptual Model Diagram.



Actinide Transport Rate Coefficients:

(Source: Kaiser-Hill, 1998)

R = rate of actinide transport in medium (subscripts indicate transport mechanism)
Ras = air suspension
Rad = air deposition
Rb = bio-uptake
Rbp = biotransport (including bioturbation and biopedal transport)
Rep = soil erosion and overland flow particulate/colloid transport
Red = soil erosion and overland flow dissolved transport
Rip = infiltration particulate/colloid transport
Rgd = groundwater dissolved transport
Rgp = groundwater particulate / colloid transport
Rgs = groundwater discharge
Rgr = groundwater recharge
Rpr = vegetation root uptake
Rps = raindrop splash
Rsp = surface water particulate / colloid transport
Rsd = sediment to surface water dissolved transport
Rtp = particulate vadose zone transport (subsurface storm flow)
Rtd = dissolved vadose zone transport (subsurface storm flow)

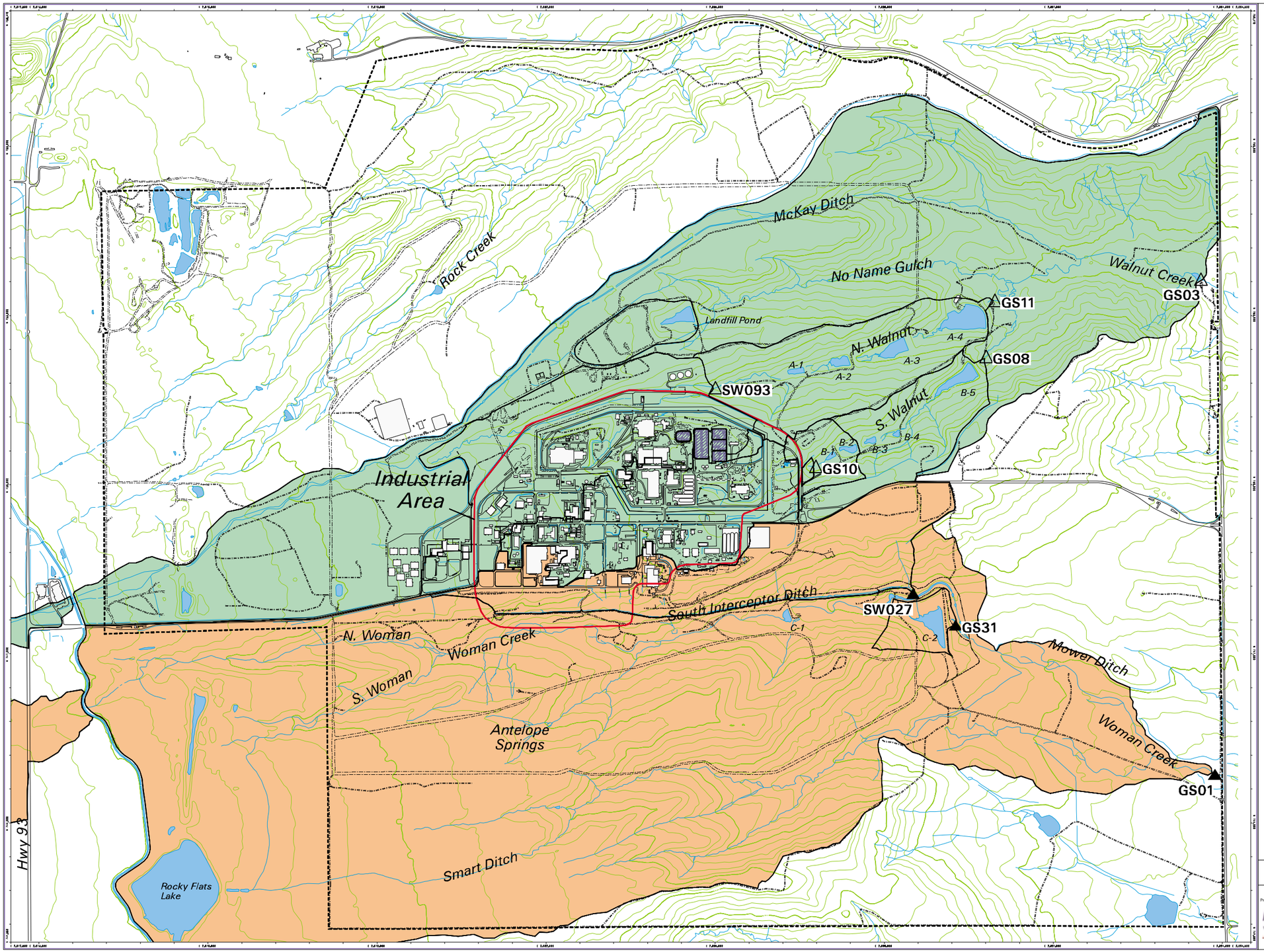


Figure TA-1-2

Actinide Migration Evaluation Pathway Report

Rocky Flats Basemap

EXPLANATION

- Walnut Creek Drainage Basin
- Woman Creek Drainage Basin
- Walnut Creek Basin Gaging Station (GS03, GS08, GS10, GS11 & SW093)
- Woman Creek Basin Gaging Station (GS01, GS31 & SW027)
- Drainage Basin Boundary
- Industrial Area Boundary

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Scale = 1 : 21330
1 inch represents approximately 1778 feet

250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy

Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: KAISER-HILL

March 22, 2002

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Figure TA-1-3. Monthly Average Precipitation at RFETS

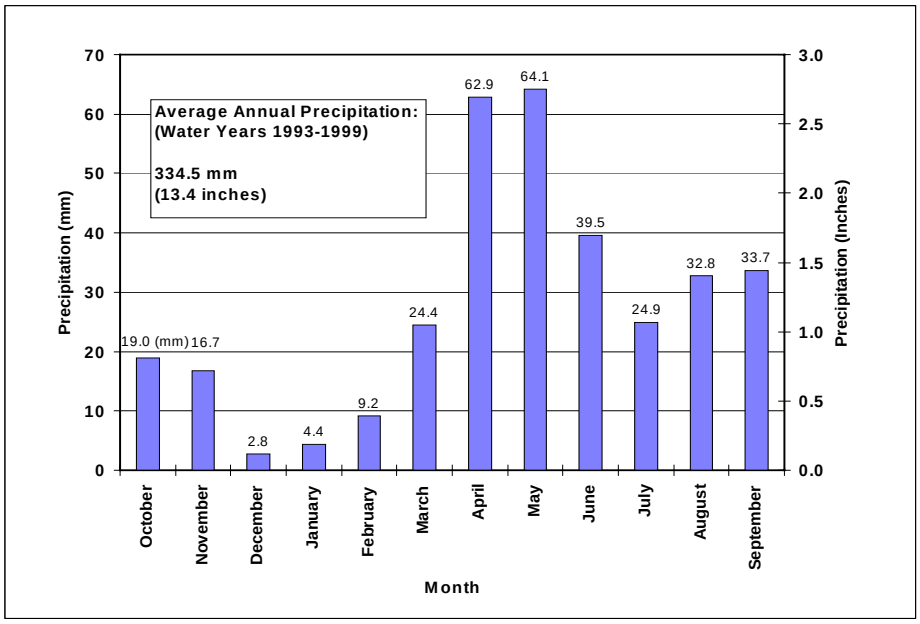


Figure TA-1-4. Correlation of RFETS Monthly Precipitation with Regional Data - for Water Years 1997 - 1999

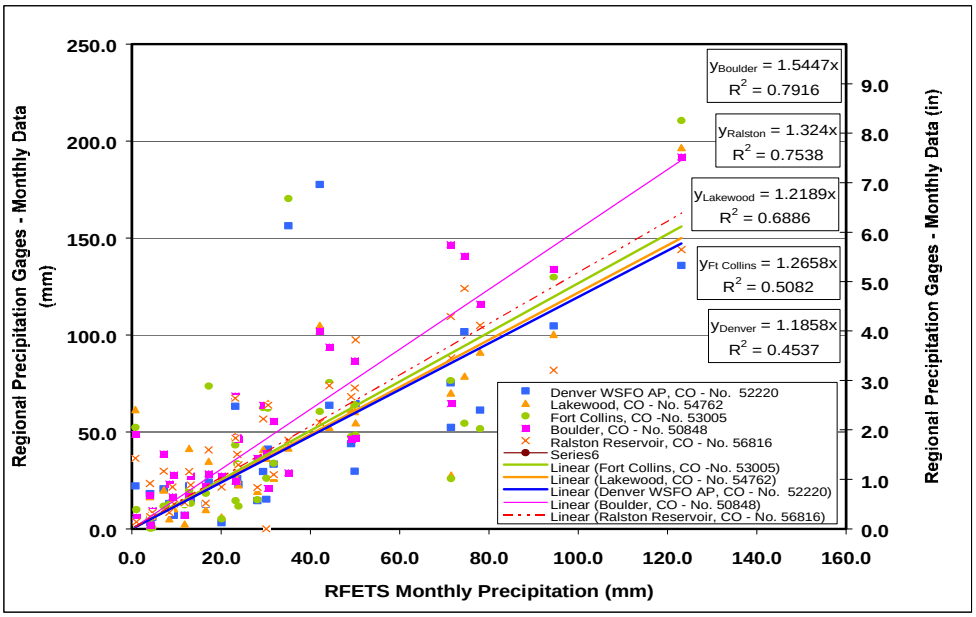


Figure TA-1-5. Precipitation at Boulder Station 50848 – Cumulative Departure of Water Years 1997 – 1997 from Monthly Normals

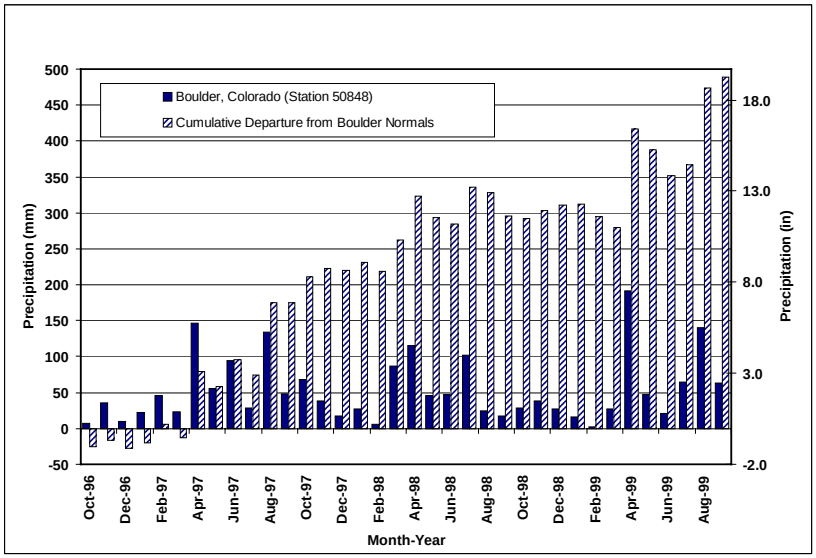
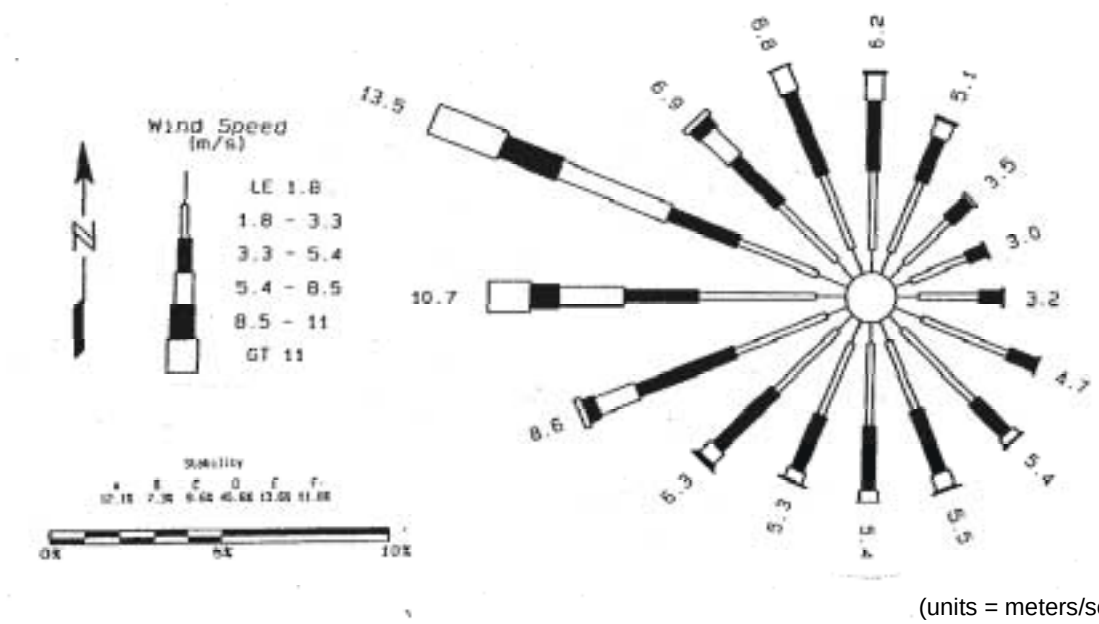


Figure TA-1-6. Mean Wind Speed and Direction Distribution at RFETS (1999)



(units = meters/second)

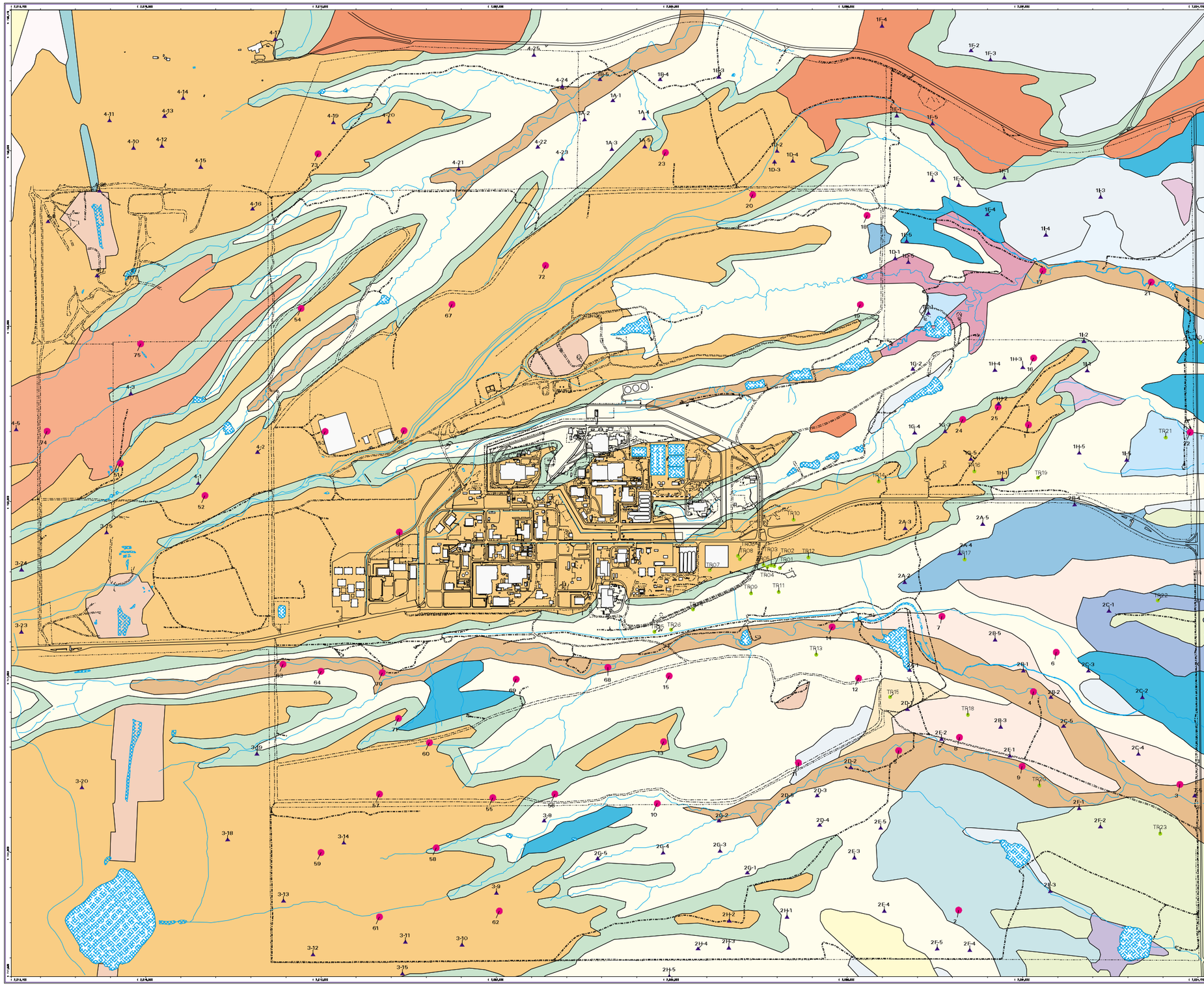


Figure TA-1-7

Actinide Migration Evaluation Pathway Report

Rocky Flats Soils Map with Hydraulic Conductivity Measurement and Soil Sampling Locations

EXPLANATION

Sampling Features

- Tension infiltrometer sampling location
- Soil Pit Location
- CDPHE Samples

Soils

- Denver clay loam, 2 - 5%
- Denver clay loam, 5 - 9%
- Denver-Kutch clay loam, 5 - 9%
- Denver-Kutch clay loam, 9 - 15%
- Denver-Kutch-Midway clay loam, 9 - 25%
- Englewood clay loam, 0 - 2%
- Englewood clay loam, 2 - 5%
- Flatirons cobbly sandy loam, 0 - 3%
- Flatirons stoney sandy loam, 0 - 5%
- Haverson loam, 0 - 3%
- Leyden-Primen-Standley cobbly clay loams, 15 - 50%
- McClave clay loam, 0 - 3%
- Midway clay loam, 9 - 30%
- Nederland very cobbly sandy loam, 15 - 50%
- Nunn clay loam, 0 - 2%
- Nunn clay loam, 2 - 5%
- Pits, gravel
- Rock outcrop, Sedimentary
- Standley-Nunn gravelly clay loam, 0 - 5%
- Valmont clay loam, 0 - 3%
- Valmont-Nederland very cobbly sandy loam, 0 - 3%
- Willowman-Leyden cobbly loam, 9 - 30%
- Yoder Fariant-Midway complex, 15 - 60%

Standard Map Features

- Buildings and other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Soils data from the US Soil Conservation Service. Uncertified Golden Area Soil Survey - 1980. Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Scale = 1 : 20240
1 inch represents approximately 1687 feet

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State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept, 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:
KH
KAISER-HILL

MAP ID: misc_maps
soil_smplaml

January 14, 2002

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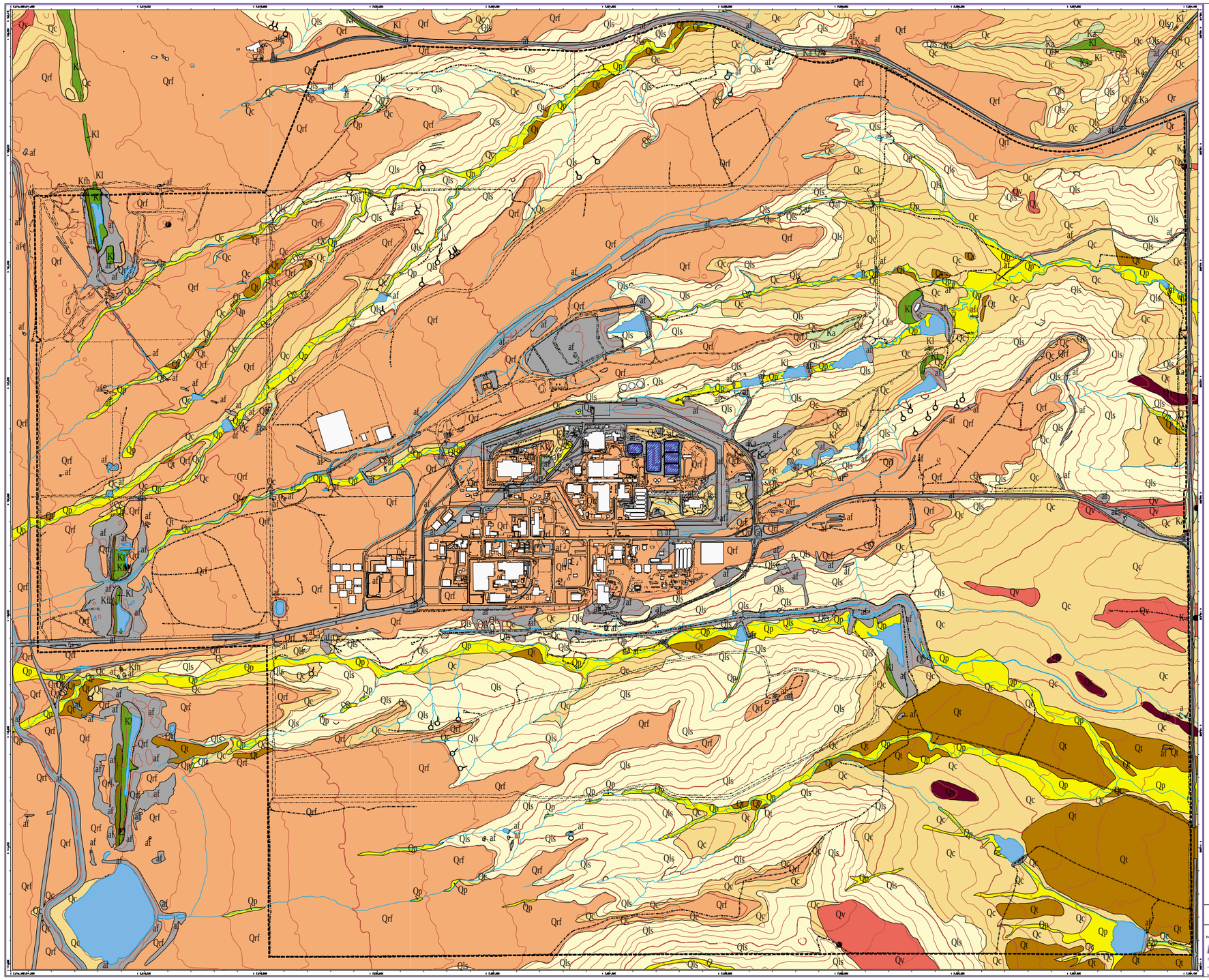

Figure TA-1-8

Actinide Migration Evaluation Pathway Report

Geologic Units at Rocky Flats Environmental Technology Site

Produced in cooperation with the U.S. Geological Survey

Geologic Map Units

af - Artificial fill
Qp - Post-Piney Creek and Piney Creek Alluvium
Qt - Terrace Alluvium
Qc - Colluvium
Qls - Landslide deposits
Qs - Slocum Alluvium
Qv - Verdos Alluvium
Qrf - Rocky Flats Alluvium
Ka - Arapahoe Formation
Kl - Laramie Formation
Kfh - Fox Hills Sandstone

Symbols

- Shallow closed depression
- Scarp of young landslide
- Areas of vegetation at and near springs
- Boundary of gravel and clay pit
- Spring
- Strike and dip of beds
- Clast identification site
- Capitol Mine (abandoned)
- Geologic Units boundaries

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Location of buildings, roads, and fences by Facilities Engr., EG&G Rocky Flats, Inc. - 1991.
Hydrology by Water Resources Division USGS - (date and author unknown)
Geologic Mapping: Shroba, R.R., and Carrara, P.E. Preliminary Surficial Geologic Map of the Rocky Flats Plant and Vicinity, Jefferson and Boulder Counties, Colorado: U.S. Geological Survey Open-File Report 94-162, Scale 1:6000
Site source of topo base; see OFR 94-162 (on map).

Subject Matter Expert:
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Stephen H Singer
RMRS T130C 107
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Phone: (303) 966-3387
Pager: (303) 212-6255

Scale = 1 : 21330
1 inch represents approximately 1778 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for:

December 13, 1997

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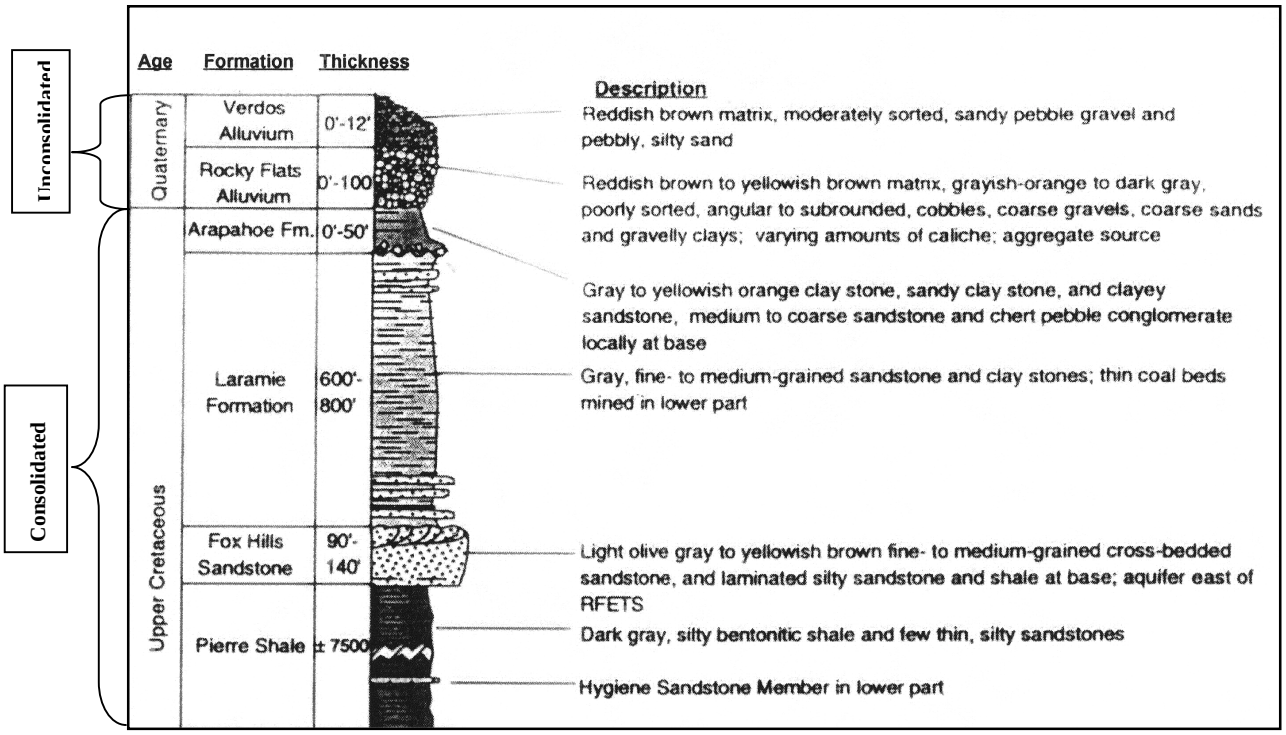
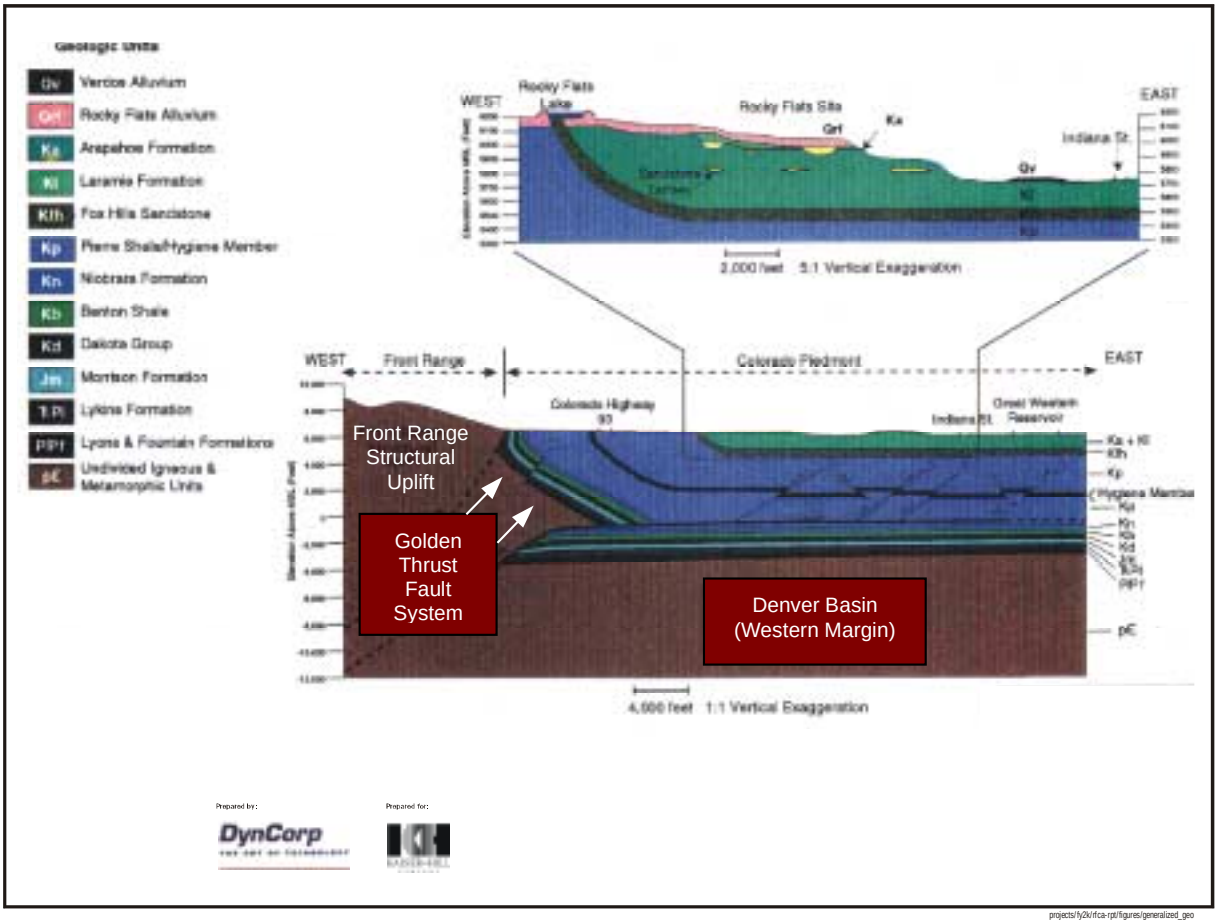
Figure TA-1-9. Generalized Stratigraphic Column for the RFETS Area



Source: Geologic Characterization Report for the RFETS, Volume 1, March 1995 (EG&G, 1995b)

Figure TA-1-10. Generalized Geologic Cross-Section of the Front Range and the RFETS Area



Source: Geologic Characterization Report for the RFETS, Volume 1, March 1995 (EG&G, 1995b)

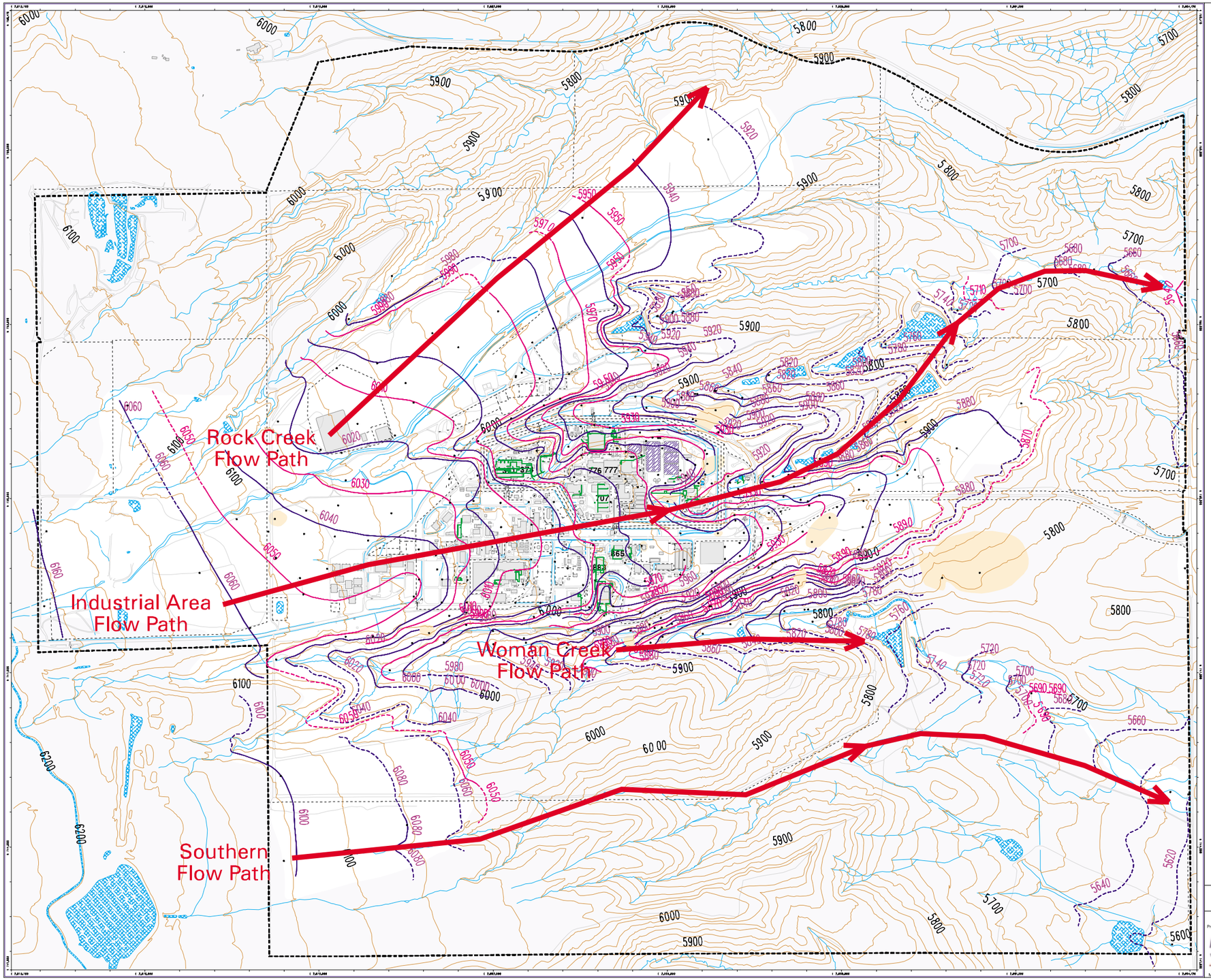


Figure TA-1-11

Actinide Migration Evaluation Pathway Report

Potentiometric Surface of Unconsolidated Surficial Deposits Second Quarter 1998

- Groundwater Monitoring Well
- Water Level Contour
- Dashed where inferred
- Intermediate Water Level Contour
- Dashed where inferred
- Foundation Drain and Elevation
- Approximate extent of Unsaturated Area
- Area without Groundwater Elevation Data

Standard Map Features

- Buildings & other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contours (20' Intervals)
- Roads
- Rocky Flats Boundary

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Scale = 1 : 21330
1 inch represents approximately 1778 feet
250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: KH Morrison Knudsen

MAP ID: misc_maps/potent98spring_nova1.aml

December 27, 2001

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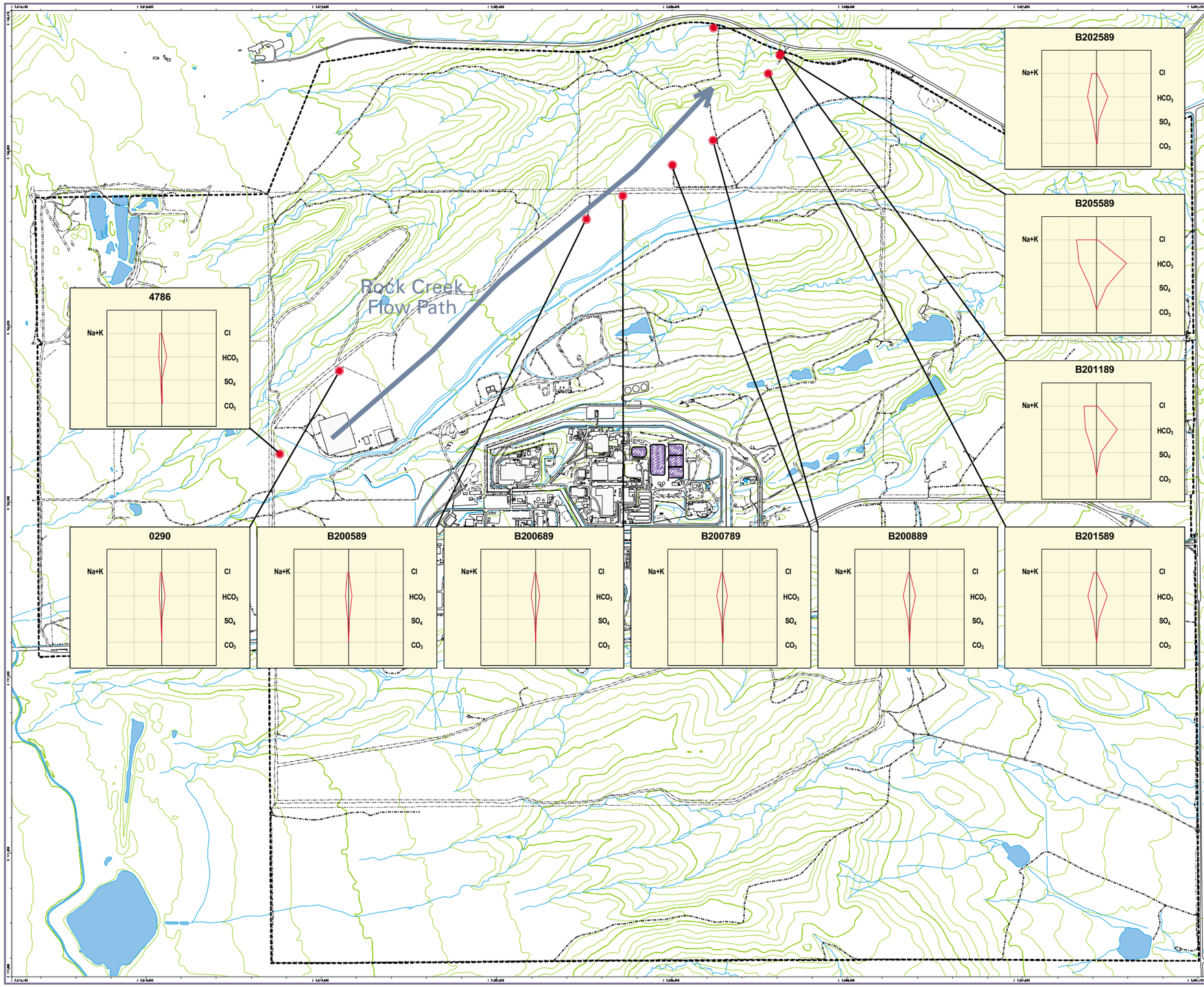

Figure TA-1-12

Actinide Migration Evaluation Pathway Report

Major Ion Concentrations in UHSU Groundwater for Rock Creek Flow Path

EXPLANATION

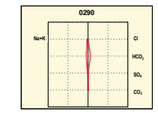

Diagram of dissolved major-ion concentrations ("Stiff plot") for selected wells. Concentrations are in milliequivalents per liter.

Flow Path

Upper Hydrostratigraphic Unit Monitoring Well

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Stiff Plot source:
Groundwater Geochemistry Report for the Rocky Flats Environmental Technology Site, Volume III of the Sitewide Geoscience Characterization Study, Final Report, EG&G Rocky Flats, January 1995

Scale = 1 : 21330
1 inch represents approximately 1778 feet
250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: Kaiser-Hill

MAP ID: uhsu_ion_maps

January 16, 2002

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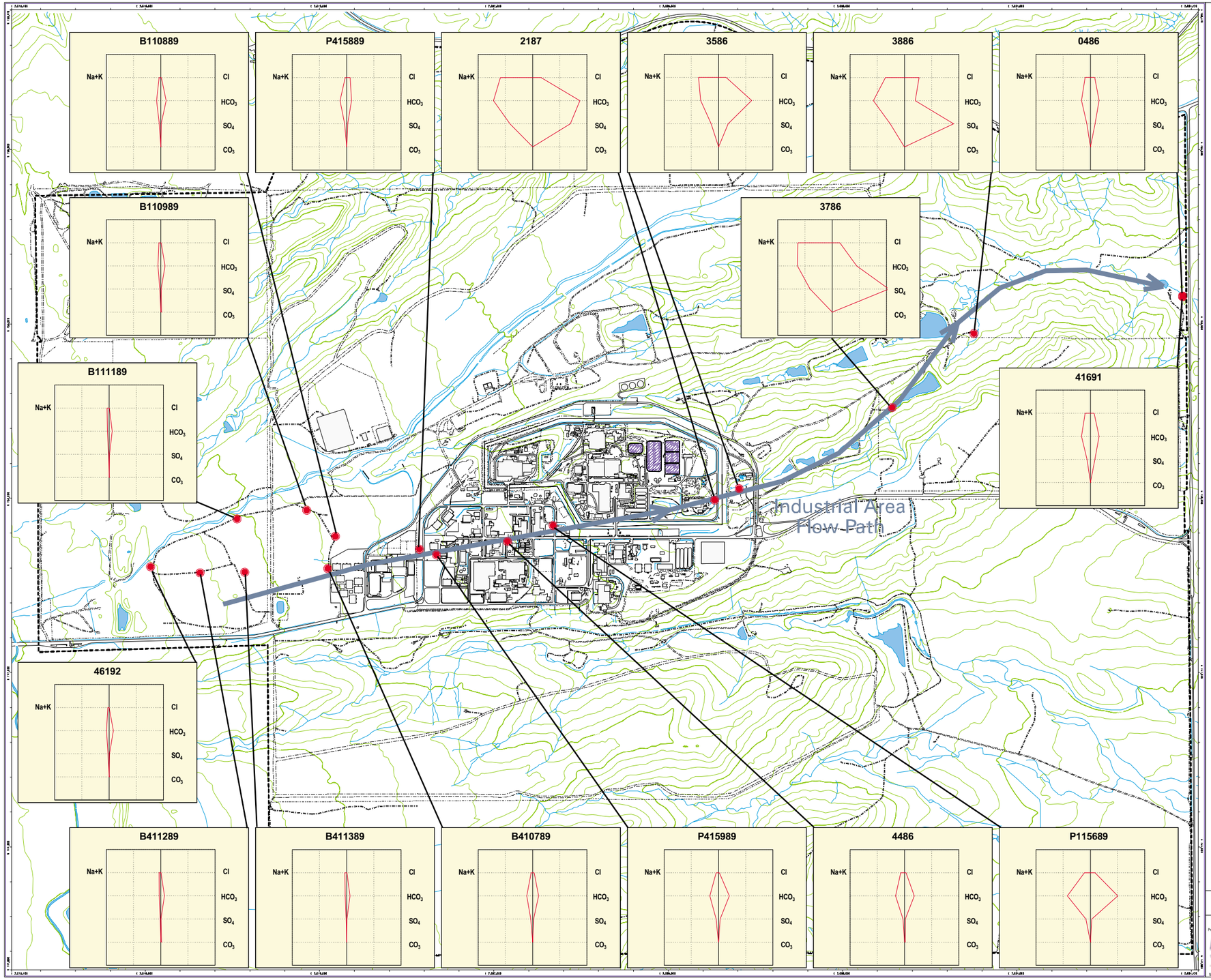

Figure TA-1-13

Actinide Migration Evaluation Pathway Report

Major Ion Concentrations in UHSU Groundwater for Industrial Area Flow Path

EXPLANATION

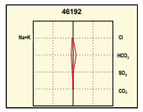

Diagram of dissolved major-ion concentrations ("Stiff plot") for selected wells. Concentrations are in milliequivalents per liter.

Flow Path

Upper Hydrostratigraphic Unit Monitoring Well

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Stiff Plot source:
Groundwater Geochemistry Report for the Rocky Flats Environmental Technology Site, Volume III of the Sitewide Geoscience Characterization Study, Final Report, EG&G Rocky Flats, January 1995

Scale = 1 : 21330
1 inch represents approximately 1778 feet
250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7797

Prepared by: DynCorp

Prepared for: K-H

MAP ID: usha_ion_maps

January 16, 2002

NT_Svr w:/projects/actinide_pathway_report/fy2002/uhsu_ion_maps/ion_conc_ia.aml

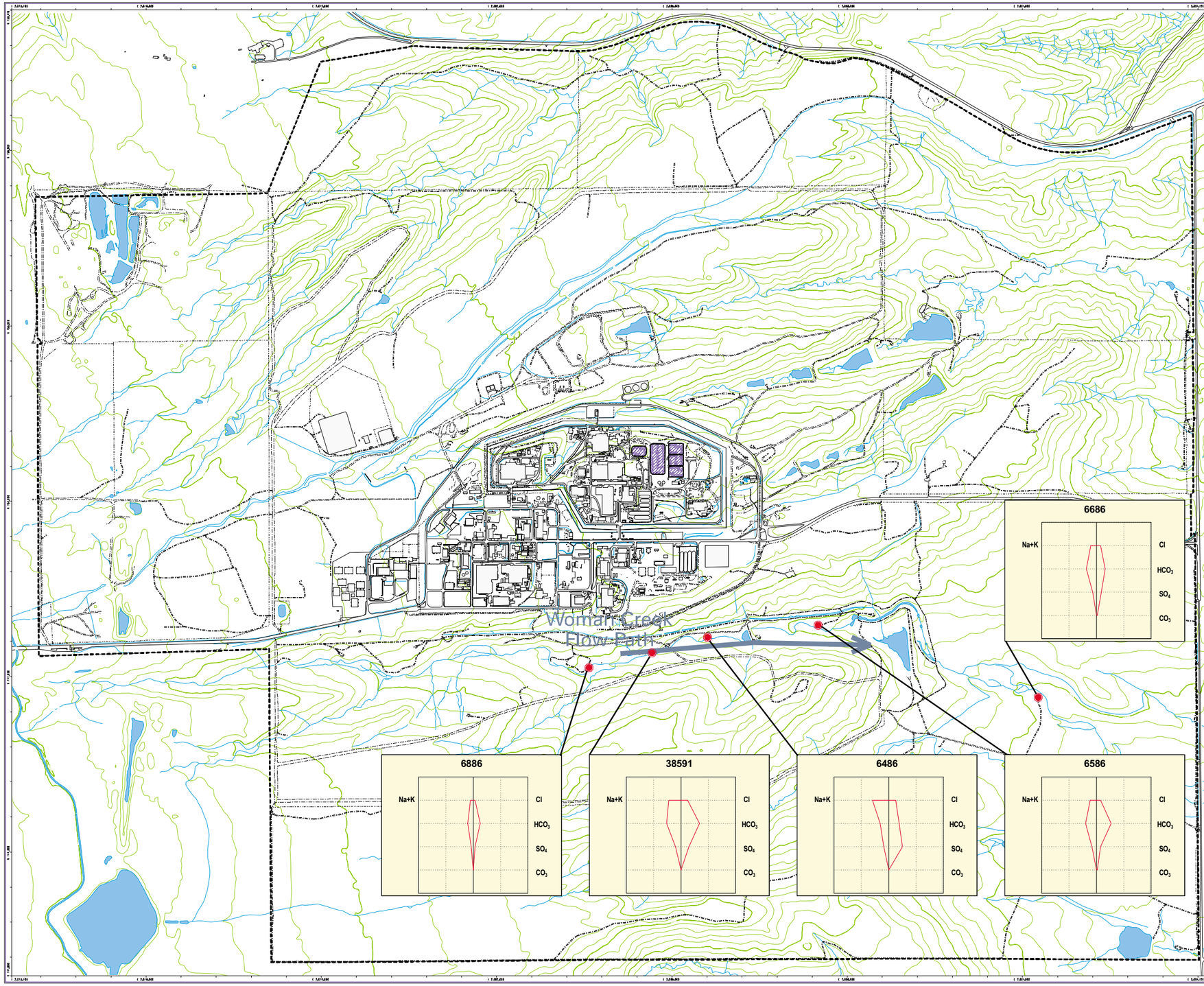

Figure TA-1-14

Actinide Migration Evaluation Pathway Report

Major Ion Concentrations in UHSU Groundwater for Woman Creek Flow Path

EXPLANATION

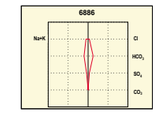

Diagram of dissolved major-ion concentrations ("Stiff plot") for selected wells. Concentrations are in milliequivalents per liter.

Flow Path

Upper Hydrostratigraphic Unit Monitoring Well

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Stiff Plot source:
Groundwater Geochemistry Report for the Rocky Flats Environmental Technology Site, Volume III of the Sitewide Geoscience Characterization Study, Final Report, EG&G Rocky Flats, January 1995

Scale = 1 : 21330
1 inch represents approximately 1778 feet
250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: Kaiser-Hill

MAP ID: ushu_ion_maps

January 16, 2002

NT_Svr w:/projects/actinide_pathway_report/fy2002/uhsu_ion_maps/ion_conc_woman_creek.aml

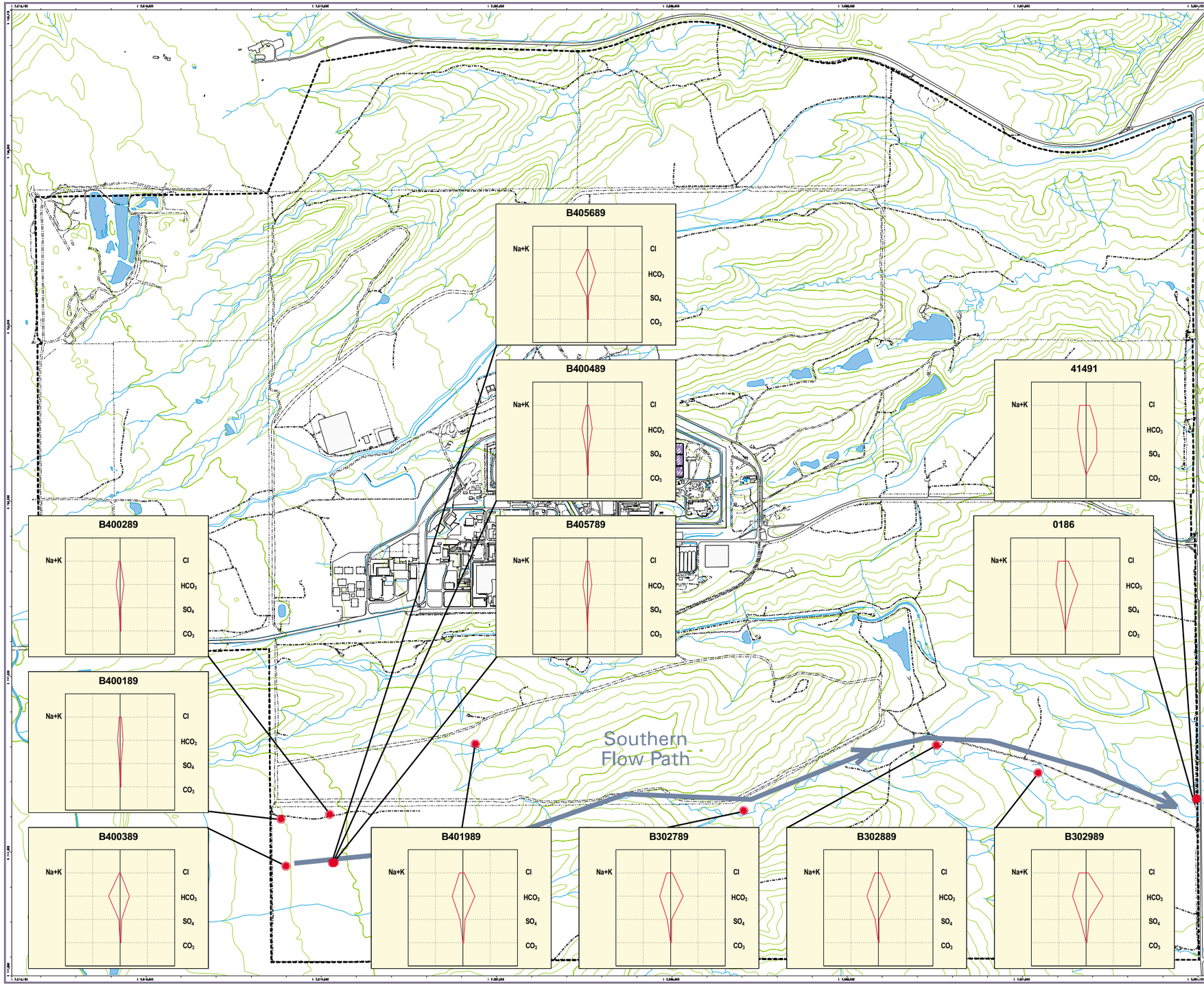

Figure TA-1-15

Actinide Migration Evaluation Pathway Report

Major Ion Concentrations in UHSU Groundwater for Southern Flow Path

EXPLANATION

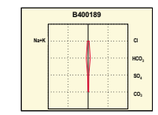

Diagram of dissolved major-ion concentrations ("Stiff plot") for selected wells. Concentrations are in milliequivalents per liter.

Flow Path

Upper Hydrostratigraphic Unit Monitoring Well

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEPs)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Topographic Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topographic contours were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Stiff Plot source:
Groundwater Geochemistry Report for the Rocky Flats Environmental Technology Site, Volume III of the Sitewide Geoscience Characterization Study, Final Report, EG&G Rocky Flats, January 1995

Scale = 1 : 21330
1 inch represents approximately 1778 feet

250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: Kaiser-Hill

MAP ID: uhsu_ion_maps January 16, 2002

NT_Svr w:/projects/actinide_pathway_report/fy2002/uhsu_ion_maps/ion_conc_southern.aml

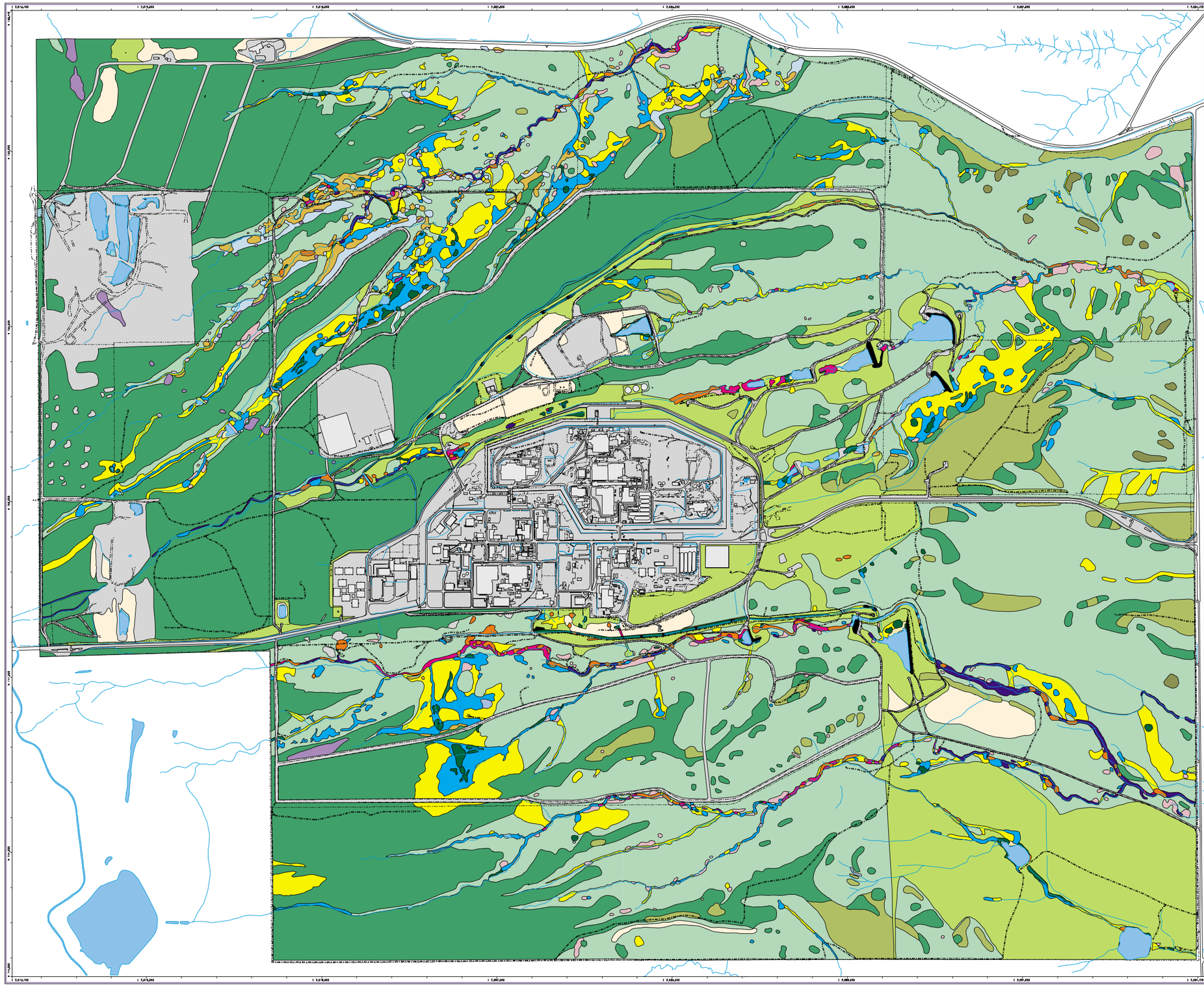

Figure TA-1-16

Actinide Migration Evaluation Pathway Report

Rocky Flats Vegetation Map

LEGEND

- Riparian Woodland
- Leadplant Riparian Shrubland
- Wet Meadow/Marsh Ecotone
- Short Upland Shrubland
- Willow Riparian Shrubland
- Annual Grass/Forb Community
- Xeric Tallgrass Prairie
- Ponderosa Woodland
- Reclaimed Mixed Grassland
- Mesic Mixed Grassland
- Savannah Shrubland
- Tall Upland Shrubland
- Short Marsh
- Xeric Needle and Thread Grass Prairie
- Short Grassland
- Disturbed and Developed Areas
- Open Water
- Riprap, Rock, and Gravel Piles
- Mudflats
- Tree Plantings
- Tall Marsh

Standard Map Features

- Buildings and other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Vegetation map data provided by PTI Environmental Services Ecology Group.
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

NOTES:

This map does not show all Federally designated wetlands. See the 1995 Site wetlands map prepared by the U.S. Army Corps of Engineers for delineated wetland features.

Scale = 1 : 20240
1 inch represents approximately 1687 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp

Prepared for: KAISER-HILL

MAP ID: misc_maps/veg_site.aml

January 21, 2002

NT_Svr w:/projects/actinide_pathway_report/fy2002/misc_maps/veg_site.aml