#1

DRAFT FINAL

PHASE I RFI/RI REPORT
WALNUT CREEK PRIORITY DRAINAGE
OPERABLE UNIT NO 6

VOLUME 3

5 0 THROUGH 9 0
TEXT TABLES AND FIGURES

DOCUMENT CLASSIFICATION REVIEW WAIVER PER CLASSIFICATION OFFICE

Reviewed for Classification/UCNI/OUO
By: Janet Nesheim, Derivative Classifier
DOE, EMCBC
Date: 10/14/08
Confirmed Unclassified, Not UCNI, Not OUO

U S Department of Energy
Rocky Flats Environmental Technology Site
Golden, Colorado

September 1995

(4047 910 0053 510) (R7 CVRS) (09 25/95 9 13am)

0006-430

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OU6 LIST OF ACRONYMS AND ABBREVIATIONS

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1,1-DCE	1,1-dichloroethene
1,1,1-TCA	1,1,1-trichloroethane
1,2-DCA	1,2-dichlorothane
1,2-DCE	1,2-dichloroethene
ac-ft	acre-feet
AEC	Atomic Energy Commission
af	man-made deposits
AGS	above ground surface
Am-241	Americium-241
AMSL	above mean sea level
AOC	Area of Concern
ARARs	applicable or relevant and appropriate requirements
BGS	below ground surface
BSL	Background Screening Level
Ca^{+2}	calcium
$CaCO_3$	calcium carbonate
CCl_4	Carbon tetrachloride
CDPHE	Colorado Department of Public Health and Environment
CDH	Colorado Department of Health
CEARP	Comprehensive Environmental Assessment & Response Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CHC	chlorinated hydrocarbons
$CHCl_3$	chloroform
Cis-1,2-DCE	cis-1,2-dichloroethene
CLC	common laboratory contaminants

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cm/sec	centimeters per second
cm	centimeter
COCs	chemicals of concern
CRQL	contract required quantitation limit
C_s-137	Cesium-137
CSM	conceptual site model
DCN	document change notice
d/m/l	disintegrations per minute per liter
DLG	Digital Line Graph
DOE	Department of Energy
DQO	Data Quality Objective
DRCOG	Denver Regional Council of Governments
ECD	Electron Capture Detector
EM	Electromagnetic
EMD	Environmental Management Department
EMRGs	Environmental Management Radiological Guidelines
EPA	Environmental Protection Agency
ER	Environmental Restoration
ERDA	Energy Research and Development Administration
ERP	Environmental Restoration Program
FDM	Fugitive Dust Model
FIDLER	field instrument for the detection of low-energy radiation
FSP	field sampling plan
GAC	granular activated carbon
gal	gallon
GS	gauging station
HCO^3	bicarbonate
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment

HPGe	high purity germanium
HRR	Historical Release Report
HSP	Health and Safety Plan
ID	inside diameter
IHSS	Individual Hazardous Substance Site
in/hr	inches per hour
IRIS	Integrated Risk Information System
K, (K^+)	hydraulic conductivity, (symbol for potassium)
Ka	Cretaceous Arapahoe Formation
Kl	Cretaceous Laramie Formation
LHSU	lower hydrostratigraphic unit
mCi	millicurie
meq/l	milliequivalents
Mgal	millions of gallons
ml	milliliter
mm	millimeters
MSL	mean sea level
Na+	sodium
NAAQS	National Ambient Air Quality Standards
NPDES	National Pollutant Discharge Elimination System
OU	operable unit
OVM	organic vapor monitor
PA	protected area
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PCOC	potential chemical of concern
pCi/g	picocuries per gram
PID	photoionization detector

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Pu-239/240	plutonium-239/240
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QAPjP	Quality Assurance Project Plan
Qc	Quaternary colluvium
QC	quality control
Q_{ls}	Quarternary landslides
Qrf	Quaternary Rocky Flats Alluvium
Qt	Quaternary Terrace Alluvium
Qvf	Quaternary Valley-Fill Alluvium
Ra-226	radium-226
RAD screen	radiological screen
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
RFA	Rocky Flats Alluvium
RfCs	reference air concentrations
RfDs	noncarcinogenic reference doses
RFEDS	Rocky Flats Environmental Database System
RFETS	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
RI	remedial investigation
SEAM	Superfund Exposure Assessment Manual
SFs	carcinogenic slope factors
SO_4^{2}	sulfate
SOP	Standard Operating Procedure
sq ft	square feet
sq mi	square mile

Sr-89,90	strontium-89,90
STP	Sewage Treatment Plant
SVOC	semivolatile organic compound
SWMU	Solid Waste Management Unit
TAL	target analyte list
TCE	trichloroethene
TCL	Target Compound List
TM	Technical Memorandum
TOC	total organic carbon
µg/kg	micrograms per kilogram
µg/l	microgram per liter
U-233/234	uranium-233/234
U-235	uranium-235
U-238	uranium-238
UHSU	upper hydrostratigraphic unit
USACE	U S Army Corps of Engineers
USCS	Unified Soil Classification System
UTL	upper tolerance limit
VOC	volatile organic compound
WARP	Well Abandonment and Replacement Program
W&I	Walnut and Indiana

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FATE AND TRANSPORT OF CHEMICALS OF CONCERN

Fate and transport of chemicals of concern (COCs) at OU6 have been evaluated to assess the potential for migration of COCs in air, groundwater, surface water, and sediment Measured and/or modeled concentrations of COCs in these media were used to estimate potential present and future onsite human exposure to these chemicals

Fate and transport of COCs are controlled by the release, transport, and persistence of COCs Transport of released COCs potentially occurs in various environmental media including the vadose zone groundwater, surface water and sediment, and air The mobility and behavior of COCs in environmental media are influenced by the physical and chemical characteristics of the COCs and media, and the rates of chemical degradation

The COCs in OU6 environmental media were identified in the Draft Final Technical Memorandum No 4 Chemicals of Concern Human Health Risk Assessment, Walnut Creek Priority Drainage Operable Unit No 6 (DOE 1994c) and are listed in Table 5 1-1

The evaluation of fate and transport of COCs in OU6 involved (1) an evaluation of transport processes for the vadose zone, groundwater, surface water and sediment, and air (Section 5 1), (2) an evaluation of the mobility and behavior of COCs (Section 5 2), (3) the development of a conceptual understanding of potential COC migration associated with OU6 areas of concern (AOCs) (DOE 1994a), incorporating COC source release mechanisms, transport processes and pathways of COC migration in the various environmental media (Section 5 3), and (4) a quantitative evaluation (modeling) of COC transport in groundwater, surface water, and air to estimate potential concentrations of COCs at exposure points to be used for the risk assessment (Sections 5 4 though 5 6) COC transport modeling of groundwater surface water, and air are described in detail in Appendixes G, H, and I Summaries of the modeling approaches and results are presented in Sections 5 4 through 5 6

It is important to note that transport processes, mobility and behavior of COCs, and migration pathways are provided in a manner that should provide for an understanding of COC migration that could potentially occur at OU6 Based on the nature and extent of COC

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(Section 4 0) and COC transport modeling results, the actual migration of COCs is not expected to be substantial

5 1 TRANSPORT PROCESSES

5 1 1 Vadose Zone

The vadose zone is the unsaturated soil zone between the ground surface and the top of the capillary fringe COCs present as residual contamination in OU6 subsurface and surface soil potentially migrate within the vadose zone Infiltrating precipitation moving downward through the vadose zone can leach COCs from the zone of residual contamination and transport them within the subsurface The leached COCs may again be adsorbed to vadose zone soils as they move Water that infiltrates the vadose zone may be held as storage or it may flow vertically to the saturated zone In addition, the infiltrate may be discharged to the surface Dissolved phase COCs not held in the vadose zone ultimately reach the saturated zone where they mix with groundwater in the saturated groundwater system

Leaching is an important transport mechanism for COCs with high aqueous solubility (e g , VOCs) COCs with lower solubilities (e g., some radionuclides, metals, and SVOCs) are less likely to be leached from the vadose zone and generally exhibit lower mobility For some of these less soluble COCs, colloidal transport may become significant under certain environmental conditions although it is not believed to be a significant process at OU6 Aqueous solubility of COCs is discussed in Section 5 2

Some vadose zone COCs, particularly VOCs may become volatilized and migrate as soil gas Soil gas may migrate through the vadose zone to the atmosphere or collect in subsurface man-made structures such as basements of buildings

5 1 2 Groundwater

Processes that affect transport of chemicals in groundwater include advection, dispersion retardation degradation, colloidal transport complexation, precipitation and oxidation/reduction behavior Advection dispersion and retardation are described briefly in

the following paragraphs Degradation, colloidal transport, complexation, precipitation, and oxidation/reduction are discussed in Section 5 2

Advection. The process by which dissolved chemicals are transported by the bulk motion of the flowing groundwater is known as advection (Freeze and Cherry 1979) Groundwater flow and advective chemicals transport occur in response to hydraulic gradients, with water and chemicals moving from areas of higher hydraulic head to areas of lower hydraulic head Reactive contaminants (i e, those that interact with the aquifer materials) usually move at rates slower than the average linear groundwater velocity. Non-reactive dissolved contaminants are carried at an average rate approximately equal to the average linear velocity of the groundwater flow

Horizontal groundwater flow rates are proportional to the horizontal hydraulic conductivity of the flow media and horizontal hydraulic gradients of potentiometric surfaces The principal hydrogeological units of the UHSU at OU6 are the Valley Fill Alluvium, Rocky Flats Alluvium, and weathered claystones of the Arapahoe and/or Laramie Formations The geometric mean of hydraulic conductivity for the Valley Fill Alluvium is 3 1 x 10^{-5} cm/s The geometric mean of hydraulic conductivity for the Rocky Flats Alluvium is 5 0 x 10^{-4} cm/s The geometric mean of hydraulic conductivity for the weathered claystones is 1 2 x 10^{-6} cm/s (Section 3 6) The range of horizontal hydraulic gradient in the UHSU at OU6 is approximately 0 03 feet/foot to 0 15 feet/foot (Figure 3 6-1)

Dispersion. Dissolved chemicals migrating with groundwater tend to spread out from the path that would be expected solely from advective transport. The spreading phenomenon is known as hydrodynamic dispersion Hydrodynamic dispersion in groundwater systems is caused primarily by mechanical mixing and to a lesser degree by molecular diffusion of solute particles Mechanical mixing is caused by variations in void spaces of porous media, variation in fluid velocity within pore spaces, and the tortuosity of the flow paths of fluid particles Molecular diffusion occurs in response to concentration gradients that cause movement of chemicals from areas of higher concentration to areas of lower concentration

Hydrodynamic dispersion occurs both parallel to and perpendicular to the direction of advective groundwater flow (i e, longitudinal and transverse dispersion, respectively)

Hydrodynamic dispersion is the process that results in the spreading of chemical plumes with increasing distance from chemical sources

Retardation Typically the migration of many chemicals in groundwater is retarded to some degree with respect to the advective flow rate This occurs due to interactions between the chemical and the aquifer materials that tend to slow the movement of the chemicals The primary process influencing retardation is adsorption Adsorption is described in more detail in Section 5 2 1

5 1 3 Surface Water and Sediment Processes

Transport processes that potentially affect the movement of chemicals via surface waters include overland flow during precipitation/runoff events flow from groundwater seeps, and advective transport and sediment transport in drainage channels and ponds Fate mechanisms include adsorption/desorption partitioning between dissolved and adsorbed phases, settling and resuspension of particulate material, volatilization of dissolved VOCs from the water column, and radioactive decay of radionuclides

Chemicals in surface soils potentially reach surface waters through erosion The energy from falling raindrops can dislodge soil particles and chemicals attached to, or found with these soil particles Overland flow of runoff can then transport these particles to drainages, perhaps eroding additional soil and chemical material through rill and gully scour Chemicals also may be discharged from the groundwater system at seeps and enter the creeks

Chemicals enter drainage channels in either dissolved or particulate phases, and migrate due to advective flow or sediment transport, respectively Advective flow and sediment transport processes are controlled by the geometric and hydraulic properties of the stream For chemicals that are sorbed to suspended solids settling and resuspension with the sediments can occur as stream velocity conditions change For the dissolved fraction of VOCs (VOCs exist primarily in the dissolved state) an important fate process is loss to the atmosphere through volatilization The chemical mass lost through volatilization depends on several factors including temperature flow depth chemical properties and travel time For radionuclides mass is lost through radioactive decay although that loss may be negligible depending on travel times

COC migration in OU6 stream water is complicated by the existence of the A- and B- Series detention ponds along Walnut Creek, which are used for water quality management and flood control purposes COCs (in either dissolved or particulate phase) coming from overland areas and groundwater seeps are subject to various transport processes within the ponds, such as advection, dispersion, deposition, and resuspension Much of the COCs associated with particulate material are rapidly deposited in the ponds due to flow deceleration. A very small portion of the particulate material will remain in suspension for an extended period of time and may be washed out of the detention pond system.

Deposition of sediments generally occurs when flow carrying capacity is less than the resistance of sediment being transported. Coarse and heavy particles are likely to deposit first in the upstream ponds and small and light particles are likely to stay in suspension throughout most of the detention ponds

Sedimentation of particles in ponds depends strongly on detention storage time, flocculation potential of the water, and flow velocity in the ponds. The flocculation potential and rate of floc growth are determined by the concentration of particles, the physiochemical properties of the sediment-water system and the agitation intensity, which depends on the flow conditions When flocs are formed, higher order aggregates may be initiated due to collisions among primary flocs, thus speeding up the sedimentation process.

Sedimentation rates of suspended solids depend on the relative rate of sediment settling versus the re-entrainment of particles. Particle re-entrainment occurs when particle aggregates break up near the bed under the action of bed shear stress. The rate of sediment deposition increases with increasing settling velocity and with suspension concentration, and decreases with increasing bed shear stress. Deposited sediment beds generally display a strong degree of stratification, exhibiting higher density and erosive shear strength with depth due to floc segregation during settling

Newly deposited sediments in lakes/ponds generally go through a consolidation process before subsequent depositional or erosional events. The consolidation of freshly deposited sediment is accompanied by release of excess pore pressure, a decrease in total bed thickness, a corresponding increase in bed density, and physiochemical changes associated with interparticle bonds For relatively thin beds, consolidation, in absence of additional

deposition is practically complete in a period on the order of one or two weeks (Mehta et al 1982) This consolidation process will eventually increase the bed shear strength with respect to erosion

Resuspension/erosion occurs when the bed shear stress induced by incoming streamflow is high enough to overcome bed shear strength (resistance to erosion) The rate of surface resuspension/erosion is generally proportional to the excess bed shear stress (bed shear stress - bed resistance to erosion) As the bed shear stress increases, particle erosion gives way to mass erosion Erosion of bed sediment by incoming streamflow is likely to occur at the inlet areas of ponds when flash floods run over shallow portions of the ponds This incoming flow will carry the sediment from shallow areas to deeper portions of the pond or may carry sediment out of the pond system

With respect to OU6 sediment transport out of the pond system is unlikely because of the large capacity of the terminal detention ponds (A-4 and B-5) and pond operation procedures to prevent this from happening (See Section 5.5 and Appendix H for detail)

5 1 4 Air Processes

Processes that affect the movement of COCs at OU6 via air pathways include

- Natural wind erosion of contaminated surface soils
- Fugitive dust generation and volatilization of VOCs from subsurface soils during construction
- Volatilization and diffusion of VOCs (contained within subsurface materials and UHSU groundwater) as soil gas to the ground surface
- Volatilization of VOCs from surface water to the atmosphere

Wind Erosion Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air Dust from these open sources is often designated as "fugitive," because it is not discharged to the atmosphere through a confined space within a

coherent flow stream Common sources of fugitive dust include unpaved roads, aggregate storage piles, heavy construction operations, and exposed areas of relatively dry soil Dust generation from these fugitive dust sources is primarily caused by two basic physical phenomena.

1 Pulverization and abrasion of surface materials by application of mechanical force through implements (e.g , wheels, blades)

2 Entrainment of dust particles by the action of turbulent air currents, such as wind erosion on exposed surfaces by wind speeds above a certain threshold value that is a function of site conditions.

The dust generation mechanism primarily responsible for potential airborne particulates from OU6 media is wind erosion of exposed surface soils. The amount of dust that may be eroded is a function of the frequency of occurrence of wind-speed episodes exceeding a threshold value required to disturb the soil surface The exposed surface areas are characterized by a finite availability of erodible material (mass/area), referred to as the erosion potential Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential Once eroded, the dispersal of the dust is dependent upon wind direction and atmospheric turbulence (as indicated by wind speed and atmospheric stability). Typically, larger dust particles are deposited near the source due to gravitational settling while the finer-sized dust particles tend to remain suspended for longer periods of time and are dispersed over much greater distances from the source

Volatilization. As stated in Section 5 1 1, VOCs present in subsurface soil or groundwater may migrate by volatilizing to soil gas, which then migrates through the vadose zone to the atmosphere or collects in man-made structures such as basements of buildings The release of VOCs to soil gas occurs in subsurface pores at the interface between the contaminated material and the adjoining subsurface layer Conceptually the contaminant release occurs by the "peeling away" of successive unimolecular layers of contaminant from the surface of the contaminated zone

The soil gas diffuses away from the contaminated subsurface zone toward the ground surface in response to chemical concentration gradients. The emission of soil gas at the ground

surface is maximized when the existing soil gas concentration of the chemical of interest at the ground surface is zero

Volatilization of VOCs from surface water in streams and ponds may also occur in OU6 VOCs present in the dissolved phase may pass from liquid to gas phase and diffuse into the atmosphere in response to chemical concentration gradients and other factors

5 2 MOBILITY AND BEHAVIOR OF CHEMICALS OF CONCERN

Migration of COCs in various environmental media at OU6 is controlled by transport processes such as advection/dispersion, sediment transport, and by a variety of physical and chemical fate processes such as adsorption and degradation The fate processes influence the transport of COCs by reducing transport velocity or by transforming one chemical to another Therefore to understand the migration of COCs in the environment at OU6, it is necessary to understand how the physical and chemical processes influence the mobility and behavior of these chemicals

Physical and chemical fate processes that influence the mobility and behavior of chemicals are affected by the physical and chemical properties of the environmental media and the chemical themselves In this section first the mechanisms of the primary physical and chemical fate processes are briefly reviewed (Section 5 2 1) Second, the physical and chemicals properties of the environmental media and COCs, and the way these properties potentially influence the mobility and behavior of COCs are examined (Sections 5 2 2 and 5 2 3, respectively) Finally, the mobility and behavior of the OU6 COCs are discussed (Section 5 2 4)

5 2 1 Primary Physical and Chemical Processes that Influence the Mobility and Behavior of Chemicals

The transport of chemicals in a particular medium is affected by a variety of physical and chemical processes, including but not limited to adsorption/desorption, ion exchange, hydrolysis oxidation/reduction, dehalogenation, precipitation complexation, volatilization, biodegradation radioactive decay colloidal transport and sediment transport The key processes affecting the transport of the VOC COCs at OU6 are believed to be adsorption,

volatilization and biodegradation. With respect to the mobility of radionuclides and metals, adsorption and sediment transport are considered to be key processes. This section describes those key processes and the major factors that influence those processes.

Adsorption. Adsorption is a process by which dissolved chemicals partition from the dissolved phase to the solid phase Adsorption is considered to be one of the most important processes that affects the rate of migration of certain chemicals in groundwater and surface water environments In the subsurface, if a chemical is strongly adsorbed to the solid fixed matrix (i e , geologic materials), the chemical is relatively immobile, and the potential for the chemical to be leached from a residual contamination source and transported with groundwater is relatively small If a chemical is weakly adsorbed, the chemical can be easily leached and transported vertically through the vadose zone or within the saturated zone (Olsen and Davis 1990) In the surface water environment, adsorption affects the degree to which a chemical is transported in the dissolved phase, or via sediment transport processes, as discussed later in this section Adsorption also affects the other geochemical processes, such as volatilization and biodegradation

Adsorption is a surface interaction between dissolved chemicals and organic or inorganic adsorbents In reality, adsorption is due to a number of forces that result in a combination of processes including ion exchange, physical adsorption, and chemical adsorption (Knox et al 1993) The potential for adsorption depends, in part, on the surface area of contact between the geologic material and chemicals dissolved in groundwater The greater the surface area per unit volume, and the greater the number of adsorptive sites, the more adsorption is promoted (all other factors being equal)

In general, the degree of adsorption depends on three major factors

- The content of adsorbents in the environmental media (e.g , organic carbon content)
- Contact area between the chemicals and adsorbents
- Physical and chemical properties of the chemicals (i.e , affinity for adsorption)

Detailed discussions regarding how these factors affect the adsorption processes are included in Sections 5 2 2 and 5 2 3

Volatilization Volatilization is a process by which a chemical is transferred from soil (adsorbed on soil) water (dissolved phase), or liquid (free product) into soil gas or the atmosphere In general the tendency of a chemical to volatilize depends upon the physical properties of the chemical (vapor pressure and Henry's Law constant), and environmental factors, such as temperature, pressure, and the available pathways In the surface water environment the degree of volatilization is influenced by the depth and the velocity of surface water and chemical-specific properties In the subsurface saturated or vadose zone environments volatilization of chemicals is influenced by the depth of the aquifer the intrinsic permeability of the geologic material and the soil-water content in vadose zone

Biodegradation Biodegradation is a combination of chemical transformations, including oxidation reduction, and dehydrohalogenation that are catalyzed by the action of microorganisms in the subsurface environment Biodegradation is potentially a significant process affecting the fate of organic chemicals, under certain conditions (Olsen and Davis 1990)

Important factors that determine if, and at what rate, biodegradation will occur, include

- The structure of the organic compound (i e whether it is a hydrocarbon or a substituted hydrocarbon will affect the rate of chemical reaction)
- Whether aerobic (oxidizing) conditions or anaerobic (deficit of oxygen) conditions exist in the subsurface, and what type of environment is required for degradation to occur
- The microbial population in the subsurface
- The organic carbon content and the concentration of organic chemicals in the environmental media

A more detailed discussion of the potential biodegradation of VOC COCs is given in Section 5 2 3

Colloidal Transport. Colloids are particles of organic or mineral matter with diameters in the range of 10^{-3} to 10^{-6} mm (Freeze and Cherry 1979) that can be suspended in water Colloidal particles may be mobile in the subsurface environment, potentially moving vertically with infiltrating water through the vadose zone, or laterally by advection with groundwater flow in the saturated zone Colloidal particles can adsorb organic and inorganic chemicals Mobile colloids can, therefore, transport chemicals, thereby increasing the amount of chemicals that flow with groundwater (McCarthy and Zachara 1989) As demonstrated in a shallow aquifer in a semi-arid environment (at Los Alamos, New Mexico), plutonium and americium can be transported for significant distances by colloids ranging in diameter from 0 025 to 0 45 μm (Penrose et al 1990)

To be mobile over significant horizontal distances, suspended colloidal particles must be stable (resisting aggregation with other like particles), must not settle in groundwater, and must not be filtered when passing through pores. Whether a particle will be stable, aggregated, filtered, or will settle in groundwater depends on a complex combination of particle density, size, surface chemistry, water chemistry, and groundwater flow rates. Therefore, it is very difficult to predict or simulate colloid behavior in subsurface environments (McCarthy and Zachara 1989)

Sediment Transport. In surface waters, sediment transport is the predominant transport mechanism for those chemicals that are strongly associated with solids. Chemicals with high partition coefficients tend to sorb onto suspended solids in the water column and are then transported along with the suspended solids in the bulk advective flow These particulate chemical forms can settle out of the water column under low velocity conditions or, after settling, be resuspended under high velocity (scour) conditions In addition to this advective transport of suspended particles, chemicals sorbed onto the stream sediments can be transported in reaches as bedload Bedload transport occurs as the bed sediment is moved downstream (rolling or sliding) without becoming completely resuspended Sediment-transport processes tend to slow the overall migration of chemicals with high partition coefficients relative to chemicals with low partition coefficients that are transported mainly by advective flow processes

5 2 2 Physical and Chemical Properties of the Media that Affect Mobility and Behavior

As stated in Section 5 2 1, the mobility and behavior of chemicals is affected by the physical and chemical properties of the environmental media The physical characteristics of environmental media at OU6 are described in Section 3 0 meteorology and climatology are discussed in Section 3 3, surface soils in Section 3 4, site geology in Section 3 5, site hydrogeology in Section 3 6, and surface water hydrology in Section 3 7 This section focuses on the physical and chemical properties of surface soil surface water, and subsurface soil and water that most influence the mobility and reactivity of COCs at OU6 These properties include (1) subsurface properties such as organic carbon content, clay content and mineralogy, groundwater pH, oxidation potential, and the availability of microorganisms and (2) surface properties, including grain size distribution of the surface soil, organic carbon content, and surface water pH

Organic Carbon Content The fraction of organic carbon in geologic materials is strongly correlated with the potential for adsorption of chemicals, especially for adsorption of organic compounds The partitioning of organic chemicals from the dissolved phase to the solid phase is usually proportional to the organic carbon content of the media Organic carbon content also influences biodegradation Microorganisms, required to catalyze chemical-degradation reactions are dependent on organic carbon as a food source Total organic carbon concentrations for all media are presented with inorganic parameters in Appendix D

The observed site-wide organic carbon content in subsurface soil is relatively low The average total organic carbon content, measured from 81 samples collected from the ground surface to 8 feet deep from 45 boreholes at OU6, is approximately 0 6 percent, ranging from 0 05 to 1 9 percent The total organic carbon content from samples in the interval from 4 to 8 feet deep is lower, with an average value of 0 28 percent

The total organic carbon content in the surface soil is relatively high as expected due to surface vegetation and plant roots, with an average value of 1 2 percent

The average total organic content in stream sediment measured from 15 samples at OU6 is approximately 0 88 percent ranging from 0 48 to 2 2 percent

The average total organic content in pond sediment, measured from 19 sediment samples in the A-series ponds and 28 sediment samples in the B-series ponds, is approximately 1 1 percent, ranging from 0 66 to 1 8 percent and approximately 1 7 percent, ranging from 0 67 to 3 0 percent, respectively The average total organic content in A- and B-series ponds, is approximately 1 4 percent In addition, five pond sediment samples were collected from the Walnut and Indiana (W&I) pond. The total organic carbon in these samples was approximately 0 84 percent, ranging from 0 76 to 1 1 percent.

Whether chemicals adsorb onto organic or inorganic materials depends on the fraction of organic carbon relative to a specific critical level of organic carbon (McCarty et al 1981) This critical level is chemical-specific and dependent on site conditions As the organic carbon content approaches the critical level, organic adsorbents begin to dominate the adsorption process. However, if the fraction of organic carbon is small, adsorption of organic chemicals to inorganic adsorbents (mostly clay) is important. Discussion of the estimation of the potential for adsorption is provided in Section 5 2 2

Clay Content and Mineralogy of Subsurface Soils: Clay content and mineralogy are important parameters affecting the adsorption of both organic and inorganic chemicals A high content of clay in geologic materials provides favorable conditions for adsorption because of the following: (1) clay minerals have negatively charged surfaces and behave as inorganic adsorbents, (2) clays have relatively large specific surface areas, and adsorption tends to be greater when the surface area of the medium is greater (all other factors being equal), and (3) substantial clay content in geologic materials tends to reduce the effective hydraulic conductivity, thereby reducing groundwater flow velocities and increasing residence time so that the probability of geochemical processes approaching equilibrium is increased

Based on the geologic characterization presented in Section 3.5, clay content in much of the geologic materials of the UHSU appears to be relatively high Within OU6, the UHSU consists of Rocky Flats Alluvium, colluvium, Valley Fill Alluvium, and claystone, siltstone, and sandstone of the Arapahoe and upper Laramie Formations. Grain size analytical results obtained from the borehole logs of OU6 Phase I soil borings (Appendix C-2) and historical monitoring wells (Appendix C-3) were used for calculating the average clay content percentage The average clay content, based on soil boring and monitoring well soil sample grain-size sieve analyses is approximately 40 percent

Clay mineralogy is potentially significant to the adsorption process because the surface area and the cation exchange capacity (CEC) of clays varies with the specific mineralogy The common clay minerals can be divided into five groups smectites, vermiculites illites kaolinites, and chlorites Their specific surface area in terms of meters^2/gram (m^2/g) and cation exchange capacity can vary by orders of magnitude Site-specific information for surface soils and subsurface materials is limited and determination of the specific clay types present at OU6 has not been performed

Groundwater pH Field measurements of groundwater pH ranged from 4 3 to 10 3 with a average reported pH value of 7 3 The average pH value indicates slightly alkaline or near-neutral conditions exist in OU6

The groundwater pH influences other geochemical characteristics of the media The groundwater pH will affect the magnitude and type of surface charge on clays and other media solids Acidic or near-neutral pH values result in positively charged surfaces, and relatively low CEC and cation adsorption values Alkaline pH values result in negatively charged surfaces and relatively high CEC and cation adsorption values (Drever 1988) The observed pH conditions suggest that cation exchange capacity is relatively low However, it is believed that cation adsorption may be significant at OU6 At pH values greater than 5 or 6 most inorganic cations will precipitate as hydroxides or carbonates therefore, the mobility of these inorganic cations in groundwater or the vadose zone will be reduced

Oxidation Potential Oxidation-reduction (or redox) potential is the potential for the loss or gain of electrons to occur (Knox et al 1993) There are several ways in which oxidation potential influences the fate and transport of chemicals in the subsurface

First the oxidation state (reflected by the charge that an ion would have if an atom or molecule were to dissociate) of metals and radionuclides that have multiple oxidation states determines the solubility and the stability of the species This determines the mobility of the chemical and, in some cases, the toxicity For example, trivalent plutonium Pu(III) is soluble and mobile relative to Pu(IV), which forms an insoluble oxide, PuO_2 The oxidation states of metals and radionuclides are primarily determined by the oxidation potential of the environment At OU6 it is believed that PuO_2 is the dominant form of plutonium due to the oxidizing environment described below

Second, the oxidation potential is an indicator of the potential for biodegradation of organic chemicals Some organic compounds are only degradable in aerobic conditions and some are only degradable in anaerobic conditions (McCarty et al 1984).

At OU6, the subsurface environment generally appears to have aerobic, or oxidizing, conditions This is supported by lithologic descriptions of geologic materials from borehole logs (Appendix A) and dissolved oxygen values measured during groundwater sampling (Appendix C) Geologic materials in OU6 exhibit colors such as orange-brown, red-brown, yellow-brown and olive-brown These colors suggest the presence of iron oxides Site-wide, the dissolved oxygen in groundwater is high, with an average value of 6 4 mg/l According to Matthess (1982), an oxygen content of about 0 01 to 0 7 mg/l at 8°C water temperature has been defined as the threshold oxygen concentration between oxidizing and reducing conditions According to this criterion, the measured dissolved oxygen level indicates that oxidizing conditions generally exist in the groundwater system at OU6 An OU6 area that may have anaerobic conditions locally is the vicinity of Well 3586 (Section 5 2 4 1)

The general oxidizing conditions in OU6 may be due to the transient UHSU groundwater system observed at OU6 (Section 3 6). OU6 groundwater is replenished by infiltrating precipitation (typically in the spring), and groundwater elevations fluctuate significantly, following an annual cycle as described in Section 3 6. This provides seasonal opportunities for oxygen replenishment in the subsurface.

Grain-Size Distribution in Surface Soil. One of the most important factors that influences wind erosion and sediment transport processes is surface soil grain-size. Grain-size analyses were performed by Colorado State University (CSU) on 1 5 surface soil samples collected from OU2, OU5, and OU6 during the Phase II OU2 RFI/RI (DOE 1995) Results indicate that the average sample grain size distribution was grain diameters greater than 100 µm (49 percent), grain diameters from 10 to 100 µm (22 percent), and diameters less than 10 µm (30 percent)

In the Unified Soil Classification System, particles smaller than 74 µm are considered to be fines (silt or clay) Thus, a relatively large percentage of surface soils in the area are fine-grained This promotes wind erosion and sediment transport at the site The large percentage

of clay also promotes adsorption of chemicals to soils, thus increasing potential for COC migration as the soils are transported

Surface Water pH The field parameter measurements at 30 surface water sampling locations result in an average pH value of 7 8 (Appendix D), indicating that surface water is slightly alkaline to or near neutral This is slightly more alkaline than groundwater pH conditions

5 2 3 Physical and Chemical Properties of COCs that Influence Mobility and Behavior

5 2 3 1 Volatile Organic Compounds

VOC COCs were identified in subsurface soil, groundwater, and pond surface water in OU6 (Table 5 1-1) The physical and chemical properties of VOCs that most influence the mobility and behavior in OU6 environmental media include water solubility, vapor pressure and Henry's Law constant (K_h), the octanol-water partition coefficient (K_{ow}), and the organic carbon partition coefficient (K_{oc}) These properties are described in the following section

Water Solubility Water solubility is perhaps the most important property of organic compounds in estimating their mobility and behavior The water solubility of a compound is defined as the saturated concentration of the compound in water at a given temperature and pressure (Montgomery and Welkom 1989) Organic compounds with high solubility tend to desorb from soils and sediments, are less likely to volatilize from water and are generally susceptible to biodegradation Conversely, organic compounds with low solubilities tend to adsorb onto soils and sediments, volatilize more readily from water, and bioconcentrate in aquatic organisms (Montgomery and Welkom 1989)

Values of solubility for VOC COCs at OU6 range from 150 mg/l (PCE) to 20 000 mg/l (methylene chloride) as shown in Table 5 2-1 In general the solubilities of these compounds are moderate to relatively high

Vapor Pressure and Henry's Law Constant The vapor pressure of a substance is defined as the pressure exerted by the vapor (gas) of a substance when it is under equilibrium conditions given specific temperature and total pressure (Montgomery and Welkom 1989) This parameter is used to calculate the Henry's Law Constant K_h which is defined as the ratio of

the partial pressure of a compound in air to the concentration of the compound in water at a given temperature under equilibrium conditions K_h is a function of both the solubility and vapor pressure It is directly proportional to the vapor pressure, and inversely proportional to the solubility

K_h provides an indication of the relative volatility of a substance from the liquid phase. Chemicals with a K_h of less than 10^{-7} atm-m^3/mole are considered to have a low volatility Chemicals with a K_h on the order of 10^{-7} to 10^{-5} atm-m^3/mole are considered moderately volatile and will volatilize slowly Volatilization becomes an important transfer mechanism if K_h is in the range of 10^{-5} to 10^{-3} atm-m^3/mole. Values of K_h exceeding 10^{-3} atm-m^3/mole indicate volatilization will proceed rapidly (Montgomery and Welkom 1989)

K_h values for the VOC COCs at OU6 range from 2×10^{-3} (methylene chloride) to 1 22 atm-m^3/mole (vinyl chloride) as listed in Table 5.2-1. These high values of K_h indicate that VOCs at OU6 will likely volatilize from contaminated surface waters and groundwater, other factors permitting

<u>Octanol-water Partition Coefficient (K_{ow}) and Organic Carbon Partition Coefficient (K_{oc}).</u> The octanol-water partition coefficient, K_{ow}, is a measure of the degree to which an organic substance will preferentially dissolve in an organic solvent compared to water The coefficient is the ratio of the equilibrium concentration of the substance in octanol to the equilibrium concentration in water (Fetter 1993) The greater the K_{ow} value, the greater the tendency for the chemicals to partition from dissolved aqueous phase to solid organic phase

The organic carbon partition coefficient, K_{oc}, is defined as the ratio of adsorbed chemical per unit weight of organic carbon to the aqueous solute concentration (Montgomery and Welkom 1989). This parameter provides an indication of the tendency of dissolved organic compounds to partition on geologic materials containing organic carbon The greater the K_{oc} value, the greater the tendency for the chemical to partition on geologic materials.

K_{ow} values have been measured in the laboratory for many chemicals Relationships between K_{oc} and K_{ow} have been studied and are represented by a number of linear regressions Estimates of K_{oc} values are based on the measured K_{ow} values and the regression equations The K_{ow} and K_{oc} values for VOC COCs at OU6 are listed in Table 5 2-1

5 2 3 2 Semi-volatile Organic Compounds

SVOCs have been detected in OU6 subsurface soil, pond sediment, and stream sediment The characteristics that were considered the most important for understanding the mobility and behavior of SVOC compounds are the solubility, Henry's Law constant, octanol-water partition coefficient and organic carbon partition coefficient These characteristics are explained in Section 5 2 3 1, and discussed with regard to SVOCs below

Water Solubility The SVOC COCs identified in OU6 media, excluding di-n-butyl phthalate, have very low water solubilities that range from 10 µg/l [benzo(a)anthracene and benzo(a)pyrene] to 400 µg/l [bis(2-ethylhexyl)phthalate] (Table 5 2-1) These compounds have low solubilities due in part to the high molecular weight of the nonpolar molecules Di-n-butyl phthalate has a water solubility of 400 mg/l

Henry's Law Constant K_h for the SVOC COC compounds identified in OU6 range from approximately 3×10^{20} for indeno(1 2 3-cd)pyrene to 6×10^{5} atm m^3/mole for di-n-butyl phthalate (Table 5 2-1) indicating low to moderate volatility

Octanol-water Partition Coefficient (K_{ow}) and Organic Carbon Partition Coefficient (K_{oc}) The K_{ow} and K_{oc} values for SVOCs at OU6 range from approximately $1 6 \times 10^{4}$ (bis(2-ethylhexyl)phthalate) to 5×10^{7} (indeno(1,2 3-cd)pyrene)

5 2 3 3 Metals

Barium has been identified as a COC in subsurface soil Antimony, silver vanadium and zinc have been identified as COCs in surface soil and pond sediment Cobalt strontium vanadium, and zinc are identified as COCs in Walnut Creek stream/dry sediment As described in Section 2 1, "dry sediments" are sediment samples collected in A- and B-series pond inlet areas by the RFP method No metals were identified as surface water or groundwater COCs

The physical and chemical properties of these metals that influence their mobility and behavior include oxidation states and solubility and precipitation and co-precipitation At OU6 the oxidation states and solubility and their effects on sorption appear to be the key

processes influencing mobility and behavior Physico-chemical properties of the COC metals are provided in Table 5 2-2

Oxidation States and Solubility. Oxidation states of metals control their stability and solubility in the environment. In general, because none of the metals COCs were observed above background levels in OU6 waters, it is believed that the metals are present in oxidation states that are associated with low solubility Oxidation states and solubilities for each metal COC are discussed below

Antimony (Sb) exists in the valence states of -3, 0, +3, and +5, with Sb (III) and (V) the prevalent oxidation states in aqueous solution. In an oxidizing environment, such as that found at OU6, the predominant species of antimony would be expected to be $Sb(OH)_6$ Sorption or coprecipitation of antimony onto hydrous iron and aluminum oxides appears to be important in removing antimony from solution (Battelle 1984)

Barium (Ba) occurs in barite ($BaSO_4$), a fairly common mineral As is the case for other alkaline earth elements such as calcium and magnesium, barium exhibits only the +2 valence state in aqueous solutions (Battelle 1984)

Cobalt (Co) can exist in the +2 or +3 oxidation states, similar to those of iron When associated with manganese oxide, the oxidation state of cobalt is generally +3. With the possible exception of complex ions, aqueous species of Co +3 are not thermodynamically stable at pH conditions of groundwater and surface water at OU6 The solubility of $Co(OH)_2$ is low and probably does not substantially contribute to cobalt concentrations in the surface water or groundwater $CoCO_3$ has a very low solubility in water Coprecipitation or adsorption of cobalt by oxides of manganese and iron can be an important factor in controlling the amounts that can occur in solution in natural water (Hem 1985)

Silver (Ag) occurs as a native element and with other sulfides and chlorides The +1 oxidation state occurs in aqueous solution, although other oxidation states are assigned in silver compounds Silver is strongly sorbed by manganese oxide and thus is expected to concentrate in sediments

Strontium (Sr) an alkaline earth metal is a very common element replacing calcium or potassium in igneous rock Strontium occurs only in the +2 valence state in the environment $SrSO_4$ is very soluble in water, whereas, $SrCO_3$ is only slightly soluble in water

The aqueous geochemistry of vanadium (V) is very complicated Three oxidation states (+3, +4 and +5) can be stable in an aqueous system, but the dominant forms are +5 anionic complexes with oxygen and hydroxide Vanadium does not naturally occur in highly concentrated forms, native soil concentrations for vanadium range from 20 to 500 mg/kg

In aqueous solutions, zinc (Zn) is present in the +2 oxidation state At pH values up to about 8 zinc occurs in aqueous solution as Zn^{2+} (and zinc sulfate species if sulfate is present) whereas at higher pH values zinc carbonate and zinc hydroxide species predominate (Battelle 1984) Zinc would be expected to be a relatively mobile metal in oxidizing conditions such as those believed to exist at OU6 Zinc is sorbed onto hydrous oxides of manganese and iron organic material, and clay minerals

5 2.3 4 Nitrate

Nitrate was identified as a COC in the UHSU groundwater at OU6 Nitrate is the main form in which nitrogen occurs in groundwater Nitrate is a negatively charged species consisting of nitrogen and oxygen, referred to as an oxyanion Nitrates are highly soluble and, typically concentrations in groundwater are not limited by solubility constraints Due to nitrate's soluble nature and its anionic form it is highly mobile and has the propensity to be transported over long distances Nitrate does not adsorb onto aquifer materials and it does not precipitate as a mineral These two factors allow large quantities of dissolved nitrate to remain in groundwater

5 2.3 5 Radionuclides

Radionuclide COCs in UHSU groundwater subsurface soil, surface soil, pond sediment and stream/dry sediment at OU6 are Pu-239/240 Am-241 and Ra-226 U-233/234 U-235 and U-238 were also identified as COCs in subsurface soil The physical and chemical properties of these species that most influence the mobility and behavior in environmental media are oxidation state, solubility and radioactive decay

Oxidation States and Solubility. Oxidation states of radionuclides control their stability and solubility in the environment The oxidation states for each radionuclide COC are discussed below

Plutonium is stable in two oxidation states in most natural environments; as Pu(III) or Pu(IV) Pu(III) is the dominant species in acidic environments, whereas Pu(IV) is the dominant species as solid plutonium dioxide (PuO_2) under alkaline or oxidizing conditions (Brookins 1988) Pu(IV) has a very low solubility at near-neutral and oxidizing conditions (National Research Council 1983) This suggests that the activity concentrations of dissolved Pu in groundwater or vadose zone soil water will be low at OU6, given the near neutral pH and oxidizing subsurface site conditions Thus, the primary phase of plutonium existing at OU6 appears to be the solid phase

Americium has the potential to exist in two oxidation states under natural conditions, Am(III) and Am(VI) For soil-water pH values greater than 6, the carbonate solid, $Am_2(CO_3)_3$, and the solid americium dioxide, AmO_2, are stable (Brookins 1988) The solubility of americium under oxidizing and near-neutral conditions, such as occur in OU6, is also very low (National Research Council 1983)

In the environment, uranium species are found in three oxidation states, U(IV), U(V), and U(VI) Under most redox conditions, U(VI) complexes are more stable than U(IV) and U(V) species An increase in the oxidation state increases the mobility of uranium in the soil system

In the environment, radium (Ra) species are found in one oxidation state, Ra (II) Isotopes of radium are radioactive, the longest lived being Ra-226 This isotope is formed in the natural decay series of U-238 Radium chloride and bromide are soluble in water, whereas the carbonate and sulfate are insoluble in water

Radioactive Decay. Radioactive decay is another key behavior of radionuclides It is a first-order kinetic process and can be expressed in terms of a constant half-life The radionuclides of concern have very long half-lives, ranging from 433 years (Am-241) to 4 47 x 10^9 years (U-238) (Gilbert et al 1989) as listed in Table 5 2-3

5 2 4 Mobility and Behavior of COCS

The mobility and behavior of COCs at OU6 were evaluated by examining the potential for adsorption biodegradation, and volatilization to occur within the various environmental media In the following discussion, organic compounds (Section 5 2 4 1) are discussed separately from metals and radionuclides (Section 5 2 4 2) due to the differing importance of the processes that affect the mobility and behavior of these chemical groups

5 2 4 1 Mobility and Behavior of Organic Compound COCs

The mobility and behavior of organic compound COCs at OU6 are believed to be dominated by biodegradation volatilization and adsorption These processes, as they apply to the various media of OU6 are discussed below

Biodegradation Literature values for organic compound COC biodegradation rates are listed on Table 5 2-4 Each of the VOC COCs at OU6 is classified as a chlorinated hydrocarbon based on the chemical constituents of the compound Biodegradation of halogenated aliphatic compounds such as chlorinated hydrocarbons may occur under anaerobic conditions Aerobic treatment of chlorinated solvents shows that less chlorinated solvents (e g TCE and TCA) are degradable under methanotrophic conditions (EG&G 1994) However biodegradation of highly chlorinated hydrocarbons under aerobic conditions occurs very slowly if at all (Vogel et al 1987)

The biodegradation of an SVOC (napthalene, benzo(a)pyrene, and benzo(a)anthracene) is based upon the complexity of the SVOC chemical structure In general, SVOCs with two to three aromatic rings are readily degradable (General Physics 1990) Studies suggest degradation of SVOCs with more than 3 aromatic rings (e g pyrene) is enhanced when a primary substrate (e g , napthalene) is present

The subsurface environment at OU6 exists under oxidizing (aerobic) conditions with relatively low organic carbon content, as described in Section 5 2 2 Thus in general the subsurface at OU6 is not believed to be a favorable environment for biodegradation of chlorinated hydrocarbons In addition the natural field conditions are not favorable for microorganisms

that rely on organic matter for food It is expected that the potential for biodegradation of the organic COCs (including the SVOC COCs) at OU6 may be low

Biodegradation may, however, occur in some areas if favorable conditions exist locally Available evidence indicates that biodegradation of chlorinated hydrocarbons may be the source of vinyl chloride observed in groundwater at well 3586 Vinyl chloride can occur from the transformation of its parent products (PCE, TCE, 1,1-DCE, 1,1,1-TCA) under anaerobic conditions Groundwater data collected from OU3 (south of OU6) indicate that these parent products are present at high concentrations in Arapahoe Formation No 1 Sandstone wells located upgradient of well 3586 (DOE 1995), but vinyl chloride is absent. Other possible upgradient sources include the Industrial Area (IA) and the Triangle Area (IHSS 165)

Well 3586 is located near the Sludge Dispersal Area (IHSS 141) The sludge deposited in the area originated at the WWTP and likely contained bacteria grown in chlorinated hydrocarbon environments Further, the nearby WWTP is located near Well 3586 and may provide a possible source of bacteria

Volatilization. As discussed in Sections 5 2 1 and 5.2 2, it is expected that volatilization of VOC COCs will be a dominant fate process in OU6 groundwater, surface water, and soil Volatilization of vinyl chloride from groundwater to soil gas in the vicinity of well 3586 is discussed in Appendix H, and summarized in Section 5 4

The SVOCs are not expected to volatilize to a significant degree, due to their strong adsorption coefficients and moderate to low Henry's Law constants

Adsorption. The mobility of a chemical in a soil-water system is usually described by the soil-water distribution coefficient (K_d) K_d is defined as the ratio of mass of solute on the solid phase per unit mass of solid to the concentration of solute in dissolved phase (Freeze and Cherry 1979) It is a medium-specific and chemical-specific parameter

K_d values can be directly measured in the field or laboratory, or estimated based on the properties of media and chemicals, using the following expression

$$K_d = f_{oc} K_{oc} \quad (5\ 2\ 1)$$

(Olsen and Davis 1990)

where

f_{oc}	=	the fraction of organic carbon content (dimensionless),
K_{oc}	=	the organic carbon partition coefficient (L^3/M),

and where adsorption to inorganic adsorptive sites is ignored Table 5 2-5 presents the soil-water partitioning coefficient, K_d, for each organic compound COC, calculated using Equation 5 2 1 based on the range of total organic carbon content in the respective medium where the compounds were detected and the K_{oc} values in Table 5 2-1

The effects of adsorption on groundwater contaminant migration are expressed in the fate and transport equation for groundwater by the retardation factor, R Under the linear adsorption isotherm assumption (i e , the amount of a solute adsorbed onto a solid is linearly proportional to the concentration of the solution) R can be calculated using the following expression (Javandel 1984)

$$R = 1 + \frac{\rho_b K_d}{n_e} \quad (5\ 2\ 3)$$

where

ρ_b	=	the soil bulk density (in M/L^3)
n_e	=	the effective porosity of the aquifer (dimensionless)
K_d	=	the soil-water partition coefficient (in L^3/M)

A range of retardation factors for each COC calculated using Equation 5 2 3 are presented in Table 5 2-4 The VOC COC retardation factors are in the range of slightly greater than one to about ten indicating the migration of VOC COCs is retarded by adsorption by up to a factor of ten

It is important to note that at OU6 the concentrations of organic compounds in groundwater are significantly less than 1 part per million (Section 4 6) Therefore the process of

adsorption and the resulting retardation is expected to severely limit the transport of organic compounds in groundwater at OU6

VOCs in surface water, surface soil, and dry sediment are highly susceptible to volatilization Volatilization is expected to deplete these chemicals from these types of environments to a high degree Thus, adsorption of these chemicals is not expected to be a key process in these media.

Adsorption is a key process in the accumulation of chemicals with high adsorptive properties in pond sediment The SVOC COCs detected in pond sediment (Section 4 8) have strong adsorptive properties and are expected to remain in the sediment.

5 2 4.2 Mobility and Behavior of Radionuclides and Metals

Radionuclide and metal COCs have been observed in surface soil, subsurface soil, and pond and stream/dry sediment at OU6. Radionuclides have also been observed in groundwater It is expected that the majority of mass transport of these COCs in OU6 occurs above the ground surface due to wind erosion, and sediment transport Transport of radionuclides and metals in the subsurface (groundwater and/or soil) appears to be limited due to the strong adsorption of these species onto the soil matrix. However, transport of adsorbed compounds may occur in association with migration of colloids in groundwater. In the following section, adsorption, colloidal transport, wind erosion, and sediment transport are discussed

Adsorption. K_d and R values for radionuclides (Table 5 2-6) indicate that the transport of these elements will be strongly retarded in the subsurface environment. This, coupled with the low activities of radionuclides in groundwater, suggests that radionuclide transport in groundwater will be minimal No metals were identified as groundwater COCs at OU6

The strong adsorption of radionuclides and metals (Table 5 2-2) to surface soils and sediment allows for these elements to be transported by colloidal transport, wind erosion and sediment transport, as described below

Colloidal Transport The high potential for adsorption of radionuclides and metals limits the transport of these species in the dissolved phase However species adsorbed to colloids are not subject to the same adsorptive forces that tend to retard transport of dissolved-phase groundwater contaminants Rather these adsorbed compounds move with the colloids which are transported by advection and are restricted by settling filtration, and aggregation of particulates

COC radionuclides have been detected above BSLs in unfiltered groundwater samples at low activity concentrations in the A-series Ponds area The radionuclide distributions do not appear to indicate substantial radionuclide migration in groundwater by colloidal transport or other processes There are no groundwater COC metals, thus colloidal transport of metals is not significant from a human health risk assessment perspective

Wind Erosion Based on prevailing wind directions the airborne dispersion of surface soils disturbed by wind erosion in OU6 has the potential to spread radionuclides and metals further east, east-southeast and southeast (Section 3 3) The wind erosion processes generally involve initial disturbance of surface soils transport of particulate matter and deposition of particulate matter as discussed in Section 5 1 4 These processes are affected by the wind conditions including speed and direction (Section 3 3 and Appendix I), ground surface conditions including roughness and cover, topographic conditions, such as steepness of the slope and surface soil conditions, including particle sizes, soil texture and structure, organic content, and moisture content

Because radionuclide (and metals to a lesser degree) particles are almost always aggregated with soil particles the processes that control their movement in the surface and air environments are the same as those that control movement of soil particles in the surface and air environments Whether soil particles can be lifted by the wind, depends upon the wind speed near the ground surface and the particle-size distribution of the soil The amount of surface soils that could be lifted into the atmosphere is designated as erosion potential Quantitative evaluation of annual average erosion potential at OU6 is discussed in Appendix I and summarized in Section 5 6

Once soil particles are lifted from the ground surface into the atmosphere the time, distance, and height above the ground that the particulate can be transported depends on the wind

speed at the corresponding height and soil particle size Usually, the smaller the particulate, the longer, the higher, and the further it can travel Colloidal size particles (airborne particulate matter) suspended in the atmosphere can potentially be transported by wind over a great distance for a very long time period Suspended soils will tend to settle closer to the area of origination when the wind speed decreases Settling and resuspension are very complicated and highly transient processes, depending on particle-size distribution and erodibility as a function of wind speed

Sediment Transport. Sediment transport is probably the most prevalent process that can potentially transport metals and radionuclides adsorbed to the surface soils and stream/dry sediments in OU6 Sediment transport at OU6 involves overland flow transport and channel flow transport Overland flow is non-channelized runoff resulting from storm events. Sediment transport with overland flow is affected by rainfall-runoff conditions, including rainfall intensity and runoff rate, ground surface conditions, such as the roughness and the vegetation cover, surface soil conditions, including particle-size distribution of surface soils, organic content in surface soils, texture and structure of soils, and topographic conditions, such as slope and the length of slope These factors are very similar to the factors that influence wind erosion The fundamental difference between wind erosion and water erosion is associated with the difference in the density of the fluid media (Vanoni 1975)

At OU6, the amount of surface soil loss by overland flow depends on the highly variable precipitation events. The higher the intensity and the longer the rainfall period, the greater the soil loss Rainfall erosivity is a parameter used to quantify the capability of rainfall to erode the surficial soils.

The potential for soil erosion also depends upon the soil grain sizes and the other relevant conditions as mentioned above The quantification of the soil erodibility at OU6 is discussed in Appendix H.

Once the soil particles are suspended in the overland flow, they are transported along with the flow, with settling and resuspension, depending on the variation of the flow rate along the pathway Due to the variation of the topographic conditions and the vegetation conditions, it is expected that redeposition or resuspension may occur on the hillsides of OU6 Therefore, redistribution of the radionuclides over the hillsides may occur

Once soil particles and associated contaminants are transported into creeks, their movement will be controlled by the transport mechanism of open channel flow Sediment transport in open channels is primarily affected by the channel flow conditions (including the flow rate, the slope of the channel the width of the channel the depth flow in the channel), and the physical characteristics of the particles (size shape and density) However, at RFETS, creeks flow intermittently, more or less associated with precipitation events and pond operations The transport of the contaminated particles is expected to be relatively significant during or immediately after storm events During lower flow periods between storm events, particles will tend to settle and transport will be less significant Therefore sediment transport in the creeks is a discontinuous process

5 2 4 3 Nitrate

As described previously nitrate is highly mobile in aqueous environments, because of its high water solubility and lack of adsorption to solids Therefore, nitrates observed in OU6 groundwater are expected to be transported large distances in the UHSU However, the distribution of nitrates in the Valley Fill Alluvium in the North Walnut Creek drainage north of the Solar Ponds (Figure 4 6-15) suggests that the nitrates are not transported significant distances in groundwater at the site Dilution of nitrates in groundwater may account for some of the decrease in concentrations in the downgradient direction

5 3 OU6 COC MIGRATION PATHWAYS

Contaminant migration begins when chemicals are released to environmental media, and continues as the contaminants are transported by various processes (Section 5 1) and are subjected to geochemical processes that affect their mobility and behavior (Section 5 2) This discussion of COC migration pathways follows the transport of COCs from source release to potential receptor locations through the transport media

COCs were directly released into the OU6 environment at several source areas (IHSSs) where waste materials were disposed of or stored These IHSSs were primary sources of contamination to local areas of surface soils and subsurface soils COCs migrate from these local areas to larger areas within the affected medium and to other media (i e surface water air) Thus the locally contaminated areas act as secondary sources of contamination

Chemicals from upgradient operable units migrate into OU6 via surface water, groundwater, and possibly in air OU6 encompasses major surface water drainages for RFETS COCs transported in surface water from other areas were deposited in the A- and B-series detention ponds of North and South Walnut Creeks Fugitive dust also may have been deposited in the ponds These ponds are also considered IHSSs and potentially behave as secondary sources of COCs

Groundwater from OU4 (Solar Ponds area) and other operable units, and groundwater seepage from OU2 are additional sources of chemicals to OU6 Groundwater COC fate and transport is discussed in general terms in this section More detail related to groundwater COC fate and transport is presented in Section 5 4

A separate discussion for COC migration from each of the OU6 areas of concern (AOCs) is presented in this Section (Sections 5 3 1 through 5 3 4)

OU6 AOCs are defined as one or more IHSSs that are in close proximity and can be evaluated as a unit in the human health risk assessment (HHRA) presented in Section 6 0 AOCs were delineated in the CDH Letter Report (DOE 1994a) Six OU6 IHSSs were determined to not be sources of COCs in groundwater or pose exposure risk and were eliminated from further consideration, based on the screening process described in that report. Those IHSSs (166, 167 3, 142 4, 142 9, 142 12, and 216 1) are not associated with any OU6 AOCs The OU6 AOCs include the following IHSSs

- AOC No. 1
  - IHSS 167 1 (North Spray Field)

- AOC No 2
  - IHSS 165 (Triangle Area)
  - IHSS 156 2 (Soil Dump)
  - IHSS 141 (Sludge Dispersal Area)

- AOC No 3
  - IHSSs 142 1 to 142 4 (A-series Ponds)

- AOC No 4
  - IHSSs 142 5 to 142 9 (B-series Ponds)

The AOC discussions describe the migration of COCs in surface water air, groundwater, and the vadose zone Potential COC migration pathways for the AOCs are presented in schematic form in Figures 5 3-1 to 5 3-3

5 3 1 Area of Concern No 1

COCs were released at IHSS 167 1 (North Spray Field) due to spraying of waste water to enhance evaporation The spray water originated from the west landfill pond at RFETS and footing drain water from Buildings 771 and 774 located in the IA (DOE 1992b) Surface and subsurface soils in the area show evidence of COCs from the spraying activities Surface soil COCs detected in area surface soils include metals at low concentrations (antimony, vanadium and zinc) and radionuclides (americium and plutonium) Subsurface soil COCs detected in boreholes in the area were barium and several radionuclides (americium, plutonium, U-233/234, and U-238). Potential migration pathways from this AOC are presented on Figure 5 3-1

Surface water and wind erosion are the chief processes that potentially transport surface soil COCs from the IHSS 167 1 area Each of the metal and radionuclide COCs in the area are strongly adsorbed to soil particles, based on their physicochemical properties (Section 5 2) Therefore, their mobility in the environment is highly dependent on the transport of the soil particles to which they are adsorbed

Surface soil particles and COCs may be mobilized due to storm events and carried in storm runoff (overland flow) until discharged to the Unnamed Tributary of Walnut Creek, the stream channel in the vicinity of IHSS 167 1 COCs may be redeposited with surface soils before reaching the tributary if soil particles settle out of the overland flow COCs that discharge to the Unnamed Tributary are transported by rolling or sliding on the stream bed or by suspension due to the turbulence of the stream flow COCs in stream flow may be redeposited within the stream channel as particles settle out

COCs that are transported within the channel may ultimately be deposited in the Walnut and Indiana (W&I) Pond The W&I pond is located downstream of the confluence of the Unnamed Tributary and Walnut Creek near Indiana Street Suspended solids that are discharged to the pond likely settle to the pond bed, resulting in sedimentation The sediments in the W&I Pond potentially could be resuspended during a large storm event, allowing for the possibility of discharge of contaminated sediment from the pond to Walnut Creek This scenario is unlikely based on data that indicate the W&I Pond is not a contaminated IHSS (the W&I Pond is not included in AOC No 1)

Surface soil COCs re-suspended in air as fugitive dust due to wind erosion may be transported to other areas of OU6 or potentially to offsite areas Fugitive dust may be redeposited on surface soils or in surface water Dust that is redeposited on surface soils is subject to subsequent wind or surface water erosion. Dust that settles onto surface water may be transported via surface water processes and eventually settle to the bottom of the creek or pond, becoming sediment deposits

Another COC migration scenario with limited potential for occurrence in the area is vertical migration of COCs from subsurface and surface soil contamination as infiltrating precipitation percolates through the vadose zone As precipitation infiltrates through the subsurface, COCs that are adsorbed to subsurface soil particles may dissolve in the infiltrate The infiltrate would then percolate deeper into the vadose zone where adsorption of the COCs to soils could reoccur The infiltrate could potentially migrate downwards until encountering the saturated zone The only well located in the vicinity of the North Spray Field (Well 77192) is typically dry, thus groundwater is not well characterized and it is not known if COCs are migrating to groundwater in the area. However, because of the adsorptive properties of the COCs and apparent lack of groundwater, it is expected that migration of soil COCs to the saturated zone, or subsequent migration in groundwater is minimal

5.3.2 Area of Concern No 2

COCs were released in the AOC No 2 area from multiple sources Leakage of drums stored in the Triangle Area resulted in VOC and radionuclide COCs in surface and subsurface soils Contaminated sludges from the WWTP that were placed in drying beds in the Sludge Dispersal Area were a source of radionuclides and nitrates to area soils Radionuclides were

also present in soils excavated from the IA that were disposed of at the Soil Dump Area Other sources of COCs to the area include migration of nitrates in groundwater originating from the OU4 area, and potentially, deposited fugitive dust from areas outside of OU6 Potential migration pathways for COCs in this AOC are shown on Figure 5 3-2

Residual contamination (metals radionuclides semi-volatiles) in surface soils is subject to surface water and wind erosion Surface soil COCs can be dislodged due to precipitation and transported with sediment in overland flow Surface water in this AOC may flow either to North or South Walnut Creek depending on the location within the IHSS, as the area is bisected by a topographic ridge (see Figure 3 7-1 for drainage sub-basin boundaries) COCs in overland flow may be redeposited before entering the creeks as particles settle COCs that enter the creeks are transported as bed or suspended load in the creeks Adsorbed COCs may be re-deposited in the creeks or discharged to detention ponds in the drainages The sediments in the ponds potentially could be resuspended during large storm events, allowing for the possibility of discharge of contaminated sediment from the ponds to the creek, and possibly to offsite locations This scenario is considered highly unlikely due to the effectiveness of the ponds in trapping sediments The process of sedimentation is described in Section 5 1 3 More detail on COC migration in the detention pond system is provided in the discussions of AOCs 3 and 4 (Sections 5.3 3 and 5 3 4)

Surface soil COCs re-suspended in air as fugitive dust due to wind erosion may be dispersed to other areas of OU6 or potentially to offsite areas Fugitive dust may be redeposited on surface soils or surface water Dust that is redeposited on surface soils is subject to subsequent wind or surface water erosion Dust that settles onto surface water may settle to the bottom of the stream or pond becoming sediment deposits

Residual VOC contamination in subsurface soil may migrate as soil gas Volatilization of VOCs in subsurface soils may occur, resulting in the formation of soil gas that may diffuse to the atmosphere and disperse in air

Residual contaminants (VOCs and other chemicals) in subsurface soils also may be leached by infiltrating precipitation and carried to the saturated zone These dissolved chemicals may re-adsorb to soils in the vadose zone or reach the saturated zone and be transported with groundwater In addition, contaminated groundwater from other OU locations, such as OU4

may migrate into the saturated zone of OU6, this is the expected source of nitrate observed in OU6 groundwater

VOCs present in groundwater may volatilize to soil gas and diffuse to the atmosphere VOC concentrations in groundwater are generally less than 100 µg/l (Section 4 6) and volatilization at those concentrations is expected to be minimal. Vinyl chloride, a particularly volatile compound (Section 5 2), has been observed at concentrations as high as 860 µg/l at well 3586, located in the vicinity of the Sludge Dispersal Area. Volatilization is considered to be a significant migration process for vinyl chloride. A discussion of vinyl chloride volatilization in this area is provided in Section 5 4.

Groundwater COCs not volatilized are advected/dispersed within the saturated units of the area. Groundwater in the area flows toward the surface water drainages and is discharged to the creeks or to the Valley Fill Alluvium that underlies the drainages Groundwater in the Valley Fill Alluvium potentially interacts with surface water (creeks or ponds) The groundwater may discharge to surface water under certain hydraulic conditions, however, the relationship of groundwater and surface water in the drainages is not well characterized

Groundwater COCs flowing in the Valley Fill Alluvium can potentially migrate beyond the terminal ponds of Walnut Creek to offsite locations Offsite migration is not expected to occur, however, due to the low groundwater chemical concentrations. In addition, detention pond dams in North and South Walnut Creek will likely intercept a majority of groundwater flow before offsite migration. Detections of three organic compounds (methylene chloride, toluene, and bis[2-ethylhexyl]phthalate), all of which are common laboratory contaminants, have been reported in samples from wells located downgradient of the W&I Pond (Figures 4 6-29 and 4 6-30) Metals and radionuclides have been detected above BSLs in these wells The source of these chemicals is unknown, but it is unlikely to be related to AOC No 2 due to the large distance from, and low concentrations of these chemicals in groundwater at AOC No 2 It does not appear that COC plumes extend to this area from upgradient areas

5.3.3 Area of Concern No. 3

Potential COC migration pathways for AOC No 3 are presented on Figure 5.3-3 COCs possibly have been introduced to AOC No 3 via surface water, groundwater, and air

pathways from AOC No 1, AOC No 2 AOC No 4 (i e , water transferred from the B-series ponds) and from source areas outside OU6 such as the IA and OU4 COCs have been observed in pond water stream/dry sediments and pond sediment, and UHSU groundwater in AOC No 3 These various contaminated media can interact with each other at a particular location or COCs can be transported to affect downstream areas, as discussed below

Migration of COCs in surface water and air from upstream locations such as the IA have resulted in COCs in stream and pond dry sediments in AOC No. 3 Dry sediments are collected either along stream reaches between the ponds or in the inlet areas and shorelines of ponds The dry sediments and any adsorbed chemicals are subject to wind erosion and air transport processes that transport the fugitive dust and associated chemicals to downwind locations The fugitive dust and chemicals can either be redeposited to downwind onsite soils, or potentially can be transported to offsite locations If redeposited to onsite soils they can be subject to wind erosion and air transport processes or to surface water erosion and transport processes, described below If the fugitive dust settles onto surface water, it may settle to the bottom of the pond or creek as wet sediment deposits

Surface soils or dry sediments and associated adsorbed chemicals are also subject to surface water erosion and transport This can occur during storm events due to overland flow in areas away from the creeks or as creek bed erosion and sediment transport within the creeks The soils and sediments and associated chemicals may be redeposited onsite (including to ponds) and subjected to further wind and/or surface water erosion and transport, or may be transported to offsite locations Transport of COCs to offsite locations via surface water processes is considered unlikely because of the presence of the A-series ponds, which effectively capture sediments transported along Walnut Creek

During the OU6 Phase I investigation, detections of COCs in AOC No 3 surface water were limited to methylene chloride detections in the A-series ponds No COCs were detected in creek surface water However transport of chemicals in OU6 surface water may occur in the future due to erosion of contaminated soil and sediments This discussion is limited to dissolved phase contaminant migration in surface water Chemicals adsorbed to solids whether in suspension or in the creek bed or pond bed, will be discussed below in relation to creek and pond sediments COCs dissolved in creek and pond water may be transported downstream via advective and dispersive processes The contaminated water can be

discharged to a downstream pond, or it can be potentially transported to offsite locations Transport of COCs offsite in surface water is considered unlikely because of the presence of the A-series ponds and their effectiveness at capturing COCs onsite, the absence of COCs in creek surface water, and the low concentrations of COCs in pond surface water (Section 4 7)

VOC constituents in surface water can be volatilized directly to onsite atmosphere, particularly where surface water is agitated, such as at dam spill ways and outlet works. Once in onsite air, the VOCs are expected to disperse to levels below detection limits prior to reaching offsite locations This is expected to be an effective process for removing methylene chloride because of its volatility (Table 5 2-1).

COCs in creek and pond sediments (including chemicals adhered to soil particles in suspension) can be transported downstream in the creeks via sediment transport processes Pond sediments can be eroded from the pond bottoms, resuspended, and carried out of the ponds during storm events and redeposited in the downstream creek bed or in a downstream pond They can also potentially be transported to offsite locations, however, this pathway is considered unlikely due to the presence of the A-series ponds and their effectiveness in capturing sediment Additionally, as discussed in Section 5 5 and Appendix H, the process of resuspending pond sediments is unlikely to occur except during the most extreme storm events

Lastly, groundwater COCs from upstream sources, such as the IA and OU4, have migrated into the Valley Fill Alluvium in the drainage These groundwater COCs can migrate downstream in the alluvium, potentially discharging to downstream creek reaches and ponds COCs in alluvial groundwater can potentially also be transported to offsite locations, however this pathway is considered highly unlikely based on observed nitrate and VOC COC concentrations in groundwater that decrease substantially from west to east, and occur at low concentrations (i e , less than 1 mg/l for nitrate, and 2 µg/L for VOCs) in samples from Well 1386, upstream of the westernmost A-series pond, Pond A-1 Moreover, migration of groundwater COCs directly to offsite locations is inhibited by the A-series pond dams that cut entirely across the alluvium and act as barriers to alluvial groundwater flow

VOC constituents in groundwater can be volatilized to soil gas and then to onsite atmosphere Once in onsite air, the VOCs are expected to disperse to levels below detection limits prior to reaching offsite locations

5.3 4 Area of Concern No 4

COC contaminant transport in AOC No 4, which comprises the South Walnut Creek drainage and includes the B-series ponds, is expected to be very similar to COC transport in AOC No 3 The contaminated media and pathways are very similar although the COCs and their distribution and concentrations vary from those in AOC No 3

In AOC No 4 COCs have been shown to be present in dry sediment, pond surface water, creek and pond sediment, and groundwater The primary sources of COCs to AOC No 4 are believed to be OU6 AOC No 2, groundwater plumes from OU4 (nitrates), contaminated groundwater seepage from OU2 (VOCs) and possibly, contaminated surface water runoff and fugitive dust from areas outside OU6, such as the IA

COCs in dry sediments pond water, and creek and pond sediments in AOC No 4 are expected to be transported via the same processes as described for AOC No 3

Groundwater VOC COCs have been observed in a few wells located west of Pond B-1, the westernmost B-series pond In particular, vinyl chloride has been detected at high concentrations in samples from Well 3586 located approximately 600 feet west of the Pond B-1 inlet However no VOCs have been detected in Well 3686 located near the inlet of Pond B-1 Therefore, it appears that the VOC COCs present in the Valley Fill Alluvium near Well 3586 are not migrating at significant concentrations as far as the inlet area for Pond B-1, and are not expected to affect areas further downgradient One of the mechanisms acting to reduce the VOC concentrations in the groundwater is believed to be volatilization as discussed in Section 5 4 1

Similarly low levels of nitrate and radionuclide COCs in groundwater are not expected to migrate at significant concentrations to the B-series ponds Nitrate concentrations, which occur at low levels in the vicinity of Well 3585 drop to less than 1 mg/l at Well 3686 Am-241 and Pu-239/240 activity concentrations at Well 3586 are very low (less than 0 01 pCi/l)

These COCs are not expected to migrate substantially due to their strong affinity for adsorption

5 4 GROUNDWATER EVALUATION

OU6 groundwater conditions were evaluated to determine the necessity of quantitatively modeling groundwater COC transport. The evaluation was based on the OU6 hydrogeologic system (Section 3 6), the nature and extent of COCs in groundwater (Section 4 6), and information regarding groundwater COC sources outside of OU6 that impact the area. Three key potential groundwater COC conditions were assessed regarding the need for modeling It was determined that only one of the identified conditions (the occurrence of vinyl chloride in well 3586) required some type of quantitative modeling Qualitative modeling of vinyl chloride transport in groundwater is described in Section 5 4 1.

The second identified groundwater COC condition, the occurrence of nitrate in the area upgradient of the A-series ponds, was considered to be a result of nitrate migration from the solar ponds in OU4 The nitrates observed in OU6 are only a portion of the nitrate plume, the majority and more concentrated portion of the plume occurs in the IA (DOE 1992 RCRA Report) It was considered inappropriate to model the migration of this plume due to its origin in another operable unit and its distribution, therefore, no modeling of nitrate migration in groundwater was performed for this OU6 RFI/RI The occurrence of nitrates in groundwater is discussed in more detail in Section 5 4 2

The third condition the occurrence of VOCs in the Trench Area, was considered to be related to a groundwater plume of TCE observed in the Landfill Pond area. The source of the plume has not yet been identified, Operable Unit 10 is considered a potential source Contaminant transport modeling of TCE in the Landfill and Trench Areas is being conducted as part of the OU7 RFI/RI, therefore no modeling was performed for this report The occurrence of VOCs in groundwater in the Trench Area is discussed in Section 4 6 and in more detail in Section 5 4 3

5 4 1 Summary of Vinyl Chloride Modeling

Analytical modeling of the migration of vinyl chloride in groundwater was performed to estimate potential downgradient concentrations of vinyl chloride, and to provide an explanation of the distribution of this chemical Vinyl chloride was observed at Well 3586 at concentrations ranging from 200 µg/l to 860 µg/l during the 1991 to 1993 period Well 3686, located approximately 600 feet east and hydraulically downgradient of Well 3586, had no detections of vinyl chloride in the eight samples collected during that period The preliminary explanation for the lack of migration of vinyl chloride from Well 3586 to Well 3686 is that volatilization depletes the chemical from groundwater before it arrives at the downgradient location Dilution may also contribute to the decrease in concentration

As described in Section 5 1 3, volatilization of VOCs such as vinyl chloride occurs as successive unimolecular layers of the chemical are peeled away from the surface of the contaminated zone which is, in this case, the UHSU groundwater potentiometric surface in the Valley Fill Alluvium in the vicinity of Well 3586 The rate at which volatilization of vinyl chloride potentially occurs is proportional to the Henry's Law constant for this chemical As shown on Table 5 2-1 a representative Henry's Law constant for vinyl chloride is 1 22 atm-m^3/mole The range of Henry's Law constants for vinyl chloride based on a review of related literature is 0 022 to 2 78 atm-m^3/mole (Appendix G) The volatility of vinyl chloride is substantially greater than that of other VOCs detected in OU6

An analytical groundwater contaminant transport equation incorporating advection and volatilization (Appendix G) was developed and used to estimate concentrations of vinyl chloride downgradient of Well 3586 The fate and transport processes of dispersion retardation, and biodegradation, discussed in Section 5 1, were conservatively ignored in the development of the equation The following assumptions were made in the application of the solution

- Groundwater flow in the Valley Fill Alluvium is uniform, one-dimensional and steady

- Solute transport occurs under steady-state conditions

- Only advection and volatilization were considered Dispersion, adsorption, and degradation were ignored

- The source and concentration of vinyl chloride at Well 3586 is constant

The results of the analytical modeling confirmed that vinyl chloride is not expected to migrate any significant distance from Well 3586 under normal conditions. This is consistent with measured results from groundwater samples collected at Well 3686 Vinyl chloride concentrations in groundwater at Well 3586 were evaluated in the OU6 human health risk assessment, as described in Section 6 0 The detailed discussion of the vinyl chloride groundwater modeling is presented in Appendix G

5 4 2 Nitrate Evaluation

Nitrate in OU6 UHSU groundwater was evaluated to determine if modeling of nitrate migration was necessary to assess human health effects related to OU6 contaminant sources It was determined that the source of nitrates was located outside of OU6 in the solar ponds area (OU4), based on the distribution of nitrates in groundwater and temporal trends in nitrate concentration observed in wells installed in 1986 Therefore, modeling of nitrate migration in groundwater was considered unnecessary and was not performed for this OU6 RFI/RI report This section describes the basis for that conclusion

Nitrate concentrations in the Valley Fill Alluvium of North Walnut Creek upgradient of Pond A-1 show a marked decrease along the direction of groundwater flow, which is eastward, following the creek The maximum concentration of undifferentiated nitrate/nitrite observed in the drainage during the period beginning first quarter 1991 and ending fourth quarter 1993 was 1760 mg/l, occurring at well B210489, located about 750 feet west of Pond A-1 (Figure 4 6-15). Other area detections of nitrate/nitrite ranged from approximately 300 mg/l to 700 mg/l at wells 1786 and B208589 during the study period In well 1586, located about 300 feet east (downgradient) of well B210489, observed concentrations ranged from 39 mg/l to 68 mg/l over the same period. Approximately 300 feet further east at well 1386, all nitrate/nitrite concentrations were less than 1 mg/l or below the method detection limit

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Nitrates were observed at higher concentrations during the same time period at wells located in the IA north of the solar ponds (P208989, P209589 and P209889) These wells are located between the solar ponds and the interceptor trench system (ITS, a k a "French drain") located to the north of the ponds (Figure 3 6-1) The maximum concentrations of nitrate/nitrite for the 1991-1993 period at wells P208989 P209589, and P209889 were 4,010 mg/l, 5 600 mg/l, and 8,260 mg/l, respectfully

As shown on Figure 3 6-1 the UHSU groundwater flow direction north of the solar ponds is northward North of the solar ponds groundwater flows toward the North Walnut Creek drainage discharging to Valley Fill Alluvium in the channel area. Wells P208989 P209589, and P209889 are considered to be hydraulically upgradient of the North Walnut Creek wells in AOC No 3 Contaminant concentrations, therefore, decrease in the direction of flow suggesting that the nitrates are all part of the same groundwater plume, and that they are migrating from the solar ponds area to the drainage

Correlations between nitrate concentrations over time in OU6 wells and changes in operations at the solar ponds provide another indication that the solar ponds are the source of nitrates to OU6 Solar pond sludge cleanout began in mid-1986 (DOE 1992b) The removal of the sludge, and the termination of routine placement of process waste in the ponds correlates with a dramatic decrease in nitrate concentrations in OU6 groundwater as shown at well 3086 (Figure 5 4-1) located south of the ITS, and wells 1586 and 1786 (Figures 5 4-2 and 5 4-3, respectively) located in the North Walnut Creek drainage This correlation indicates that OU6 nitrate concentrations are the result of migration of contamination from the solar ponds

Also of note is that the observations of decreasing nitrate/nitrite concentration in wells both upgradient (3086) and downgradient of the interceptor system (1586 1786) indicate that contaminated groundwater flowed (and continues to flow, albeit at lower concentrations) from the solar ponds area to the drainage despite the presence of the ITS This conclusion is consistent with earlier studies that concluded "elevated levels of nitrate/nitrite, radionuclides organics and other analytes detected in alluvial and bedrock wells north and downgradient of the [ITS] suggests that contaminant migration persists despite the presence of this containment system" (DOE 1992 **RCRA Report)**

5 4.3 Trench Area VOC Contamination

VOCs have been detected in OU6 UHSU groundwater in the Trench Area (IHSSs 166 1, 166 2, 166 3, and 167 3), primarily at wells 7287 and B206489 TCE occurred at the highest concentrations of the VOCs observed in groundwater, ranging in concentration at these wells from 16 to 150 µg/l (Figure 4 6-3) These wells are located within the IHSS 166 1 boundary, south of the Landfill Pond, in OU7

IHSS 166 1 is located on the north slope of a topographic ridge that separates the North Walnut Creek and Unnamed tributary drainages. The groundwater flow direction in the vicinity of this IHSS is north to northeast toward the Landfill Pond (Figure 3 6-1) A groundwater divide that trends toward the northeast appears to be present beneath the topographic ridge Due to the groundwater flow direction and the presence of the groundwater divide, contaminants are potentially transported within groundwater from the Trench Area toward the Landfill Pond (Section 3 6)

It is believed that the VOCs detected in the area are part of a larger groundwater plume observed in the vicinity of the Landfill Pond. The source of the plume is believed to be outside of OU6 (possibly OU10) and not contamination in the trenches. Subsurface soil VOC concentrations are lower than groundwater concentrations. The maximum soil TCE concentration observed is 12 µg/kg In addition, analytical data indicate that higher concentrations of VOCs in groundwater are present in the Landfill Pond area (DOE 1992 RCRA Report) than in the trenches area. The source of TCE in the Trenches and Landfill areas is being investigated in a coordinated effort that involves OU6, OU7, and OU10

Groundwater modeling of the Landfill Pond plume, that is being conducted for the OU7 RFI/RI, covers a majority of the Trench Area, including wells 7287 and B206489 Therefore, because modeling of site conditions is being conducted as part of investigations for another operable unit, and the VOC contamination in OU6 represents only a small part of a larger plume, no modeling of Trench Area contaminant transport was performed for this OU6 RFI/RI

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5.5 SURFACE WATER FLOW AND CONTAMINANT TRANSPORT MODELING

This section summarizes the surface water modeling conducted as part of the OU6 Phase I RFI/RI The details of the surface water modeling activities are presented in Appendix H of this report Sections, tables, or figures that are applicable to the modeling and are referenced in full numeric form (e g , Section 4 0, Table 5 5-2, or Figure 5 5-3) appear in the main body of this report When they are referenced beginning with letter "H" (e g Section H2 5 Table H4 2 or Figure H5 1), they appear in Appendix H

A comprehensive mathematical model, the Hydrological Simulation Program - FORTRAN (HSPF) (Bicknell et al 1993), was applied to simulate the movement of water, surface soil sediment, and associated chemicals to and through ditches, creeks, and ponds in the Walnut Creek surface water system The model simulates the migration of chemicals from primary source areas in OU6 to Walnut Creek (and eventually to the eastern facility boundary at Indiana Street) The primary objective of the surface water modeling was to estimate long-term average concentrations of selected contaminants in sediment and surface water in Walnut Creek and in the A- and B-series ponds for use in the human health risk assessment (HHRA) (Section 6 0 and Appendix J)

A second objective of the modeling effort was to establish a modeling tool capable of serving objectives other than human health risk assessment such as providing stream segment data for ecological assessments, modeling chemical loads from outside OU6 (such as groundwater seepage from OU2) supporting evaluation of future use scenarios at Rocky Flats, and performing remediation/feasibility studies

For purposes of the HHRA the model was used to estimate reasonable maximum 30-year mean concentrations of selected chemicals (discussed in Section 5 5 1) in the following media and locations

- Accumulated pond sediment in each of the A- and B-series ponds
- Water in each pond

The 30-year period was selected to correspond to the reasonable maximum residential exposure duration evaluated in the HHRA (open space recreational use) The model was used

to generate 30 simulations of 30-year average concentrations Reasonable maximum 30-year exposure concentrations were then calculated, equivalent to the 95 percent upper confidence limits (95% UCLs) on the mean of 30 model results Modeled concentrations in pond surface water and sediment were used to represent exposure concentrations for onsite receptors

Fate and transport modeling to estimate offsite exposure concentrations is not included in this report because, as agreed by EPA, CDPHE, and DOE, potential risk to offsite receptors is not evaluated in the HHRA for individual onsite OUs such as OU6 (DOE 1995) Instead, potential risk to offsite receptors is evaluated in the HHRA for OU3 and may be addressed in a comprehensive site-wide HHRA

5.5 1 Selection of Modeled Contaminants

To support the OU6 HHRA, only sources within OU6 were used to estimate contaminant loads to the Walnut Creek drainage system OU6 sources to the drainage system are surface soils and stream/pond sediments within the OU6 IHSSs. Groundwater loads were not considered a significant source and were not included in the model because the extent and degree of COCs in groundwater in OU6 are minimal

Fate and transport of VOCs observed in pond water samples also were not modeled because their concentrations are low enough (ranging from 2 to 140 µg/L) that fate and transport processes, such as volatilization, would likely render their concentrations negligible over a 30-year time frame In lieu of using model predictions, measured concentrations were used in the HHRA for exposure of onsite receptors (Appendix J).

Six COCs were identified in surface soil antimony, silver, vanadium, zinc, Pu-239/240 and Am-241. The metals are noncarcinogens and the radionuclides are carcinogens Of these, the three COCs that would contribute most to health risk were selected for modeling, namely antimony, Pu-239/240, and Am-241 Antimony was selected as the "worst-case" metal to model, for the following reasons

- Antimony is the most toxic of the metals detected in OU6 surface soil and contributed 80 percent of the total risk factor in the concentration/toxicity screen for selecting noncarcinogenic COCs in surface soil (Table J3-4)

- Concentrations of the other less toxic metal COCs are not high enough to outweigh the potential effects of antimony

- The contribution of metals to overall risk will be relatively minor compared to that from radionuclides Therefore a single representative metal is adequate to demonstrate impacts on surface water and sediment from metal COCs in surface soil If estimated antimony concentrations in surface water and sediment resulting from transport in storm runoff are shown to be of no concern for the HHRA, other metal COCs in surface soil will also be of no concern

A total of 14 COCs were identified in pond sediment and stream sediment These included six SVOCs (including PAHs and Aroclor-1254) and the same four metals and two radionuclides identified as COCs in surface soil In addition, cobalt and strontium were identified at concentrations above background levels in stream sediment However, only antimony Am-241 and Pu-239/240 were included in the HSPF model because these three contaminants are COCs in surface soils and thus there is a source (external to the creeks and ponds) which can possibly increase concentrations of these contaminants in the ponds The other COCs identified in pond sediment and stream sediment were not modeled because they are not COCs in surface soils and thus there is not a significant external source of loading to the creeks and ponds For these other COCs, measured concentrations, rather than modeled concentrations were used in risk assessment Using measured concentrations to predict future concentrations of organic COCs, cobalt and strontium is conservative because without a source current concentrations of these contaminants are not expected to increase Additionally a screening-level evaluation of migration of pond sediment showed that contaminants are not likely to migrate out of the series of detention ponds to Indiana Street (Attachment A in Appendix H)

5 5 2 Application of HSPF to the OU6 Surface Water Modeling Study

The RFETS hydrologic drainage system includes three major intermittent streams Woman Creek Walnut Creek, and Rock Creek as shown in Plate 5 5-1 The general flow pattern is from west to east Because of the regional topography, these drainages extend westward only a short distance The western reaches of these drainage basins are characterized by a broad

alluvial fan with a general slope of 2 5%, while the east side of the plant site contains steep drainage swales with slopes up to 5 5% (EG&G 1992c). The majority of soils at RFETS have high infiltration rates and uniform vegetative cover

The OU6 surface water model domain contains all of the RFETS area in the Walnut Creek watershed that is upstream of Indiana Street and downstream of the South Boulder Diversion Canal The domain includes most of the IA, the A-series and B-series detention ponds, and the undeveloped land segments that drain to Walnut Creek and its tributaries upstream of Indiana Street The domain includes the IHSSs that lie within the Walnut Creek drainage area (Plate 5 5-1) The Landfill Pond and the Solar Ponds are designed such that they do not release surface flow into the Walnut Creek drainage system, and these hydrologic features were not included in the model

Besides the A-series and B-series ponds and the ditches used to convey storm water, other man-made features influence the surface water hydrology of the Walnut Creek watershed. Effluent from the WWTP flows into Pond B-3 and accounts for much of the water in Ponds B-3, B-4, and B-5 (B-3 and B-4 are flow-through ponds) Furthermore, water is transferred from Pond B-5 to Pond A-4, thus much of the water in Pond A-4 is WWTP effluent The other major source of water in the ponds is runoff from the IA which is relatively high because of the large percentage of impervious area (roads, roofs, parking lots) Some of the buildings of the IA also have foundation drains that contribute baseflow to the ponds, especially during the spring months Both sump and pump systems and gravitational drainage are employed at RFETS All of these features were included in the OU6 surface water model

Application of the HSPF model entails dividing the watershed into distinct hydrologic features including land segments, ponds, and creeks The entire OU6 modeling area was divided into 52 distinct HSPF computational elements (Plate 5 5-2)

- 21 pervious land segments, labeled with a "P"
- 4 impervious land segments, labeled with an "I"
- 9 reservoir segments, each reservoir representing a detention pond along Walnut Creek, labeled with an "R"
- 18 stream reaches, labeled with an "R "

The land segments were delineated to be consistent with the Storm Water Management Model (SWMM) elements of the "Rocky Flats Plant Drainage and Flood Control Master Plan" (EG&G 1992c) The smaller drainage areas to each of the ponds were selected to be consistent with areas in the "Event-Related Surface-Water Monitoring Report Rocky Flats Plant Water Years 1991 and 1992" (EG&G 1993b) These elements were delineated using topographic contours and information on soil characteristics such as infiltration rates

The number of model elements was appropriate for the amount of data available for calibration and consistent with the objectives of the current modeling study The IA, for example, was only divided into three pervious segments (P7 P8, and P14) and four impervious segments (I1, I2, I3 and I4) because there are no gaging data to measure runoff from smaller segments For future studies, additional computational segments could be added to the existing HSPF model

Nine ponds were included in the HSPF model - the four A-series ponds and the five B-series ponds The small flow-through pond along Walnut Creek near Indiana Street (known as the W&I Pond) upstream of where Walnut Creek leaves the RFETS eastern boundary was not modeled because of its low storage capacity and the lack of volume data for this pond Available flow data indicate that this pond has little impact on daily average flows through the downstream gaging station GS03 For example, the flow data show that the W&I pond does not attenuate flows between Pond A-4 and the gauging station GS03 The W&I pond is an element that could be added in future modeling efforts

HSPF is kinematic in the sense that downstream elements have no influence on upstream elements In the OU6 network, no land segments are downstream of reaches, spillway flows from ponds go directly into the creeks below the dams The gaging stations shown on Plate 5 5-2 are not elements in the hydrologic model but are shown to illustrate calibration points For example flows through GS10 are illustrated as the surface water outflows (i e , outflows other than infiltration) from Reach 19

5.5 2 1 Meteorological Data and Other Hydrologic Inputs

The HSPF model requires the input of time series data for seven meteorological parameters precipitation, air temperature, dew point temperature, wind speed, solar radiation, lake evaporation, and potential evapotranspiration For the model simulations used to predict 30-year average concentrations of the three selected contaminants, these meteorological data were simulated using a climate generation program (CLIGEN) discussed in Appendix H (Section H5 2) For the calibration of the model, however, actual meteorological data were required

For much of the calibration period (April 1986 and August 1993), hourly meteorological data are available from RFETS for precipitation, air temperature, dew point temperature, wind speed and solar radiation at RFETS However, there were significant gaps in these data (mostly prior to 1989) that had to be filled prior to input to the OU6 model For small gaps in the data sets (two hours or less), linear interpolation was performed using the surrounding data. To fill longer gaps in the air temperature, dew point temperature, wind speed, and solar radiation data sets, monthly averages (based on the available record) and observed diurnal variations were employed.

To fill in precipitation gaps greater than 2 hours, data from other meteorological stations were considered In the general proximity of RFETS, the two meteorological stations with extensive records of precipitation data are at Stapleton Airport (approximately 25 miles from RFETS) and at the Fort Collins Airport (approximately 60 miles from RFETS) Based on a conversation with Dr Neil Doesken of the Colorado Climate Center in Fort Collins, it was decided to use the Fort Collins data to fill in the precipitation gaps. Even though Stapleton Airport is closer to RFETS, Fort Collins and RFETS have the same relative proximity to the foothills of the Colorado Front Range making the Fort Collins climate more similar to the RFETS climate

Pond evaporation and potential evapotranspiration from pervious land segments were calculated by using empirical equations based on actual precipitation, solar radiation, air temperature and wind speed Pond evaporation was calculated using an equation developed by Lamoreux (1962) that was calibrated to the RFETS area in an unpublished EG&G study of the Great Western Reservoir Potential evapotranspiration was calculated with a computer

program developed by Advanced Sciences Inc that uses the Penman FAO-24 Equation (Doorenbos and Pruitt 1975)

For the nine ponds that were simulated inputs to the HSPF model include tables relating pond depth to surface area, pond volume, and spillway outflows Depth/area and depth/volume relationships were estimated based on the 1992 pond survey data (Merrick and Company 1992) Spillway flows as a function of pond depth were calculated using a commonly accepted weir equation (Linsley et al 1992) For this model, it was assumed that infiltration through the pond bottoms and seepage under the toes of the dams were negligible for the following reasons

- The dams were constructed from impermeable materials and some of them were keyed to bedrock

- The terminal ponds are clay lined

- Unpublished water budget studies of the ponds conducted for this modeling effort have indicated minimal seepage under the dams as well as minimal leakage from the ponds into subsurface materials

For the stream reaches in the model, depth/area and depth/volume relationships were estimated from stream cross section measurements at RFETS These data are a necessary input to HSPF to perform hydraulic routing through the creeks and ditches For the HSPF model to account for losses from creeks and ditches due to infiltration, potential infiltration rates must be supplied by the user These rates were estimated outside of HSPF using a Soil Conservation Service survey (Price and Amen 1980) and input to the OU6 model

Based on local hydrogeologic information it was determined that inflow of groundwater from areas outside of the Walnut Creek surface water system is minimal, and thus no such inflows were included in the OU6 model The hydrogeologic information does indicate however that local groundwater (originating as precipitation in the Walnut Creek watershed) contributes to flows in the creeks and ditches This flow was included in the OU6 model Interflow, flow in the unsaturated zone that resurfaces as overland flow was also included in the model Groundwater flow and interflow were allowed to enter the creeks (during and after

precipitation events) Infiltration losses from the creeks and ditches are assumed to evapotranspire and thus are lost from the surface water system

Other hydrologic inputs to the OU6 model are effluent from the WWTP and drainage from building foundation drains (shown in Plate 5 5-2) Daily records of WWTP flows into Pond B-3 were obtained for January 1992 through July 1994 No variation was observed among the years of WWTP flow data, nor were any monthly trends observed Thus, the 31 months of daily WWTP data were repeated to generate the seven years of WWTP data needed for calibration and input into the OU6 model

Baseflow between 0 01 and 0 1 cfs was recorded at GS10 and GS13 (Figure 3 7-1) Based on discussions with EG&G hydrologists, the most likely source of these flows is building foundation drains These drains are of two types: (1) a system of tranches and perforated pipes that slopes away from the building and uses gravity to drain water to a storm sewer or outfall at a lower elevation and (2) a sump and pump system in which water is pumped to a storm sewer or other discharge location Foundation drains at RFETS are described in more detail in "A Description of Rocky Flats Foundation Drains" (EG&G 1992) Time series data based on 1991 through 1993 gaging records were input to the model to simulate these flows and their seasonal variation. Because of the limited amount of gaging data, no variation among years was simulated. Footer drainage in March, April, and May was the same (approximately 0 09 cfs), no matter how wet or dry the previous winter was. Similarly, footer drainage was consistent from year to year for other seasons. approximately 0 05 cfs in the summer and approximately 0.03 cfs in the winter and fall

5.5.2.2 External Module to the HSPF Model: Pond Operation Simulation

The water in the A-series and B-series ponds is regulated for the following three purposes

- To ensure that water quality in Walnut Creek meets stream segment standards (CDPHE 1994) as it leaves RFETS Prior to releases from the terminal Pond A-4, water quality is monitored If necessary, a granulated activated carbon treatment system is used.

- To ensure that each pond is kept sufficiently full to keep pond sediments moist and to protect sediments from wind erosion

- To protect the structural integrity of the dams for Ponds A-4 and B-5 by keeping the water elevation below certain levels

The timing of releases from Pond A-4 Pond A-3, and Pond B-5 depends upon these three factors and any model of the OU6 surface water hydrology must incorporate these operations

Historically, the objectives of the pond operations were achieved by implementing decisions on a daily basis rather than by following a consistent set of operating rules However records of releases are not available for an extended period, and to simulate past operations (for calibration of the model) a set of rules had to be developed Furthermore, a set of operating rules is necessary to perform simulations of possible future events (for predicting water quality) A summary of the pond operation rules and exception rules that were developed for purposes of this modeling effort is given in Appendix H The rules indicate that release of water from a pond or addition of water to a pond is controlled by many factors including volume conditions at other ponds upstream and downstream Unfortunately, HSPF is not capable of continuously simulating these pond operations and a separate program was written for this purpose Whenever pond release data were not available, simulation of pond operations based on the pond operation rules was applied

A computer program called PONDSIM was developed (in the Pascal programming language) to simulate the releases of water from Ponds A-3, A-4, and B-5 in accordance with the pond operation rules Prior to running PONDSIM HPSF is run to calculate runoff from the part of the watershed upstream of the three ponds This runoff, along with initial pond volumes and meteorological data, is input to the PONDSIM program PONDSIM produces three time series with binary decision variables for each of Ponds A-3 A-4 and B-5 for each hour of the simulation, releases from each pond are either turned "on" or "off" to meet all of the pond operations rules (if that is possible) or to meet the exception rules if there are conflicts The outputs from PONDSIM become inputs to a new HSPF simulation (which uses the same baseline parameter values as the HSPF simulation performed prior to PONDSIM) that models the entire OU6 surface water system including the operation of the ponds

Ponds A-1, A-2, B-1, and B-2 are reserved for flood control and spill control, and water from these ponds seldom enters the Walnut Creek surface water system (rare exceptions could occur during very extreme runoff events) Nevertheless, sediments in these ponds must be kept moist, and, during dry periods, water is sometimes added to these ponds (sources include Walnut Creek, the WWTP, and the Landfill Pond) to keep the volume at or above 10 percent of the total capacity Furthermore, Pond B-2 receives some inflow from groundwater in the spring months, and occasionally water will enter these ponds from leaks and overflows in the bypasses (Plate 5 5-2) These inflows to Pond B-2 were not included in the pond simulation module because these ponds are not important components of the Walnut Creek hydrological system, they are isolated from the rest of the system by bypasses that route water around them, and the volumes of these inflows are considered very small compared to the overall water budget of the watershed. Thus, Ponds A-1, A-2, B-1, and B-2 were allowed to drop to zero volume during the HSPF simulation, since the inflows to these ponds are not included in the simulation However, for the calculations of concentrations of the modeled contaminants, pond volumes were assumed to be at 10 percent capacity when simulated volumes were below this level because the water in these ponds is always kept at or above 10 percent of the total pond capacity in actual pond operation

5.5.2.3 Sediment and Water Quality Inputs

Inputs to HSPF for sediment transport modeling include soil erosion and washoff coefficients for the pervious and impervious land segments and bed sediment size and deposition/scour values for the reach/reservoir segments. While most of these inputs are calibration parameters, initial concentrations of chemicals to be modeled in surface soil of the pervious and impervious land segments and in stream/pond sediment for the reach/reservoir segments were calculated for each sub-basin and reach/reservoir segment using the results of soil and sediment sampling conducted during the 1991 field investigation within the OU6 IHSSs The initial concentrations in surface soils in each of the land segments were based on the area-weighted average concentrations in the IHSS and non-IHSS areas within each segment Within each IHSS, the concentration was the arithmetic mean of measured concentrations, values below detection limits were replaced by one-half the sample reporting limit For non-IHSS areas (which were not sampled) concentrations of contaminants were assumed to be zero so that the model results reflect OU6 contaminant sources only The calculated average concentrations in each sub-basin are summarized in Table H3-1

Initial concentrations in the reach/reservoir sediments are based on 1992 sampling results These concentrations are summarized in Table H3-2

5 5 3 Model Calibrations

A surface water flow and transport model is generally calibrated by adjusting a set of model parameters to produce simulated flows, TSS concentrations, and contaminant concentrations that match field measured values within a quantifiable range of error or within reasonable limits There are basically two ways of adjusting model parameters to achieve calibration (1) manual trial-and-error adjustment of parameters and (2) automated parameter estimation Calibration of HSPF for the OU6 surface water model was achieved with the manual trial-and-error method

Flow parameters were calibrated to a 5-month record of flow and pond volume data This short record is due to the fact that much of the recorded RFETS flow data are not in RFEDS or have been determined to be unreliable according to EG&G hydrologists

- The data collected prior to the current program (i e prior to 1991) are not in RFEDS, are limited to few sampling locations and are of questionable accuracy

- Some of the data collected during the current program (before April 1993) are considered relatively inaccurate because the gaging equipment was not consistently calibrated before that time

- Winter records are not reliable because of ice in the flumes and also because gaging equipment is sometimes turned off during cold periods to prevent damage to the equipment

The gaging data for water year 1994 were not available before this modeling effort was completed Therefore the only reliable gaging record was for April through September 1993 Because of gaps in the meteorological data, September 1993 was not included in the calibration period Thus the time period for flow calibration is April through August 1993

Sediment parameters were calibrated to pond sedimentation rates during a 7-year time interval (April 1986 - March 1993) This time period was used because of the availability of the meteorological data at RFETS Meteorological data for years prior to 1986 are generally not available

Because of limited historical data, simulated concentrations were not calibrated to measured concentration values within the OU6 drainage system However, a qualitative evaluation of the modeling results was conducted by comparing the range of estimated concentrations of TSS and the selected chemicals to the ranges of measured concentrations along Walnut Creek during a 7-year time interval (April 1986 - March 1993)

5.5.3 1 Water Quantity Calibration

The OU6 hydrologic model was calibrated by adjusting HSPF parameters (listed in Section H4 1 2) so that simulated stream flows and pond volumes were similar to observed data.

Two methods were employed for comparing observed data to simulated flows and volumes

1. Quantitative comparisons - The simulated average daily flows and the observed flows were each summed to obtain the total simulated and observed flows at GS03 and GS10 for the 5-month period (April to August 1993) The percent differences between observed flow volumes and simulated flow volumes were then calculated for the two locations. For Pond A-3, the percent difference between the observed change in pond volume and the simulated change in pond volume was calculated for the 5-month period

2. Qualitative comparisons - The time series of observed data and the simulated flows and volumes were plotted. The graphs were compared to determine if the model results are similar in shape and temporal occurrence to the measured data. In particular, the timing and magnitudes of runoff peaks were checked

The HSPF model simulated a total flow volume of 182 acre-feet at GS03 for April through August 1993 (excluding May 18 through May 28 when the record is unreliable) The observed total flow volume for this time period is 176 acre-feet The difference between

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these values is 4 percent of the observed flow volume which is considered a very good calibration in the HSPF guidance literature (Donigian et al 1984) Since much of the flow at GS03 comes from releases from Pond A-4 the simulation of storm runoff is not as accurate as this low percent difference might indicate Nevertheless, this percent difference was considered within a reasonable range of error given the short record of reliable gaging data

Figure 5 5-1 shows observed and simulated flows at GS03 for the entire 5-month time period (observed data were not reliable for May 18 through May 28 and were not plotted on the figure) To improve the clarity of the beginning of the simulation the flows during April were also plotted separately on Figure 5 5-2 Both of these figures also show releases from Pond A-4 as well as precipitation to help distinguish between the sources of runoff at GS03 These figures indicate

- During periods of release in which there was very little precipitation and virtually no runoff (e g , July 24 through August 12), the releases were higher than flows at GS03 because of infiltration in Walnut Creek downstream of Pond A-4 For these time periods the model fits the observed data very well

- After large precipitation events (e g April 12) the flow at GS03 is greater than releases from the pond Although the runoff was sometimes overestimated and sometimes underestimated, the model reasonably reproduced the flows at GS03

The total flow volumes at GS10 for the 5-month period (excluding flows on days when the record is unreliable, that is May 7 through 10 and June 17 through 18) were 22 8 acre-feet for the observed flows and 24 6 acre-feet for the simulated flows The difference between these values is 8 percent of the observed flow volume Again, the percent difference was considered very good according to guidance literature

Figure 5 5-3 shows observed and simulated flows at GS10 for the reliable record of the 5-month period Precipitation is also included on the figure Unfortunately, the data gap in June occurred during the largest runoff event of the period the large simulated peak of June 17 and 18 could not be compared to observed data The two sources for most of the

observed flow to this gaging station are drainage from building footer drains and runoff from impervious areas on the south side of the plant The footer drainage is shown in the figure as approximately 0 1 cfs during April and approximately 0 05 cfs after April These flows were accurately simulated by the HSPF model The peak flows from impervious runoff were not as well represented The impervious segments of the HSPF model have only one significant calibration parameter, retention storage, and the calibrated value for this parameter resulted in an underestimation of the small runoff events and an overestimation of some of the larger events Although the limited data prevented a more comprehensive comparison between observed and predicted peak flows over a large range of conditions, the sediment transport calibration (discussed in Section 5 5 3 2) indicated that the model peak flows are reasonable

For calibration of the HSPF segments that represent the north side of the plant, volume data for Pond A-3 were used The observed change in volume from April 2 to August 30 is a decrease of 20 3 acre-feet The simulated change during this time period is a decrease of 19 9 acre-feet The difference between these values is 2 percent of the observed volume change This percent difference shows an accurate representation of volumes in the pond This good comparison between observed and predicted volumes is not indicative of good runoff simulation because the volume in Pond A-3 is mostly driven by upstream releases which are input to the model Figure 5 5-4 illustrates a reasonable simulation of Pond A-3 volumes, although they are sometimes underestimated (e g., April 14 and May 9) and sometimes overestimated (e g., April 21 and June 20)

5.5.3 2 Sediment Transport Calibration

The sediment transport calibration process included calibrating the model to measured pond sedimentation rates in the A- and B-series ponds and using 1993 TSS data for a reasonableness check. The pond sedimentation calibration included two basic steps

1 Matching the simulated volume of deposited sediment with the estimated value of deposited sediment in each of Ponds A-4 and B-5 during the 7-year calibration time interval (April 1986 - March 1993)

2 Matching the simulated with the estimated value of total sediment deposits in the following groups of ponds ("pooled" ponds) during the 7-year calibration time interval

- Ponds A-1 A-2, and A-3
- Ponds A-1 A-2, A-3, and A-4
- Ponds B-1, B-2, B-3, and B-4
- Ponds B-1 B-2 B-3 B-4 and B-5

Total sediment deposits in "pooled" ponds (as opposed to individual ponds) were used for model calibration because by pooling the ponds, the effects of the somewhat uncertain operation rules become less important in the calibration As discussed in Section 5 5 2 2 routing of surface water through the A- and B-series ponds in the OU6 model involves a set of pond operation rules These rules may differ from past pond operating procedures and this uncertainty makes the comparison of simulated and estimated sediment deposits in individual ponds (especially ponds A-1 A-2, B-1 and B-2, which are not included in the PONDSIM program) less useful for calibration purposes Therefore, total sediment deposits in "pooled" ponds were used for comparison in the model calibration The total sediment deposited in the A-series and B-series ponds represents the total soil loss due to surface water erosion from the northern and southern parts of the IA, respectively

Pond Sedimentation Rate Calibration Results A comparison between simulated and estimated pond sedimentation rates is given in Table 5 5-1 and the prediction errors for the targeted ponds listed earlier are summarized as follows

Single or "pooled" ponds	Prediction Error (%)
A-1 to A-3	5 5
A-1 to A-4	2 6
B-1 to B-4	7 0
B-1 to B-5	-0 4
A-4	-16 4
B-5	-37 2

The results indicate that sedimentation rates in ponds A-1, A-2, B-1, B-2, and B-3 are significantly under-predicted as anticipated because of the difference between actual pond operation in the past and the pond operation simulated in the model The prediction errors for the pooled ponds, Pond A-4, and Pond B-5 are relatively small, indicating that the OU6 surface water model was well-calibrated in term of sediment transport. The prediction errors may well be justified considering that the actual pond operation decisions might have been significantly different than the pond operation rules in the OU6 model

Reasonableness Check of Predicted TSS Concentrations. As a further check on the sediment transport model, the simulated and measured TSS concentrations along Walnut Creek during the 1993 calibration time interval (April - August) were compared (Table 5.5-2) As mentioned earlier, this comparison is qualitative because of the inadequacy of the TSS data for calibration As indicated in Table 5 5-2, a considerable prediction error was observed. However, the simulated TSS concentrations are mostly within the same order of magnitude as the measured TSS concentrations

5.5.3.3 Reasonableness Check of Simulated Contaminant Concentrations

Fate and Transport Processes of Water Quality Constituents. As specified in Section 5 5 1, water quality modeling in this study is limited to the particulate-associated chemicals antimony, Pu-239/240, and Am-241 Adsorption/desorption between dissolved and particulate (sediment) phases was considered minimal as specified in the HSPF model The chemicals chosen are considered conservative, and chemical reactions such as hydrolysis, oxidation, photolysis, volatilization, biodegradation, and general first order decay for the dissolved phase were not considered

In the model, contaminant loads from the pervious land segment are proportional to soil loss from the segments Loads from the impervious land segments are assumed proportional to solid (natural or artificial accumulation) washoff from the segments The proportions were specified as the initial contaminant/soil ratio in the surface soils for the pervious land segments and in the surficial solids for the impervious land segments Thus, the transport of contaminants in the reach/reservoir segments is proportional to the transport of sediment in the segments The proportions of contaminants in surface soils, surficial solids, and stream sediments are discussed in Section H3 4

Because most of the available chemical concentration data were from water samples taken under baseflow conditions and a continuous record of this data during one or multiple storm events was not available, the measured contaminant concentrations are not adequate for model calibration However these data provided the basis for a qualitative check of the model prediction results

Reasonableness Check of Model Results A comparison between the simulated and the measured contaminant concentration ranges in pond water during the 7-year calibration time interval (April 1986 through March 1993) is presented in Table 5 5-3 The simulated concentrations in pond water were comparable to the measured concentrations except for simulated Ponds A-1, A-2, B-1 and B-2, where the simulated maximum concentrations were much higher than the measured maximum values

For Ponds A-1 A-2 B-1 and B-2, unusually high contaminant concentrations were predicted in the model when the pond water volume in the model drops to a certain level (generally less than 1 percent of the pond capacity) This phenomenon is mainly the result of two assumptions made in the OU6 model

- In the model, a small portion of the sediments entering the stream and the ponds was not allowed to settle This assumption was made to permit (1) a more accurate TSS concentration calibration downstream of the detention ponds and (2) a more realistic simulation of measured concentrations in the ponds when there is no outflow from the ponds and the ponds are not close to being empty

- In the model water volumes in Ponds A-1, A-2, B-1, and B-2 were allowed to drop below 10 percent capacity in contrast to the actual situation in which capacities are kept at or above 10 percent (see explanation in Section H3 3)

Since the pond operation simulated in the model differs considerably from the actual situation for Ponds A-1 A-2 B-1 and B-2 the results for these ponds are not as accurate as the estimated concentrations for Ponds A-3, A-4, B-3, B-4, and B-5 However the estimated concentrations for Ponds A-1, A-2 B-1 and B-2 are useful for risk assessment it is known

that the model gives a conservative estimation of concentrations in the water of these ponds (i e, these concentrations are not underestimated)

5.5 4 Predictions of Long-Term Average COC Concentrations

The final task of the OU6 surface water and transport model was to estimate the future concentrations of selected contaminants along Walnut Creek and its tributaries in support of the HHRA for the OU6 RFI/RI This entails estimating long-term average concentrations of contaminants in stream flow and in sediment in the ponds and in Walnut Creek at Indiana Street These estimates were based on the results of thirty 30-year simulations This section discusses the generation of thirty 30-year meteorological data series and the results of the thirty HSPF simulations

The steps in calculating the long-term average concentrations of contaminants in stream flow and in pond and stream sediments were

- Generation of thirty 30-year meteorological time series, including precipitation, solar radiation, wind speed, air temperature, dew-point temperature, pond evaporation, and potential evapotranspiration
- Generation of thirty 30-year time series for other HSPF inputs such as WWTP effluent and building footer drainage,
- Incorporation of pond operation rules,
- HSPF simulation of the Walnut Creek watershed with calibrated flow and sediment parameters,
- Calculation of 95% UCLs on the means of the 30 simulated long-term average concentrations

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5 5 4 1 Meteorological Data Generation and Other Simulation Inputs

The HSPF prediction of long-term average concentrations of contaminants in stream flow and in stream sediment along the Walnut Creek drainage required thirty 30-year time series of meteorological data These time series were created by a stochastic weather generator called CLIGEN developed for the Water Erosion Prediction Project (WEPP) (Lane and Nearing 1989) and described in detail in Appendix H

Other inputs to the model were determined as follows

- Based on the hourly meteorological data, hourly pond evaporation and potential evapotranspiration were calculated with the methods discussed in Section 5 5 2 1

- Effluent from the WWTP and drainage from building footer drains were included in the simulations These external flows to the OU6 drainage system during each of the 30-year simulations were based on the data collected from January 1992 through July 1994 The data from these years were repeated as many times as necessary to complete the 30-year simulations

- The external module PONDSIM which was used to simulate the pond operation rules (Section H3 3) was used along with the HSPF model to complete the thirty 30-year simulations

5.5 4 2 Simulation Results

30-year Average Concentration in Deposited Stream/Pond Sediment The average concentration of a contaminant in the newly deposited sediment was defined as the ratio of the total deposited mass of contaminant to the total deposited mass of sediment over the 30-year simulation If sediment deposition does not occur the average concentration of a contaminant in the newly deposited sediment is zero The predicted 30-year average concentrations of contaminants in newly deposited stream/pond sediment are summarized in Tables H5-1 through H5-10 The 95% UCLs on these averages are presented in Table 5 5-4 and are considered the reasonable maximum estimates of these concentrations

For risk assessment, the average concentration of a modeled contaminant in pond sediment was determined as a depth-weighted average concentration of the initial concentration in stream/pond sediment and the concentration in the deposited sediment (the "reasonable maximum" estimate) Results are presented in Table 5 5-5 The concentrations were averaged over a depth of 2 feet to correspond to the pond sediment sampling interval used in the OU6 field investigation

30-year Average Concentration in Stream/Pond Water. The average concentration of a contaminant in stream/pond water over a 30-year interval was calculated as the volume-weighted average of the mean daily concentrations in the stream/pond water

The simulated average concentrations of contaminants for each 30-year simulation in stream/pond water at the selected locations are given in Tables H5-1 to H5-10 For risk assessment, 95% UCLs on these averages were calculated. Results are presented in Table 5 5-5

5 6 AIR MODELING APPROACH AND RESULTS

5 6 1 Introduction

Onsite air modeling was conducted to estimate concentrations of COCs at human receptor locations within OU6 The air modeling approach was limited by design to support the HHRA it is not intended to serve as a comprehensive air modeling study of OU6

To estimate exposure point concentrations of airborne emissions from OU6, air dispersion modeling was performed for airborne emissions of particulate matter less than 10 microns in diameter (PM_{10}) occurring during natural wind erosion and from construction activities Emission sources evaluated at OU6 were AOC No. 1 (approximately 10 acres), AOC No 2, and a 30-acre maximum exposure area in AOC No 2 . The AOCs and the maximum exposure area were delineated for purposes of conducting the HHRA They are described in more detail in Section 6 and in Appendix J Briefly, AOC No 1 is equivalent to IHSS 167 1 (North Spray Field Area) AOC No 2, which is approximately 50 acres, contains IHSS 141 (Sludge Dispersal Area), IHSS 156 2 (Soil Dump Area), and IHSS 165 (Triangle Area) The 30-acre maximum exposure area in AOC No 2 is representative of a hypothetical future

industrial park Soil gas transport modeling to assess impacts resulting from soil gas transport into an office building from contaminated subsurface soil and groundwater was also performed

This section summarizes the air dispersion and soil gas transport modeling approaches and presents the modeling results Greater detail is presented in Appendix I

5 6 2 Air Dispersion Modeling

To assess onsite ambient air quality resulting from the release of airborne contaminants during baseline (i e , undisturbed) conditions and construction (i e , disturbed) conditions, emissions of airborne PM_{10} were estimated for the following scenarios

- Fugitive PM_{10} emissions as a result of wind erosion of the surface soils in AOC No 1 and AOC No 2 and the maximum exposure area in AOC No 2 (with dispersion to onsite receptors)

- Fugitive PM_{10} emissions as a result of construction activities in subsurface soils (onsite exposures)

Particulate COCs (i e metals, radionuclides, and semi-volatiles) were evaluated for PM_{10} impacts It was assumed that those chemicals based on their strong affinity for adsorption adhere to particles emitted as a result of wind erosion VOC emissions to outdoor air were not modeled because this exposure pathway was considered negligible for risk assessment (see Appendix J)

The Ventilated Valley Dispersion Model (VVDM) was selected to estimate impacts to onsite receptors VVDM estimates airborne PM_{10} concentrations within a confined volume from a steady-state emission rate within that volume This model assumes complete mixing of pollutants within a series of boxes defined by the surface area(s) (i e length and width of the affected area) and an imaginary lid The height of the lid is defined as the assumed mixing height The mixing height is assumed to be a function of turbulence induced by surface roughness and the length of the "box" being considered VVDM can rapidly estimate air

concentrations to receptors in the immediate vicinity of an emission source Therefore, it is considered an appropriate model for estimating onsite air concentrations

Onsite air impacts from surface soil wind erosion were evaluated for AOC No 1, AOC No 2, and the 30-acre maximum exposure area in AOC No. 2 Annual average air particulate concentrations and deposition rates were modeled for 5 years (1989 through 1993) The maximum results were used in risk assessment for estimating onsite exposures in each area.

To estimate air particulate concentrations under a construction scenario in AOC No 1 and AOC No 2, concentrations resulting from the following three emissions sources were modeled and summed (1) wind erosion from surface soil in the AOC (maximum year 1990), (2) emissions from subsurface soil during heavy construction in a 10-acre excavation (using a standard equation from AP-42), and (3) wind erosion from subsurface soil in a 10-acre excavation

Complete VVDM model results are shown in Tables I-2 through I-29 of Appendix I Maximum impacts from wind erosion of surface soils occurred during the year 1990 Concentrations at AOC No 1 for 1990 (Table 5 6-1) ranged from 4 70E-13 $\mu g/m^3$ (Am-241) to 5 22E-04 $\mu g/m^3$ (zinc) Deposition ranged from 2.09E-10 $\mu g/m^3$/day (Am-241) to 2 32E-01 $\mu g/m^3$/day (zinc) For AOC No 2, the highest concentrations were estimated at the 30-acre site in 1990 (Table 5 6-2) Air concentrations ranged from 3 13E-12 $\mu g/m^3$ (Am-241) to 1 17E-03 $\mu g/m^3$ (zinc)

The summaries for heavy construction at AOC No 1 and AOC No 2 are shown in Tables I-22 and I-26 of Appendix I, respectively The summaries of the annual average air concentrations (including contributions from construction activities and construction wind erosion) for AOC No 1 and AOC No 2 are shown in Table 5 6-3 and 5 6-4, respectively Concentrations at AOC No 1 ranged from 4 70E-13 $\mu g/m^3$ (Am-241) to 5.22E-04 $\mu g/m^3$ (zinc) Concentrations at AOC No 2 ranged from 2 59E-14 $\mu g/m^3$ (Am-241) to 1 13E-05 $\mu g/m^3$ (zinc)

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5 6 3 Soil Gas Transport Modeling

A modified soil gas transport model was used to estimate VOC concentrations in a building as a result of volatilization of those compounds from groundwater The soil gas transport modeling was performed under the assumption that the volumetric exchange rate of air from the subsurface source of contamination to the ground surface beneath a building is only 0 1 percent of the exchange rate from the ground surface to the interior above the building floor Therefore, only 0 1 percent of the volumetric exchange rate within the building is used to simulate soil gas transport in the subsurface

Results of the soil gas transport model are shown in Tables I-34 to I-36 of Appendix I Modeling was not performed for AOC No 1 since no VOC COCs were identified in subsurface soil or groundwater The highest resultant building concentration for AOC No 2 was for the entire 50-acre area (Table 5 6-5) Concentrations ranged from 1 08E-08 $\mu g/m^3$ (chloroform) to 1 16E-02 $\mu g/m^3$ (methylene chloride)

TABLE 5 1-1
ROCKY FLATS OU6
SUMMARY OF CHEMICALS OF CONCERN

	Surface Soil	Subsurface Soil	Groundwater	Pond Sediment	Pond Surface Water	Stream Sediment
Chemical of Concern						
Aroclor-1254				X		
Benzo(a)anthracene						X
Benzo(a)pyrene		X		X		X
Benzo(b)fluoranthene		X		X		X
Bis(2-ethylhexyl)phthalate				X		
Di-n-butylphthalate					X	
Indeno(1,2,3-cd)pyrene						X
Chloroform			X		X	
1 2-Dichloroethene					X	
Methylene chloride			X			
Tetrachloroethene			X			
Trichloroethene			X		X	
Antimony	X			X		
Barium		X				
Cobalt						X
Silver	X			X		
Strontium						X
Vanadium	X			X		X
Zinc	X					X
Nitrate			X			
Americium-241	X	X	X	X		X
Plutonium-239,240	X	X	X	X		X
Uranium-233 234		X				
Uranium-238		X				
Radium-226			X			
Special - Case Chemicals of Concern [1]						
Vinyl chloride			X			

[1] Detected at less then 5 percent frequency but at relatively high concentration

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TABLE 5 2-1
PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC COMPOUND COCs AT OU6[1]

Compound	Formula	Density (g/ml)	Water Solubility (mg/l)[2]	Vapor Pressure (mm Hg)[2]	Henry's Law Constant (atm-m³/mole)	K_{ow}[5]	K_{oc} (ml/g)
Benzo(a)anthracene	$C_{18}H_{12}$	1 27	0 010	5×10^{9}	$6\ 6 \times 10^{7}$	407 380	1 380 384
Benzo(a)fluoranthene	$C_{20}H_{12}$	ND	0 014	5×10^{7}	$1\ 2 \times 10^{5}$	3 175 350	549 541
Benzo(a)pyrene	$C_{20}H_{12}$	1 27	0 010	5×10^{9}	$2\ 4 \times 10^{-6}$	407 380	1 380 384
Di n butylphthalate	$C_{16}H_{22}O_4$	1 05	400	<0 01	$6\ 3 \times 10^{5}$	61 660	1 380
Indeno(1 2 3-cd)pyrene	ND	ND	0 062	1×10^{10}	$2\ 96 \times 10^{20}$	50 118 700	30 900
1 2 Dichloroethene	$C_2H_2Cl_2$	1 26	600	200[6]	$3\ 8 \times 10^{1}$	123	59
Aroclor 1254	ND	1 505	0 057	$7\ 71 \times 10^{5}$	$2\ 7 \times 10^{3}$	407 380	407 380
Bis(2-ethylhexyl)phthalate	$C_{24}H_{38}O_4$	0 9861	0 4	2×10^{7}	$1\ 1 \times 10^{5}$	15 849	100 000
Chloroform	$CHCl_3$	1 48	8,200	160	$2\ 9 \times 10^{3}$	79 93	44
Methylene Chloride	CH_2Cl_2	1 33	20 000	349	$2\ 0 \times 10^{3}$	22 9	8 7
Tetrachloroethene (PCE)	C_2Cl_4	1 62	150	14	$1\ 53 \times 10^{2}$	398	300 360[3]
Trichloroethene (TCE)	C_2HCl_3	1 46	1 100	58	$9\ 1 \times 10^{3}$	338	100 150[4]
Vinyl Chloride	C_2H_3Cl	0 91	1 100	2 580	1 22	3 98	2 45

[1] Montgomery and Welkom 1989 and Knox et al 1993
[2] Water solubility and vapor pressure obtained at 20°C ~ 25°C
[3] Schwille 1988 and Fetter 1988
[4] Piwoni and Banerjee 1989
[5] K_{ow} is dimensionless
[6] Vapor pressure @ 14°C

ND Not Definitive

TABLE 5.2-2
PHYSICAL AND CHEMICAL PROPERTIES OF INORGANIC COMPOUND COCs AT OU6

Chemical	Formula	Molecular Weight (g/mole)	Water Solubility[1]	Specific Gravity	K_d[2]
Antimony	Sb	121 7	Insoluble	6 68	NA
Cobalt	Co	58 9	Insoluble	8 9	4 0
Barium	Ba	137 3	Decomposes	3 51	NA
Strontium	Sr	87 6	Decomposes	2 6	3 3
Silver	Ag	107 9	Insoluble	10 5	4 7
Vanadium	V	50 9	Insoluble	5.96	NA
Zinc	Zn	65 38	Insoluble	7.13	2 8

1 Water solubility based on elemental state
2 K_d values from Dragun 1988

NA - Information not available

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TABLE 5 2-3
RADIOACTIVE HALF-LIVES FOR RADIONUCLIDE COCs[1]

Element	Radioactive Half Lives (year)
Americium 241	433
Plutonium 239	24 100
Plutonium 240	6 570
Radium 226	1 620
Uranium 233	159,000
Uranium 234	246 000
Uranium 235	704 000 000
Uranium 238	4 470 000 000

[1] Information obtained from Gilbert et al 1989

TABLE 5 2-4
BIODEGRADATION RATES FOR ORGANIC COMPOUND COCs[1]

Compounds	Groundwater Half-Lives	Soil Half-Lives	Surface Water Half-Lives
PCE	12 months - 2 years	6 months - 1 years	NCOC
TCE	10 7 months - 4 5 years	6 months - 1 years	6 months - 1 year
$CHCl_3$	8 weeks - 5 years	4 weeks - 6 months	4 weeks - 6 months
Methylene Chloride	2 weeks - 8 weeks	7 days - 4 weeks	7 days - 4 weeks
Vinyl Chloride	8 weeks - 95 months	4 weeks - 6 months	NCOC
Benzo(a)pyrene	114 days 2.9 years	57 days - 1 45 years	0.37 hours 1 1 hours
Benzo(b)fluoranthene	1 97 years 3 34 years	360 days - 1 67 years	8 7 hours 720 hours
Benzo(a)anthracene	204 days 3 73 years	102 days - 1.86 years	1 hour - 3 hours
Di-n-butylphthalate	2 days - 23 days	2 days - 23 days	1 day 14 days
Indeno(1,2,3-cd)pyrene	3 29 years 4 0 years	1 64 years 20 years	125 days - 250 days
1 2 Dichloroethene	8 weeks - 95 months	4 weeks - 6 months	4 weeks - 6 months
Bis(2-ethylhexyl)phthalate	10 days - 389 days	5 days - 23 days	NCOC
Aroclor-1254	NA	NA	NCOC

[1] Information obtained from Howard et al 1991
NA information not available
NCOC - not a COC in surface water for OU6

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TABLE 5 2-5
CALCULATED DISTRIBUTION COEFFICIENTS AND RETARDATION VALUES FOR ORGANIC COMPOUND COCs IN GROUNDWATER

	Soil-Water Partition Coefficient K_d (cm^3/g)	Retardation Factor R
Aroclor 1254	4 888 3 585	NR
Benzo(a)anthracene	16 565 12 147	NR
Benzo(a)fluoranthene	6 594 4 836	NR
Benzo(a)pyrene	16 565 12 147	NR
Bis(2 ethylhexyl)phthalate	1 200 880	NR
Indeno(1 2 3 cd)pyrene	371 - 272	NR
1 2 Dichloroethene	0 35	7 44
$CHCl_3$	0 26	5 86
Methylene Chloride	0 052	1 96
PCE	1 8 2 16	34 1 40 7
TCE	0 6 - 0 9	12 1 17 6
Vinyl Chloride	0 020	1 44

Explanation

$K_d = f_{oc} \bullet K_{oc}$ K_{oc} from Table 5 2 1

Total organic carbon (TOC) values for subsurface soil were used to calculate K_d for VOC COCs (average TOC in subsurface soils = 0 6%)

TOC values for surface soils and sediments were used to calculate the range of K_d for SVOC COCs (average TOC in surface soils and sediments = 1 2% and 0 8% respectively)

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

ρ_b = 1 84 g/cm^3
n_e = 0 10

NR retardation factors calculated for groundwater COCs only

TABLE 5.2-6

SOIL WATER DISTRIBUTION COEFFICIENTS, K_d,(cm^3/g) FOR RADIONUCLIDE COCs

	K_d Study by Sheppard and Thibault[1]						Assumed Retardation Factor by Dames & Moore[2]			
	SAND		LOAM		CLAY		SAND		CLAY	
	Mean	Range	Mean	Range	Mean	Range	R	K_d[3]	R	K_d[3]
Americium	1 900	8 2 - 308,000	9,600	400 - 48,300	8,400	25 - 400,000	300	(16 3)	2,500	(136)
Plutonium	550	27 - 36 000	1,200	100 - 5 933	5 100	316 190,000	840	(45 6)	7,200	(391)
Radium	3 2	57 - 21,000	36,000	1,262 - 520,000	9,100	806 - 56 000	30	(1 58)	250	(13 5)
Uranium	35	0 03 - 2,200	15	0 2 - 4 500	1,600	46 - 395,100	840	(45 6)	7,200	(391)

1 Values correspond to all isotopes of each element.

2 Dames & Moore data are from Staley, G B , G P Turi, and D L Schreiber U.S Nuclear Regulatory Commission, "Radionuclide Migration from Low-Level Waste A General Overview," Management of Low-Level Radioactive Waste, Volume 2, Pergamon Press, New York, 1979

3 K_d is calculated by Eq (5.2 3) with ρ_b = 1 84 g/cm³ and n = 0 10, lower values for K_d were used in model.

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TABLE 5 5-1
RESULTS OF POND SEDIMENTATION RATES CALIBRATION

Pond	Prediction Error (%)	Estimated Sediment Deposited in 7 years based on field data (Tons)	HSPF Predicted Sedimentation Rate Total in 7 years (Tons)	Yearly Average (Tons/Yr)	Daily Maximum (Tons/day)
A 1	-99 9	137 32	0 0692	0 0099	0 068
A 2	99 8	160 59	0 322	0 046	0 306
A-3	66 5	514 62	857	122 4	73
A-4	-16 4	125.54	105	15	5.54
B 1	-100 0	90 81	0 0288	0 00411	0 0272
B-2	-99 9	102 95	0 0822	0 0117	0 0816
B 3	-100 0	73 64	0 0252	0 0036	0 0238
B-4	282 4	103 82	397	56 71	42 4
B-5	-37 2	74 5	46 8	6 69	10 4
Total of A-1 to A-3	5.5	812.53	857 39		
Total of A-1 to A-4	2 6	938 07	962 39		
Total of B-1 to B-4	7 0	371 22	397.14		
Total of B-1 to B-5	-0 4	445.72	443 94		

Note
1) Prediction Error = (100%) (Predicted - Estimated)/(Estimated)
2) Target for calibration is the total in each branch of the Walnut Creek
3) Highlighted individual or "pooled" ponds are targeted for calibration, see text for detail

TABLE 5 5-2
COMPARISON OF MEASURED AND PREDICTED TSS CONCENTRATIONS ALONG WALNUT CREEK DURING THE 1993 CALIBRATION TIME INTERVAL

Location	Approx Physical Location	Dates Sampled	Measured TSS conc. (mg/L) Result	Qual-Lab	RFP-Limit*	Predicted TSS conc (mg/L)	Prediction Error (%)
SW68593	Out of BNDY	5/17/93	1900		4	NA	
SW68693	R 23	5/17/93	55		4	0 90	-98 4
SW68793	R-8	5/17/93	250		4	302 2	20 9
SW68893	NA	5/17/93	390		4	NA	
SW68993	R-19 or R-20	5/17/93	60		4	210 9	251 5
SW69093	R-9	5/17/93	21500		4	385 8	-98 2
SW69293	R-8	5/17/93	140		4	302 2	115 9
SW69393	R-8	5/17/93	190		4	302 2	59 1
SW061	R-19	4/7/93	17		5	13 64	-19 8
SW061	R-19	4/22/93	4	U	4	0 054	0 0
SW061	R-19	5/5/93	9		5	0 036	-99 6
SW061	R-19	5/19/93	5	U	5	26 107	422 1
SW061	R 19	6/2/93	5		5	0 0089	-99 8
SW061	R-19	6/16/93	5	U	5	0 00063	0 0
SW061	R 19	6/30/93	8		5	0.029	-99 6
SW061	R-19	7/14/93	5	U	5	112.6	2152.0
SW061	R-19	7/28/93	5	U	5	0.012	0 0
SW061	R-19	8/11/93	5	U	5	0.00074	0 0
SW061	R-19	8/27/93	4	U	4	0 00011	0 0

*) "RFP-Limit" - Detection Limit set for Rocky Flats Environmental Test Site.

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TABLE 5 5-3
COMPARISON OF MEASURED AND PREDICTED CONTAMINANT CONCENTRATIONS IN POND WATER

Pond ID	Americium Concentrations		Plutonium Concentrations		Sb Concentrations	
	Measured Range (PCI/L)	Predicted Range (PCI/L)	Measured Range (PCI/L)	Predicted Range (PCI/L)	Measured Range (mg/L)	Predicted Range (mg/L)
SWA1	0 0 02	0 30 85	0 01 0 24	0 64 1	NA	0 0 00262
SWA2	0 0 05	4 46E-03 0 144	0 02 0 17	0 0146 0 453	NA	0 1 87E 10
SWA3	0 - 0 02	0 - 0 00951	0 0 03	0 0 0275	NA	0 - 2 05E-05
SWA4	0 0 102	0 0 00038	0 - 0 02	0 8 69E-04	NA	0 8 36E-07
SWB1	0 0 08	0 311 - 1210 0	0 03 - 4 2	0 0696 - 271 0	NA	0 2 01E-05
SWB2	0 0 23	0 00532 - 264 2	0 02 - 0 5	0 125 620 0	NA	0 - 5 34E-15
SWB3	0 0 05	0 0 0944	0 04 0 15	0 0 089	NA	0 1 14E-06
SWB4	0 0 02	0 0 341	0 - 0 01	0 1 14	NA	0 - 1 60E-05
SWB5	0 - 0 034	9 94E-06 0 0098	0 - 0 016	0 - 0 00239	NA	0 5 03E-06

TABLE 5 5-4
MODELED NEWLY DEPOSITED SEDIMENT VOLUME AND CHEMICAL CONCENTRATIONS IN SEDIMENT

Location	Total Deposited Sediment at 30 year		Depth (1)	Average concentration in deposited sediment (2)		
				Am 241	Pu 239/240	Sb
	tons	ft^3	(ft)	pCi/g	pCi/g	mg/kg
Pond-A1	18 34	4 90E+02	0 015	0 213	0 811	4 18
Pond-A2	43 20	1.14E+03	0 024	0 060	0 503	1 62
Pond-A3	6334	1.68E+05	6 50	0 023	0 047	0 32
Pond-A4	1025 2	2.72E+04	2 69	0 019	0 079	0 16
Pond-B1	23 38	6 20E+02	0 049	0 800	0 270	3 33
Pond-B2	8 92	2 37E+02	0 0070	0 805	1 583	2 79
Pond-B3	19.34	5 09E+02	0 030	0 335	0 824	1 08
Pond-B4	2414 8	6.40E+04	5 73	0 0035	0 0083	0 16
Pond-B5	727 6	1 93E+04	3 59	0 015	0 028	0 41
Walnut Creek at Indiana Street	153 1	4 09E+03	0 86	0.008	0 196	19 56

Notes.
(1) Net deposition is based on the current bathymetry of the ponds and creek and the elevation-capacity curve of the ponds
(2) Values shown are 95% UCLs on the 30-year means, these were calculated assuming normal distributions of data; see Tables H5-1 through H5-10

TABLE 5.5-5
LONG-TERM AVERAGE CONCENTRATIONS IN SEDIMENT (0 - 2') AND SURFACE WATER

Location	Initial Concentrations (1)			Concentrations in newly Deposited Sediment (2)			Depth of Deposit at 30 yr	Concentrations for Risk Assessment					
								Sediment (3)			Water		
	Am 241	Pu 239/240	Antimony	Am 241	Pu 239/240	Antimony		Am 241	Pu 239/240	Antimony	Am 241	Pu 239/240	Antimony
	(pCi/g)	(pCi/g)	(mg/kg)	(pCi/g)	(pCi/g)	(mg/kg)	(ft)	(pCi/g)	(pCi/g)	(mg/kg)	(pCi/l)	(pCi/l)	(mg/l)
Pond A 1	9 31	29 04	20 52	0 213	0 811	4 18	0 015	9 28	28 93	20 46	0 014	0 043	4 42E-08
Pond A 2	1 011	3 187	12	0 060	0 503	1 62	0 024	1 005	3 171	11 938	0 013	0 042	1 21E-08
Pond A 3	0 413	1 214	13 5	0 023	0 047	0 32	6 50	0 023	0 047	0 317	2 04E-05	4 65E-05	1 92E-07
Pond A-4	0 0695	0 155	28 75	0 019	0 079	0 16	2 69	0 036	0 104	9 524	1 75E-06	5 84E-06	1 59E-08
Pond B-1	100 57	56 33	12	0 800	0 270	3 33	0 049	99 34	55 64	11 893	0 167	0 038	6 08E-11
Pond B-2	11 378	26 76	12	0 805	1 583	2 79	0 0070	11 36	26 72	11 984	0 029	0 069	3 37E-08
Pond B-3	23 69	78 89	47 4	0 335	0 824	1 08	0 030	23 51	78 30	47 049	3 26E-05	1 10E-04	3 02E-09
Pond B-4	0 848	2 61	17 075	0 0035	0 0083	0 16	5 73	0 004	0 008	0 162	1 03E-04	3 41E-04	9 69E-08
Pond B-5	0 128	0 237	10 625	0 015	0 028	0 41	3 59	0 027	0 050	1 455	2 99E-06	6 53E-06	5 73E-08
Walnut Creek at Indiana St	0 04	0 08	8 2	0 098	0 196	19 56	0 86	0 052	0 105	10 64	7 65E-05	1 82E-04	1 53E-05

(1) Arithmetic mean of 5 samples collected in each pond 0 to 2 feet interval
Walnut Creek at Indiana St initial concentrations are based on sediment samples from the W&I pond and stream sediment samples downstream of pond A-4

(2) Modeled 95% UCL concentrations from Tables 5 5 4

(3) Weighted averages of initial concentrations and newly deposited concentrations

TABLE 5.6-1
ANNUAL AVERAGE AIR CONCENTRATIONS
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
WIND EROSION AT OU6 AREA OF CONCERN NO 1
1990

Contaminant	Soil Concentration (ug/kg)	AOC1 (ac)	AOC1 (m^2)	1990 MAX. U	Particulate Emission Potential (g/m^2-hr)	Contaminant Emission Potential (g/s)	Chi/Q 1-hr Air Concentration (ug/m^3-g/s)	Contaminant 1 hr Air Concentration (ug/m^3)	Annual Contaminant Air Concentration (ug/m^3)
Metals									
Antimony	1 65E+04	10 0	4 05E+04	5 13E+01	5 7807	1 07E-03	4.17E+01	4 47E-02	1.78E-04
Vanadium	3 34E+04	10 0	4 05E+04	5 13E+01	5 7807	2 17E-03	4 17E+01	9 05E-02	3.61E-04
Zinc	4 84E+04	10 0	4 05E+04	5 13E+01	5 7807	3 14E-03	4 17E+01	1.31E-01	5.22E-04
Radionuclides									
Americium-241	4.39E-05	10.0	4.05E+04	5 13E+01	5 7807	2 85E-12	4 17E+01	1 19E-10	4.74E-13
Plutonium-239/240	3 89E-03	10.0	4.05E+04	5.13E+01	5 7807	2.53E-10	4 17E+01	1.05E-08	[illegible]11

ac	Acres.
g/m^2-hr	Grams per square meter-hour
g/s	Grams per second.
m^2	Square meters.
ug/kg	Micrograms per kilogram.
ug/m^3-g/s	Micrograms per cubic meter-grams per second.
ug/m^3	Micrograms per cubic meter

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TABLE 5 6-2
ANNUAL AVERAGE AIR CONCENTRATIONS
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
WIND EROSION AT OU6 AREA OF CONCERN NO 2 FOR A 30 ACRE SITE
1990

Contaminant	Soil Concentration (ug/kg)	AOC2 (ac)	AOC2 (m^2)	1990 MAX U	Particulate Emission Potential (g/m^2 hr)	Contaminant Emission Potential (g/s)	Chi/Q 1 hr Air Concentration (ug/m^3 g/s)	Contaminant 1 hr Air Concentration (ug/m^3)	Annual Contaminant Air Concentration (ug/m^3)
Metals									
Antimony	1 41E+04	30 0	1 21E+05	5 13E+01	5 7807	2 75E-03	1 54E+01	4 23E-02	1 69E-04
Silver	2 64E+03	30 0	1 21E+05	5 13E+01	5 7807	5 15E 04	1 54E+01	7 93E-03	3 16E-05
Vanadium	3 43E+04	30 0	1 21E+05	5 13E+01	5 7807	6 69E 03	1 54E+01	1 03E-01	4 10E-04
Zinc	8 57E+04	30 0	1 21E+05	5 13E+01	5 7807	1 67E-02	1 54E+01	2 57E-01	1 02E-03
Radionuclides									
Americium 241	3 70E-04	30 0	1 21E+05	5 13E+01	5 7807	7 21E 11	1 54E+01	1 11E-09	4 43E 12
Plutonium 239/240	4 25E-02	30 0	1 21E+05	5 13E+01	5 7807	8 29E-09	1 54E+01	1 28E-07	5 08E 10

ac	Acres
g/m^2 hr	Grams per square meter-hour
g/s	Grams per second
m^2	Square meters
ug/kg	Micrograms per kilogram
ug/m^3 g/s	Micrograms per cubic meter grams per second
ug/m^3	Micrograms per cubic meter

TABLE 5.6-3
SUMMARY OF THE ANNUAL AVERAGE AIR CONCENTRATIONS DURING HEAVY CONSTRUCTION ACTIVITIES ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE WIND EROSION AT AOC NO 1

	Surface Soil Wind Erosion Annual Contaminant Air Concentration (ug/m³)	10 Acre Disturbed Construction Area Annual Contaminant Air Concentration (ug/m³)	Heavy Construction Activities Annual Contaminant Air Concentration (ug/m³)
Metals			
Antimony	1 78E-04		
Barium		1 55E-07	1 31E-06
Vanadium	3 61E-04		
Zinc	5 22E-04		
Radionuclides			
Americium-241	4 74E-13	4.40E-18	3 78E-17
Plutonium-239/240	4 20E-11	3.40E-16	2.87E-15
Uranium-233,234		1 55E-19	1 31E-12
Uranium-238		5 53E-09	4.67E-08

Surface soil (Table I 18) + 10 acre disturbed construction area (Table I-19) + construction activities (Table I-20)

	Concentration (ug/m³)
Metals	
Antimony	1 78E-04
Barium	1 46E-06
Vanadium	3 61E-04
Zinc	5 22E-04
Radionuclides	
Americium-241	4 74E 13
Plutonium-239/240	4.20E-11
Uranium-233 234	1 47E-12
Uranium-238	5 22E-08

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TABLE 5 6-4
SUMMARY OF THE ANNUAL AVERAGE AIR CONCENTRATIONS DURING HEAVY CONSTRUCTION ACTIVITIES ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE WIND EROSION AT OU6 AOC NO 2

	Surface Soil Wind Erosion Annual Contaminant Air Concentration (ug/m³)	10 Acre Disturbed Construction Area Annual Contaminant Air Concentration (ug/m³)	Heavy Construction Activities Annual Contaminant Air Concentration (ug/m)
Semi-VOCs			
Benzo(a)pyrene		1 56E 10	1 31E-09
Benzo(b)fluoranthene		2 04E 10	1 72E-09
Metals			
Antimony	2 04E-06		
Barium		1 91E-07	1 61E 06
Silver	2 86E-07		
Vanadium	4 47E-06		
Zinc	9 95E 06		
Radionuclides			
Americium 241	4 46E 14	8 68E 18	7 33E 17
Plutonium 239/240	4 71E 1?	2 26E 15	1 91E 14
Uranium 233 234		1 52E 13	1 29E 12
Uranium 238		2 85E-09	2 40E-08

Surface soil (Table I 22) + 10 acre disturbed construction area (Table I 23) + construction activities (Table I 24)

	Concentration (ug/m³)
Semi VOCs	
Benzo(a)pyrene	1 47E-09
Benzo(b)fluoranthene	1 92E-09
Metals	
Antimony	2 04E 06
Barium	1 81E 06
Silver	2 86E-07
Vanadium	4 47E 06
Zinc	9 95E 06
Radionuclides	

TABLE 5.6-5
SOIL GAS TRANSPORT MODEL
AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
FOR A 30 ACRE SITE AT OU6 AOC NO 2

30-YEAR AVERAGE UHSU VOLATILE COMPOUND EMISSION RATES AT AN AMBIENT TEMPERATURE OF 30 DEG. C.

Compound	Diffusion Coeff. (cm^2/sec)	Soil Porosity (cm^3/cm^3)	Henry's Law Cst. (atm-m^3/g-mole)	Phase Trans Coeff. (cm^2/sec)	Groundwater Concentration (ug/L)	Site Surface Area (cm)	Soil Depth from the Surface to Under the UHSU Layer (cm)	Kd (cm^3/g)	Bulk Soil Concentration (ug/L)	Duration of Release (sec)
Chloroform	9 40E-02	1 00E-01	2.90E-03	5 09E-04	1 00E+00	1 22E+09	4 04E+02	4 40E-02	8 54E-02	4 30E+15
Methylene chloride	8 50E-02	1 00E-01	2.00E-03	3 17E-04	1 40E+01	1 22E+09	4.04E+02	9 00E-03	2.44E-01	1 41E+15
Tetrachloroethene	7 85E-02	1 00E-01	1 [illegible]8E-02	2 24E-03	3 00E+00	1 22E+09	4 04E+02	3 60E-01	2.10E+00	7 98E+15
Trichloroethene	8 61E-02	1 00E-01	9.10E-03	1 [illegible]6E-03	6 00E+00	1 22E+09	4.04E+02	1 50E-01	1.75E+00	5.10E+15

TOTAL VOLATILE COMPOUND EMISSION RATES AND RESULTANT SOIL GAS CONCENTRATIONS UNDER THE BUILDING ASSUMING EXCHANGE RATE OF ONLY 0.1% OF BUILDING VOLUME ABOVE

Compound	UHSU Emission Rate (g/sec)	Under Bldg. Flw Rt (m³/sec)	Result. Soil Gas Conc. (ug/m³)
Chloroform	2 46E-10	2 92E-05	8 42E+00
Methylene chloride	2 15E-09	2.92E-05	7 35E+01
Tetrachloroethene	3 25E-09	2 92E-05	1 11E+02

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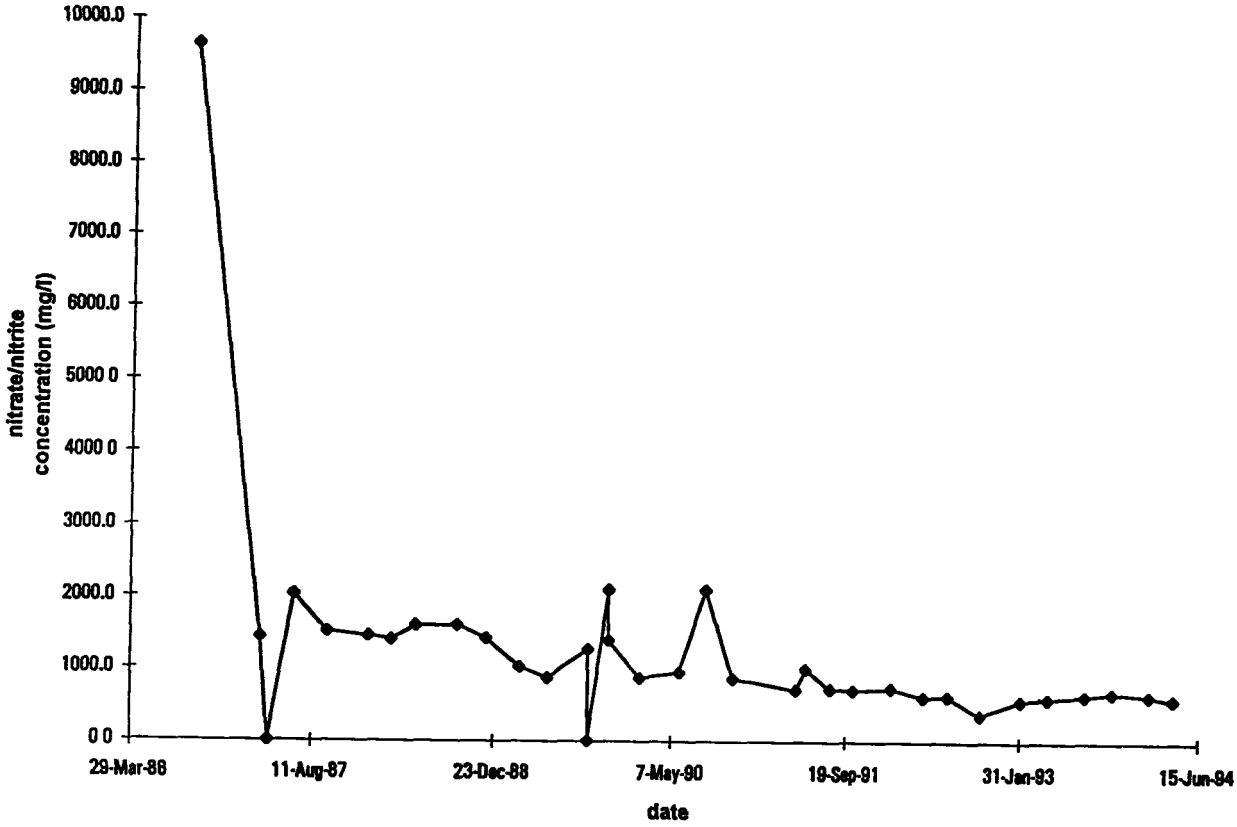

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WELL 3086 NITRATE/NITRITE
CONCENTRATION VS TIME

FIGURE 5 4-1

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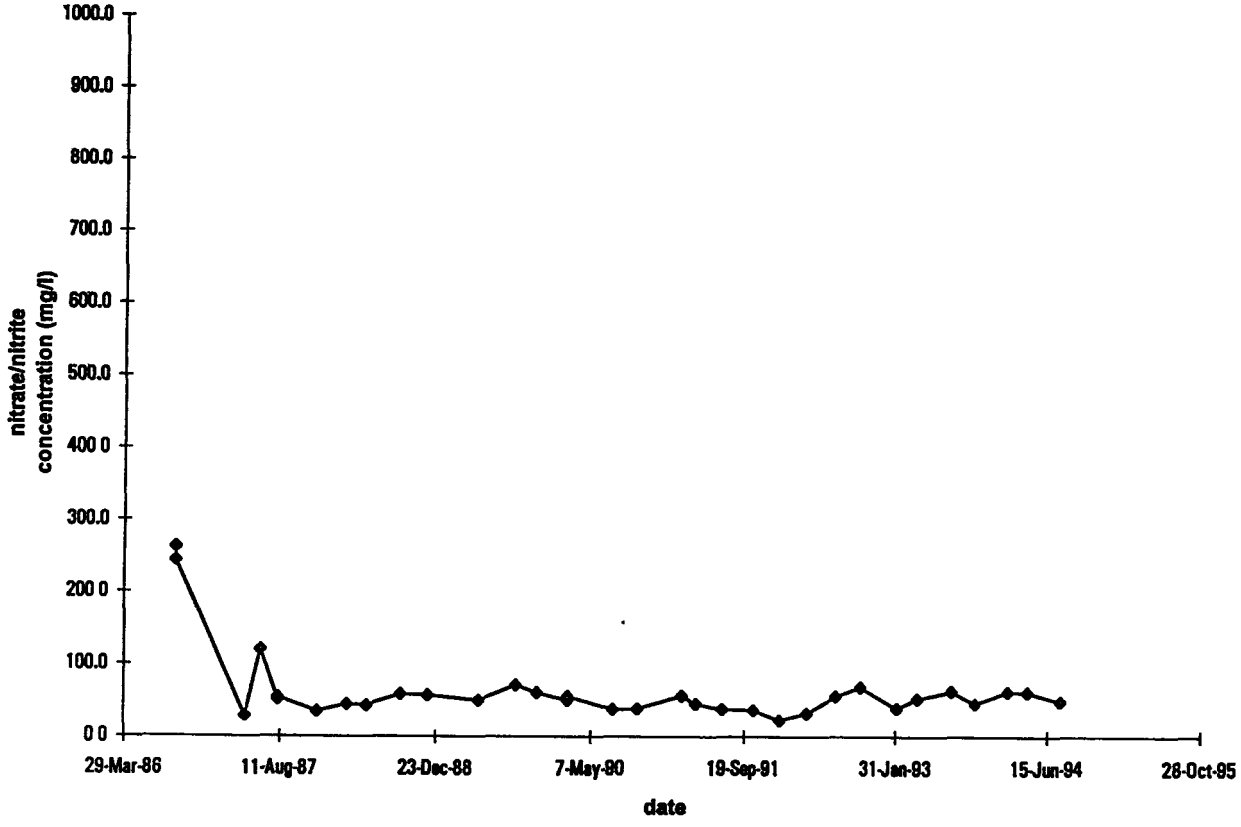

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WELL 1586 NITRATE/NITRITE
CONCENTRATION VS TIME

FIGURE 5 4-2

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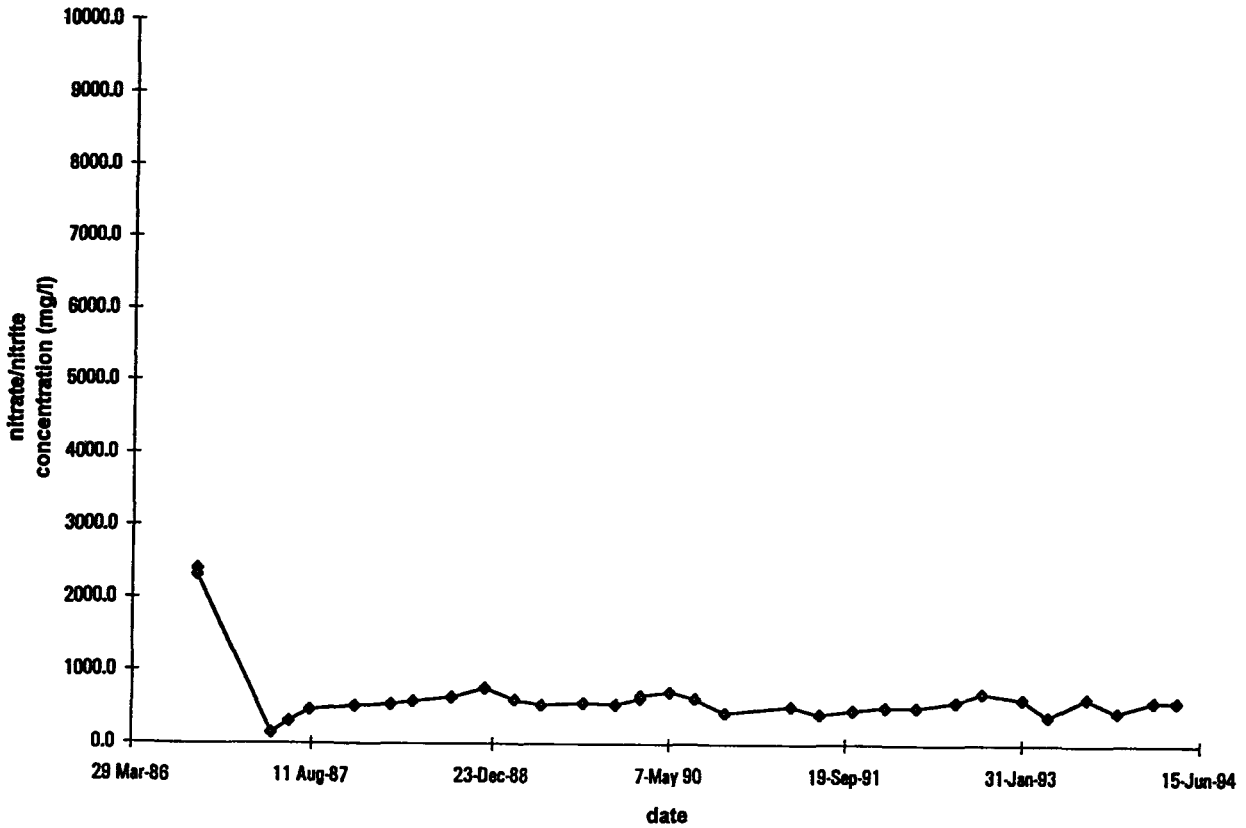

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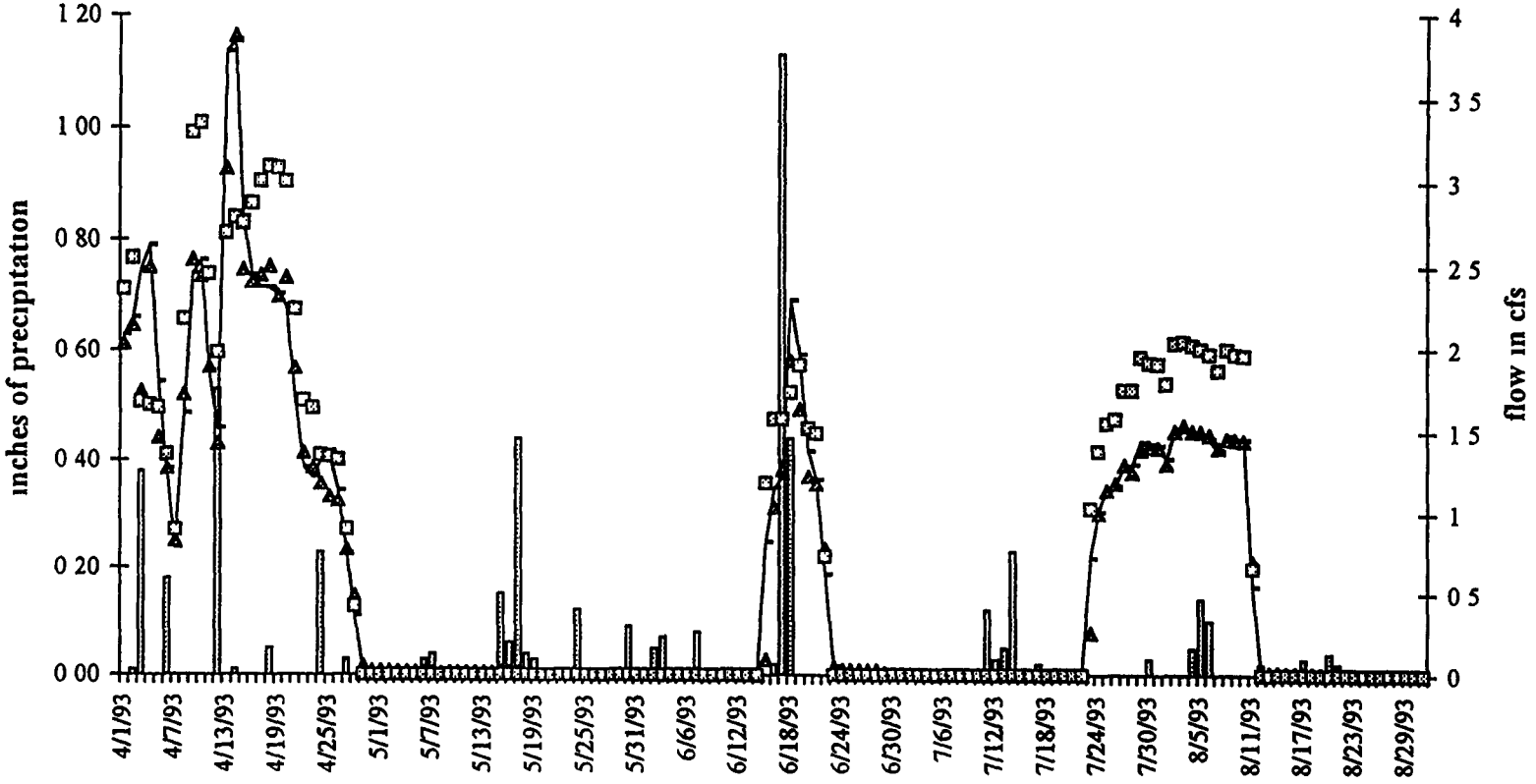
WELL 1786 NITRATE/NITRITE
CONCENTRATION VS TIME

FIGURE 5 4-3

APRIL 1995



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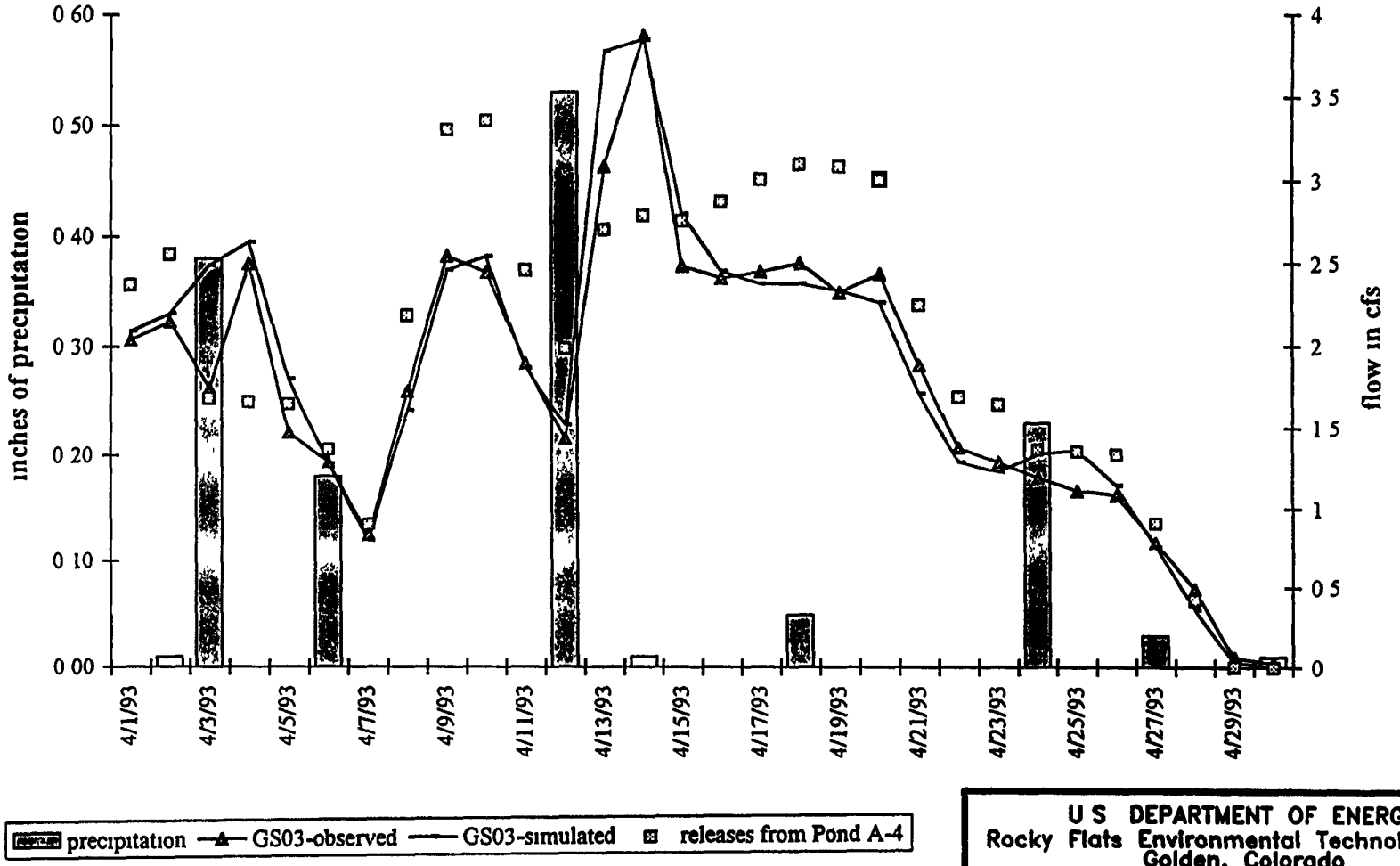
GS03 FLOWS – SIMULATED AND OBSERVED

FIGURE 5.5-1

APRIL 1995

OU6RI280 1=1



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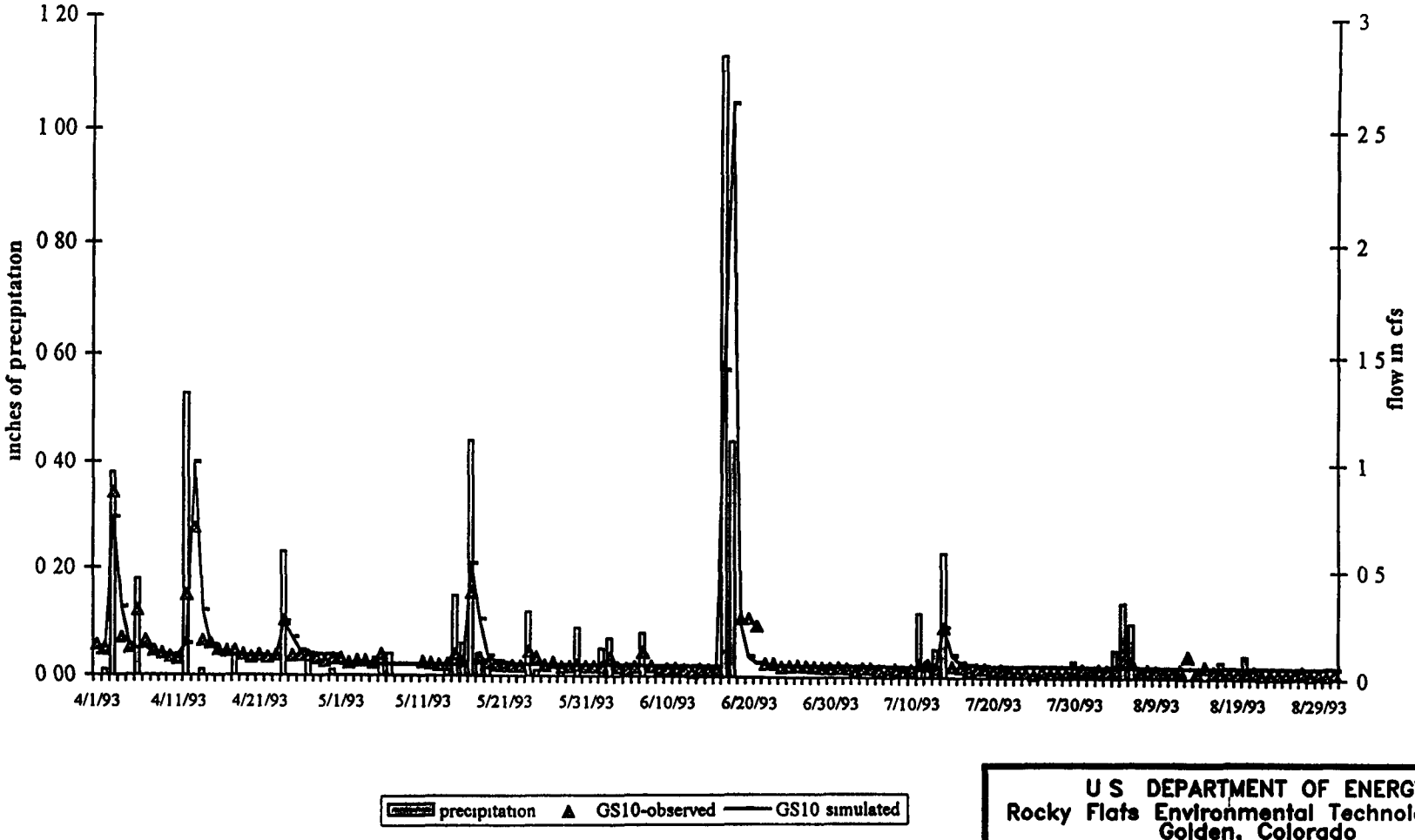
GS03 FLOWS IN APRIL
SIMULATED AND OBSERVED

FIGURE 5 5-2

APRIL 1995

OU6RI281 1=1



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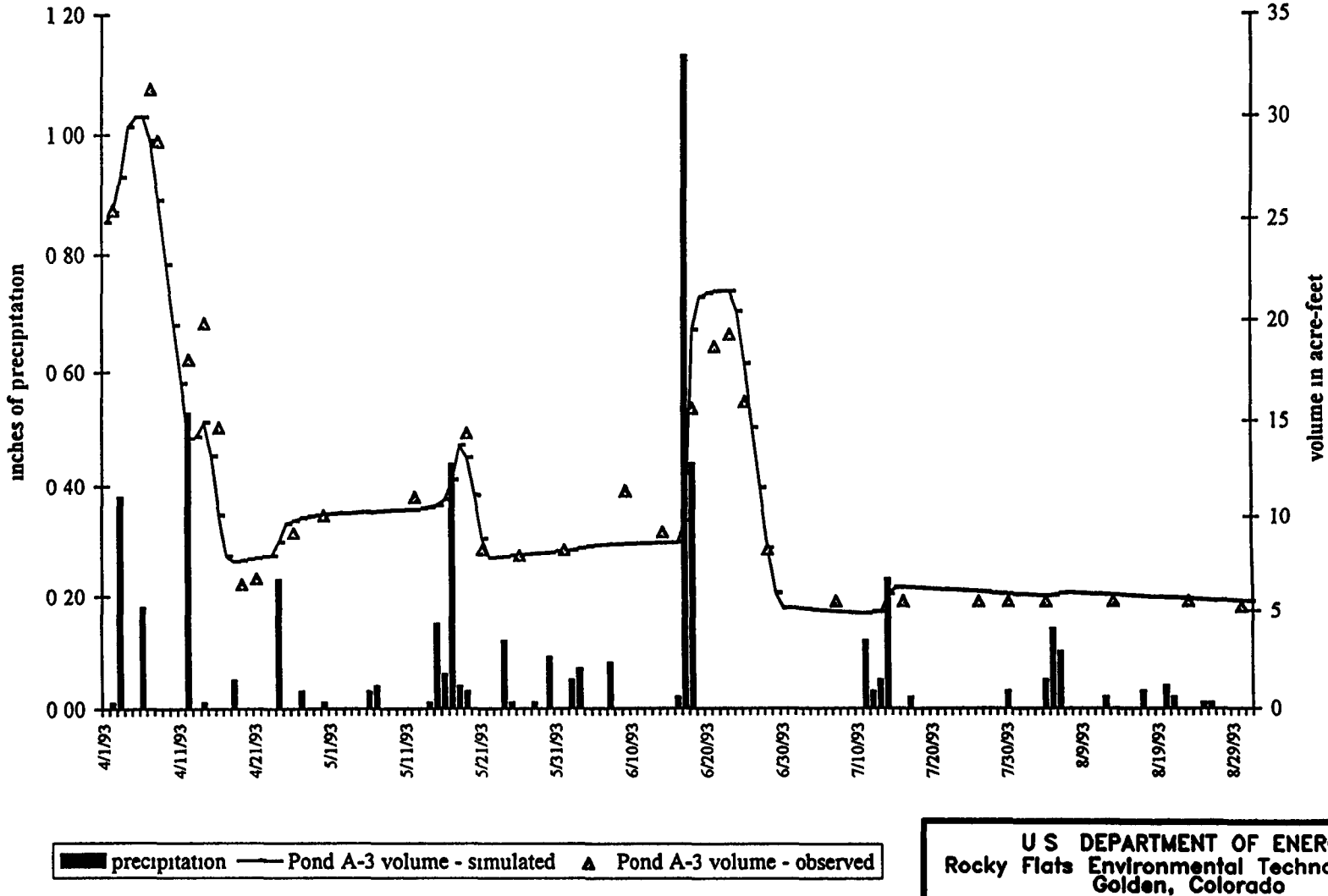
GS10 FLOWS - SIMULATED AND OBSERVED

FIGURE 5 5-3

APRIL 1995

OU6R282 1=1



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POND A3 VOLUMES
SIMULATED AND OBSERVED

FIGURE 5 5-4

APRIL 1995

OU6R1283 1=1

6 1 INTRODUCTION

This section summarizes the HHRA that was performed for OU6 at RFETS The complete HHRA is presented in Appendix J of this report

The HHRA was conducted as part of the Phase I RFI/RI Report for OU6 and is required by CERCLA (40 CFR 300 430) as part of the RI process The HHRA is intended to estimate the level of health risk from potential exposures to chemicals at or released from source areas within OU6 The estimate of health risk is used to support the determination of appropriate cleanup levels or other risk management measures in keeping with current and future land uses Health risks were estimated for both central tendency (CT) and reasonable maximum exposure (RME) conditions in keeping with EPA guidance (EPA 1989a, 1992b)

6 1 1 Site Description

This brief description of the site provides the context for delineation of exposure areas in Section 6 4 RFETS consists of an industrialized area of approximately 400 acres surrounded by an undeveloped buffer zone of about 6,150 acres OU6 consists of 20 Individual Hazardous Substance Sites (IHSSs) within the Walnut Creek Priority Drainage as well as the land area between the IHSSs (Figure 6 1-1) A detailed description of the site location general site conditions and description of the IHSSs were presented in Sections 1 0 and 3 0 of this report For reference the OU6 IHSS names and numbers are listed below

- Sludge Dispersal Area (IHSS 141)
- A-Series Ponds (IHSSs 142 1 142 2 142 3 and 142 4)
- B-Series Ponds (IHSS 142 5, 142 6 142 7, 142 8, and 142 9)
- Walnut and Indiana Pond (IHSS 142 12)
- Old Outfall Area (IHSS 143)
- Soil Dump Area (IHSS 156 2)
- Triangle Area (IHSS 165)

- Trenches A, B, and C (IHSSs 166 1, 166.2, and 166 3)
- North Spray Field and former South Spray Field Area (IHSSs 167 1 and former 167 3)
- East Spray Field Area (IHSS 216 1)

The HHRA does not evaluate potential risk at all of the IHSSs. Some IHSSs were removed from further evaluation based on findings presented in the CDPHE Source Area Delineation and Risk-Based Conservative Screen and EPA Areas of Concern Delineation Letter Report (DOE 1994a) The East Spray Field Area (IHSS 216.1), Walnut and Indiana Pond (IHSS 142 12), Pond A-4 (IHSS 142 4), and Pond B-5 (IHSS 142 9) were removed from further evaluation in the HHRA because concentrations of detected chemicals did not exceed criteria established in the CDPHE Risk-Based Conservative Screen. For the same reason, surface soil and subsurface soil in the former South Spray Field Area (former IHSS 167.3) and at Trenches A, B, and C (IHSS 166) were also removed from further evaluation in the HHRA, however, chemical constituents detected in the groundwater samples collected in those areas are expected to be evaluated under OU7 (Landfill) and are not included in this OU6 report The Old Outfall (IHSS 143 5), which is located inside the industrial area, is also not evaluated in this OU6 report because it is expected to be evaluated further in OU8, Industrialized Areas

6 1.2 Guidance Documents

The HHRA was performed using EPA guidance provided in Risk Assessment Guidance for Superfund (EPA 1989a, 1991a), Dermal Exposure Assessment: Principles and Applications (EPA 1992c), the Exposure Factors Handbook (EPA 1989b), and Guidance for Data Useability in Risk Assessment (Parts A and B) (EPA 1992d and 1992e) Other guidance documents and scientific literature were consulted as needed and are cited where used. In addition, letters and memoranda from EPA Region VIII and CDPHE provided recommendations for identification of potential receptors (exposed individuals), exposure areas, and chemicals of concern (COCs) Specific correspondence from EPA and CDPHE is cited in the relevant sections of the HHRA

Four technical memoranda were written in support of the HHRA These memoranda are TM No 2, Exposure Assessment (DOE 1995a), TM No 3, Model Description (DOE 1994b) TM

No 4 Chemicals of Concern (DOE 1994c) and TM No 5 Toxicity Assessment (DOE 1994e) These memoranda which were submitted to EPA and CDPHE and included in the OU6 workplan as appendixes provided the basis for performing the HHRA

6 1 3 HHRA Organization

The HHRA consists of the following sections which are summaries of the sections that appear in the full HHRA in Appendix J

6 2 Data Evaluation and Aggregation
6 3 Chemicals of Concern
6 4 Exposure Scenarios
6 5 Exposure Point Concentrations
6 6 Estimating Chemical Intakes
6 7 Toxicity Assessment
6 8 Risk Characterization
6 9 Radiation Dose Estimates
6 10 Uncertainties and Limitations
6 11 Summary and Conclusions

6 2 DATA EVALUATION AND AGGREGATION

This section provides a brief description of the development of the chemical analytical data set and data aggregation process used in the health risk assessment

6 2 1 Chemical Analytical Results Used in Risk Assessment

Chemical analytical data from environmental samples collected during the OU6 Phase I field investigation and from RFETS-wide sampling programs were used to characterize chemical constituents in OU6 and select COCs for risk assessment The samples and analytical programs followed approved work plans and chemical analytical results were validated in accordance with EPA and RFETS data validation guidelines Summaries of the work plan and the OU6 field investigations were presented in Sections 1 0 and 2 0 of this report Appendix E, Quality Assurance describes the chemical analytical database and additional data

review and cleanup (such as treatment of duplicate results) that were performed in establishing the final database used in the OU6 RFI/RI Report

The data sets used for evaluation of surface soil, subsurface soil, groundwater, pond sediment, pond surface water, and stream/dry sediment are described below

Surface Soil

Surface soil samples were collected using the RFP method (2-inch deep sample) Samples were collected during the third quarter of 1992 through the first quarter of 1993 Surface soil samples were collected at the Sludge Dispersal Area, Soil Dump Area, Triangle Area, North Spray Field Area, and East Spray Field Area The analytical parameters varied by location but generally included metals, radionuclides, nitrates, semivolatile organic compounds (SVOCs), pesticides, and PCBs All of the sampled areas were evaluated in the HHRA except for the East Spray Field Area, which is a candidate for no action based on the CDPHE Conservative Screen (DOE 1994a)

Subsurface Soil

Subsurface soil samples were collected during the fourth quarter of 1992 through the first quarter of 1993 Boreholes drilled for OU6 investigations were within or downgradient of IHSS boundaries established prior to the time of sampling However, boundaries of several IHSSs were slightly redefined after publication of the Historical Release Report (DOE 1992b) Two IHSSs had significant changes in boundary definition The South Spray Field Area (IHSS 167.3) was relocated further north, adjacent to the landfill pond (see Figure 6 1-1), the location sampled in OU6 is referred to as former IHSS 167.3 The location of Trench C East (IHSS 166 3) was also newly defined after the OU6 sampling was conducted

Subsurface soil samples were collected in 2- to 6-foot composites depending on sampling location Subsurface soil was sampled at the Soil Dump Area, Triangle Area, Trenches (A, B, and C), North Spray Field Area, former South Spray Field Area, and East Spray Field Area. The Soil Dump Area, Triangle Area, and North Spray Field Area were evaluated in the HHRA As stated above, the East Spray Field Area, former South Spray Field Area

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(former IHSS 167 3) and soil at Trenches A B and C were removed from further evaluation in the CDPHE Risk-Based Conservative Screen (DOE 1994a)

Laboratory analyses of subsurface soil samples generally included the following analytical groups volatile organic compounds (VOCs) semivolatile organic compounds (SVOCs) metals and radionuclides

Groundwater

Groundwater samples were collected from onsite monitoring wells on a quarterly basis under a plant-wide groundwater sampling program The plant-wide monitoring program included two monitoring wells installed during the OU6 Phase I investigation and wells installed during other investigations conducted from 1991 through 1993

Samples used for evaluation of chemical concentrations in OU6 groundwater were collected from the first quarter of 1991 through the fourth quarter of 1993 In general the groundwater samples were analyzed for VOCs SVOCs, pesticides/PCBs, metals, and radionuclides

Pond Sediment

Pond sediment samples were collected during the fourth quarter of 1992 as part of the plant-wide surface water sampling program Those samples were taken at a depth interval of 0-24" Each of the ponds was sampled at five locations In each pond one of the samples was collected within 5 feet of the inlet The second sample was collected from the deepest part of the pond The other three samples were collected at random locations within each pond Composite samples were collected from 2-foot intervals Samples were analyzed for VOCs SVOCs pesticides/PCBs, metals radionuclides and water quality parameters (WQPLs)

In 1994, additional pond sediment samples were collected at a depth of 0 to 6 inches near previously sampled locations and analyzed for PCBs and radionuclides These data are evaluated in Appendix J Attachment J5

Pond Surface Water

Pond surface water samples were collected from August to November of 1992 as part of the plant-wide surface water sampling program. Five surface water samples were collected from each of the ponds One of the five samples was collected within 5 feet of the inlet to each pond A second sample was collected from the deepest part of the pond. The third sample was collected within 5 feet of the spillway The two remaining samples were collected randomly in each pond Samples were analyzed for VOCs, SVOCs, pesticides/PCBs, metals, radionuclides, and WQPLs

Stream/Dry Sediment

Sediment samples from the stream channels of North and South Walnut Creeks were collected in May 1993 during the OU6 Phase I investigation Two-foot composite samples were collected using a 2-inch diameter core sampler with a hand driver. The samples were analyzed for VOCs, SVOCs, pesticides/PCBs, metals, radionuclides, and WQPLs

Dry sediment samples were collected in the floodplains of North and South Walnut Creeks in February 1993 The samples were collected using the RFP surface soil sampling method The samples were analyzed for SVOCs, pesticides/PCBs, metals, radionuclides, and WQPLs Results from both stream and dry sediment samples were used in evaluating potential exposure to exposed (i e not submerged) sediment in North and South Walnut Creeks Only results from samples collected upstream of Pond A-3 and Pond B-4 and east of the industrial area were used because (1) areas further downstream (i e, Ponds A-4, B-5 and the W&I Pond) were eliminated from further evaluation in risk assessment based on results of the CDPHE risk-based conservative screen (DOE 1994a) and (2) areas upgradient of the industrial area are not within OU6

6 2.2 Chemical Data Qualifiers

Chemical data qualifiers are letter codes attached to analytical results by the laboratory or validator to indicate possible problems with chemical identification, quantification, or source of contamination Use of qualified data in risk assessment depends on the type of qualifier Briefly all results above the SQL and estimated results were used as reported, U-qualified

results (analyte not detected above the SQL) were counted as nondetects B-qualified results for organics (analytes detected in corresponding laboratory blanks) were either used as reported or qualified nondetect following specified data validation and review procedures and R-qualified results (rejected during validation) were eliminated from the working data set R-qualified data were not used in risk assessment according to EPA guidance (EPA 1989a)

6 2 3 Data Aggregation for Risk Assessment

Data aggregation for risk assessment was performed in accordance with guidelines developed by CDPHE EPA Region VIII and DOE for application at RFETS (CDPHE/EPA/DOE 1994) First chemical source areas were identified on the basis of the spatial extent of chemical constituents The IHSSs within OU6 are (1) physically separated and (2) characterized by different types and origin of chemical constituents Therefore each IHSS was evaluated as an individual source area, with the exception of Trenches A, B, and C which were evaluated together as a single source area

Following the identification of possible contaminant source areas, Areas of Concern (AOCs) were delineated (DOE 1994a) AOCs were defined as one or several source areas that are in close proximity and can be evaluated as a unit in the HHRA As stated earlier the former South Spray Field Area, the East Spray Field Area, and soil at Trenches A B, and C were eliminated from further evaluation in the HHRA based on the results of the CDPHE Risk-Based Conservative Screen (DOE 1994a) Four AOCs were delineated in OU6 These are shown in Figure 6 2-1 and described below

- AOC No 1 is the North Spray Field Area This area is spatially separated from the other source areas evaluated in the HHRA

- AOC No 2 includes the Triangle Area, Sludge Dispersal Area, and Soil Dump Area These three source areas are in close proximity and represent the largest volume of potentially contaminated soil in OU6 Therefore, these source areas form a logical AOC for exposure and risk assessment and for evaluation of remedial alternatives if required

- AOC No 3 includes Ponds A-1, A-2, and A-3. These ponds all have similar chemical constituents in the pond sediment and are all in the North Walnut Creek Drainage, so they are hydrologically connected, therefore, they form a logical AOC for exposure and risk assessment and evaluation of potential remedial alternatives, if required Pond A-4 was removed from further evaluation based on the findings of the CDPHE Conservative Screen (DOE 1994a)

- AOC No 4 includes Ponds B-1, B-2, B-3, and B-4. These ponds have similar chemical constituents in the sediment and are hydrologically connected since they are in the South Walnut Creek drainage Pond B-5 and the W&I Pond were removed from further evaluation based on the findings of the CDPHE Conservative Screen (DOE 1994a).

In addition, within AOC No 2, a maximum exposure area of 30 acres was delineated for purposes of evaluating reasonable maximum risk to individuals in a future industrial or office park (30 acres)

Exposure concentrations used in the risk assessment were calculated for each media, in each AOC, using the results from all samples collected in that AOC

6.3 CHEMICALS OF CONCERN

COCs are metals and radionuclides that had concentration distributions in OU6 that differed significantly from background distributions and detected organic chemicals in soil, sediment, pond surface water, or groundwater in OU6 that are expected to contribute significantly to overall risk COCs, which are a subset of all chemicals detected in the field investigations, are selected for quantitative evaluation in the risk assessment and are the focus of transport modeling, risk assessment, and remedy selection (if warranted) This section describes the process for determining COCs in surface soil, subsurface soil, groundwater, pond sediment, pond surface water, and stream/dry sediment The process was developed and agreed upon by EPA, CDPHE, and DOE More detail is provided in the COC TM for OU6 (DOE 1994e)

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6 3 1 Process for Selecting OU-Wide COCs

COCs in each medium were determined on an OU-wide basis that is all sample results from each medium were pooled for the evaluation Risk-based and other screening methods were used to identify the chemicals that are likely to pose the greatest potential risks to human health The COC selection process is illustrated in Figure 6 3-1 and summarized in the sections below

Background Comparison Analytical results for metals and radionuclides detected in soil, sediment, groundwater and surface water in OU6 were compared to background levels using four statistical tests the Quantile test Slippage test, Student's t-test, and the Gehan test (Gilbert 1993) In addition, analytical results were compared to the 99th percentile upper tolerance limit ($UTL_{99/99}$) of the background data Any analyte that failed one or more of the statistical tests or that had one or more results exceeding the $UTL_{99/99}$ was retained as a potential COC A detailed description of the statistical methodology used in the background comparison and tables showing results of the statistical tests are presented in Appendix A of the COC TM for OU6 (DOE 1994c)

Essential Nutrients/Major Cations and Anions Calcium iron magnesium potassium and sodium were eliminated from further consideration as COCs because they are essential nutrients they occur naturally in the environment, and they are toxic only at very high doses Cyanide nitrate and nitrite were retained for further evaluation but other major cations and anions measured as water quality parameters such as carbonates were not evaluated

Frequency of Detection Metals with concentration distributions in OU6 that were significantly different from background distributions and detected organic compounds were evaluated for frequency of detection Chemicals that were detected at a frequency of 5 percent or greater were retained for further evaluation in concentration/toxicity screens to select OU-wide COCs Organic chemicals and metals that were detected at less than 5 percent frequency were evaluated separately as discussed below Radionuclides were assumed to be detected at 100 percent frequency for statistical analysis (i e , negative, zero and positive results were retained in the data set) thus the radionuclides were not screened based on frequency of detection

Professional Judgement Some analytes whose concentration distributions in OU6 were significantly different from background distributions based on results of the statistical tests were judged not to be potential OU6 contaminants based on temporal distribution, geochemical characteristics, the presence of high total suspended and dissolved solids in groundwater, or because their distribution was different from background but could not be considered to be above background. Analytes judged not to be potential OU6 contaminants were bis(2-ethylhexyl)phthalate, all metals, cesium-137, and strontium-89,90 in groundwater, manganese in pond sediment, uranium isotopes in pond surface water, and arsenic, barium, and manganese in stream/dry sediment

The evaluations and conclusions are described in detail in the COC TM for OU6 (DOE 1994c) However, to address concerns that some of these analytes, whether potential contaminants or not, could pose a health risk under long-term exposure to maximum detected concentrations, the following constituents were designated chemicals of interest (COIs) and were retained for consideration in a separate risk evaluation in the uncertainty section of the HHRA (CDPHE 1994, EPA Region VIII 1994, DOE 1994a)

- Groundwater arsenic, antimony, beryllium, and manganese
- Stream/dry sediment arsenic

Concentration/Toxicity Screens Concentration/toxicity screens were conducted separately for noncarcinogens, carcinogens, and radionuclides within each medium (surface soil, subsurface soil, groundwater, pond sediment, pond surface water, and stream/dry sediment) These screens were used to identify chemicals that, based on maximum concentrations and toxicity criteria, are likely to contribute 1 percent or more of the total potential risk in each category (noncarcinogens, carcinogens, and radionuclides) in each medium These chemicals were identified as COCs for evaluation in the quantitative risk assessment

Evaluation of Infrequently Detected Compounds Organic compounds and metals that were detected at less than 5 percent frequency in surface soil, subsurface soil, groundwater, pond sediment, and pond surface water are listed in tables accompanying Appendix J (Tables J3-3, J3-7 J3-12, J3-17, and J3-22) There were no infrequently detected compounds in stream/dry sediment For infrequently detected compounds, maximum concentrations were compared to screening levels equivalent to 1,000 times risk-based concentrations (RBCs) to determine

whether there was potential risk to human health on the basis of high concentrations and toxicity even though the chemicals were rarely detected and exposure potential was low RBCs were defined as chemical concentrations associated with an excess lifetime cancer risk of 1E-06 (1 in 1 million) or a hazard index of 1 for noncarcinogenic effects RBCs for chemicals in surface soil were calculated assuming residential exposure by ingestion of soil and inhalation of airborne particulates RBCs for chemicals in subsurface soil were calculated assuming construction worker exposure by soil ingestion and inhalation of particulates and VOCs RBCs for chemicals in groundwater were calculated assuming residential exposure by ingestion of water and inhalation of VOCs during water use The surface soil RBCs assuming residential exposure were used for comparison to chemical concentrations in pond sediment even though exposure to pond sediment would be much lower than exposure to soil The groundwater RBCs, assuming residential exposure, were used for comparison to pond surface water as a conservative measure even though the pond water is never expected to be used as a drinking water source

Infrequently detected chemicals whose maximum concentrations exceeded 1 000 times the RBC were retained as special-case COCs for separate evaluation in the risk assessment Only vinyl chloride in groundwater was identified as exceeding 1,000 times the RBC The risk-based evaluation of infrequently detected chemicals is described in detail in Appendix B of the COC TM for OU6 (DOE 1994c)

6 3 2 Summary of OU-Wide COCs

Table 6 3-1 summarized the OU-wide COCs identified in each medium For convenience they are also listed below

OU-WIDE CHEMICALS OF CONCERN

Surface Soil	Subsurface Soil	Groundwater
Antimony	Benzo(a)pyrene	Chloroform
Silver	Benzo(b)fluoranthene	Methylene chloride
Vanadium	Barium	Tetrachloroethene
Zinc	Americium-241	Trichloroethene
Americium-241	Plutonium-239/240	Nitrate
Plutonium-239/240	Uranium-233/234	Americium-241
	Uranium-238	Plutonium-239/240
		Radium-226

Pond Sediment	Pond Surface Water	Stream/Dry Sediment
Aroclor-1254	Chloroform	Benzo(a)anthracene
Benzo(a)pyrene	1,2-Dichloroethene	Benzo(a)pyrene
Benzo(b)fluoranthene	Di-n-butylphthalate	Benzo(b)fluoranthene
Bis(2-ethylhexyl)phthalate	Trichloroethene	Indeno(1,2,3-cd)pyrene
Antimony		Cobalt
Silver		Strontium
Vanadium		Vanadium
Americium-241		Zinc
Plutonium-239/240		Americium-241
		Plutonium-239/240

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COCs were identified using the process outlined in Section 6 3 1 Detection frequencies above 5 percent metals above background and concentration/toxicity screens are shown in Tables 6 3-2 through 6 3-4 (surface soil) Tables 6 3-5 through 6 3-8 (subsurface soil), Tables 6 3-9 through 6 3-12 (groundwater) Tables 6 3-13 through 6 3-16 (pond sediment) Tables 6 3-17 through 6 3-19 (pond surface water) and Tables 6 3-20 through 6 3-23 (stream/dry sediment) In the concentration/toxicity screens, analytes that contributed 1 percent or more of the total risk factor were identified as COCs

Additional pond sediment samples were collected in a separate sampling program in 1994 and were analyzed for PCBs and radionuclides These data are evaluated in Attachment J5 to the HHRA (Appendix J)

6 3 3 Chemicals without Toxicity Factors

Lead in surface and subsurface soil and in groundwater and copper in surface soil, pond sediment and groundwater exceeded background levels Because they do not have EPA-approved toxicity factors they cannot be evaluated quantitatively in toxicity-based screens In addition several organic compounds without EPA-approved toxicity factors were also detected in pond and stream/dry sediments These metals and organic compounds were retained for qualitative evaluation in the HHRA (Appendix J10 1 4)

6 3 4 Special-Case COCs

Vinyl chloride is not an OU-wide COC in groundwater because it was detected infrequently (in only 3 percent of groundwater samples collected in OU6) However, vinyl chloride was identified as a special case COC in groundwater because concentrations in one well exceeded 1 000 times the RBC of 2 8E-05 mg/l (1,000 x RBC = 0 03 mg/l) Vinyl chloride in groundwater is the only special-case COC in OU6

6 3 5 Chemical of Interest (COIs)

As mentioned previously all metals in groundwater were eliminated as contaminants and excluded from the concentration/toxicity screens because their presence in unfiltered samples was determined to be associated with local geochemical conditions and with high levels of

suspended solids in unfiltered samples (DOE 1994c) In fact, even typical rock-forming elements such as iron, potassium, and sodium were above background levels, and their concentrations in groundwater are most likely related to local geochemical characteristics and to suspended solids in the samples Even though metals in OU6 groundwater are probably not potential contaminants but rather are naturally occurring, parties to the IAG agreed to evaluate four metals (antimony, arsenic, beryllium, and manganese) as chemicals of interest (COIs) in groundwater (CDPHE 1994, EPA Region VIII 1994, DOE 1994g) Likewise, even though arsenic in stream/dry sediment does not appear to be above background, it was also agreed that it would be evaluated as a COI (DOE 1995) COIs were evaluated in the uncertainties section (Section 6 10 6).

6 4 EXPOSURE SCENARIOS

This section describes the receptors (exposed individuals), exposure areas, and exposure pathways that were evaluated quantitatively in the risk assessment. Exposure scenarios for OU6 are discussed in detail in Appendix J of this report and in the Exposure Assessment TM for OU6 (DOE 1995a) Exposure scenarios were identified for both current and future site uses

6 4.1 Current and Future Land Use

Table 6 4-1 summarizes the current patterns of land use on and near RFETS and categorizes future land use scenarios as (1) improbable (unlikely to occur) or (2) credible (could reasonably occur or is expected to occur) Receptors (exposed individuals) for evaluation in the HHRA were selected based on current onsite and credible future onsite land uses

Current Onsite Land Use Current activities in OU6 consist of environmental investigations, monitoring, cleanup, and routine security surveillance No industrial or commercial operations occur in OU6 The RFETS property is fenced and guarded, and trespassing does not occur

Future Onsite Land Use Probable future activities at RFETS include environmental restoration decontamination and decommissioning, economic development, and waste management EPA, CDPHE, and DOE, in keeping with recommendations of the Rocky Flats

Future Site Uses Working Group have agreed that future land use at RFETS will not include residential development (DOE 1995b EPA 1995b CDPHE 1995) Therefore residential development in OU6 is concluded to be improbable

The Rocky Flats Local Impact Initiative (RFLII 1992) is working with DOE and local economic development agencies to encourage business development at RFETS using new or existing facilities Commercial and industrial uses of developed portions of the site are considered beneficial Commercial development in undeveloped portions of the property has not been ruled out although preservation as open space is consistent with DOE policy and with the Jefferson County Planning Department's recommendations (Jefferson County 1990) Because of the undisturbed nature of the buffer zone and the presence of a rare species (Prebles meadow jumping mouse), onsite commercial or other development in the buffer zone may be precluded (DOE 1994h)

Onsite agricultural development is considered to be improbable because of the decline of agriculture in the Northeast Jefferson County area

In summary future onsite land use in OU6 will most likely be open space, although portions adjacent to or within the industrialized part of the plant could be developed for commercial use

Offsite Land Use Land adjacent to RFETS is lightly populated, with current use primarily open space and grazing A few residences and horse-boarding businesses are located east of RFETS The nearest resident is located across Indiana Street at the southeast corner of the property line Another nearby residence in the predominant wind direction (southeast) is located about 0 8 miles east of Indiana Street also near the southeast border of RFETS Small cattle herds graze seasonally in the fields near the site Commercial/industrial facilities such as the TOSCO laboratory and Great Western Inorganics Plant are located to the south Future offsite land use in areas adjacent to OU6 is likely to continue to be mixed (open space grazing commercial, and residential)

Current and future offsite receptors were not evaluated in the HHRA for OU6 because estimating effects from individual OUs would not address potential cumulative impacts to

offsite receptors from other sources at RFETS However, exposure of offsite receptors will be evaluated in a future site-wide risk assessment

6 4 2 Onsite Exposure Areas

Current and future onsite exposures were evaluated in four separate AOCs identified in OU6, which were described in Section 6 2 and shown in Figures 6 4-1 through 6 4-4

Area of Concern No. 1 AOC No 1 is the North Spray Field Area (IHSS 167 1) This source area forms a logical AOC because it is isolated from the other chemical source areas within OU6 The entire AOC is less than 10 acres (Figure 6 4-1)

Area of Concern No. 2 AOC No 2 includes the Triangle Area (IHSS 165), Soil Dump Area (IHSS 156 2), and the Sludge Dispersal Area (IHSS 141) These source areas form a logical AOC because they are in close proximity and have chemical constituents in the same media. The three IHSSs comprise approximately 50 acres (Figure 6 4-2)

Maximum Exposure Area in AOC No. 2 Within AOC No 2, a maximum exposure area of 30 acres was delineated This size is comparable to a hypothetical future industrial or office park and contains the highest levels of chemical constituents within AOC No 2, namely the Triangle Area and adjacent portions of AOC No 2 (Figure 6 4-2)

Area of Concern No. 3 AOC No 3 includes Ponds A-1, A-2, and A-3 and the associated stream segments Data from samples collected in these ponds and the interconnecting streams were used to estimate chemical exposure AOC No 3 is shown in Figure 6 4-3, it is approximately 50 acres in size

Area of Concern No. 4 AOC No 4 includes Ponds B-1, B-2, B-3, and B-4 and the associated stream segments Data from samples collected in these ponds and the interconnecting streams were used to estimate chemical exposure AOC No 4 is shown on Figure 6 4-4, it comprises approximately 50 acres

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In addition a separate evaluation of exposure to sediment in Ponds A-1, A-2, B-1, and B-2 using data from the 1994 pond sediment sampling program is presented in Attachment J5 to the HHRA (Appendix J)

6 4 3 Receptors Selected for Quantitative Risk Assessment

Receptors selected for quantitative evaluation in the HHRA are listed below As noted earlier receptors were identified based on current and credible future onsite land uses Offsite receptors were not evaluated in the HHRA for OU6 but are expected to be evaluated in a future site-wide risk assessment

Current Onsite Workers RFETS plant security workers who are assumed to spend a portion of their time in OU6 while conducting routine patrols in the buffer zone were evaluated for exposures in AOC No 1 and AOC No 2

Future Office Workers Future onsite office workers were evaluated for exposure in AOC No 1 and in the 30-acre maximum exposure area in AOC No 2 This receptor is the maximum exposed individual (has the highest potential exposure to chemicals and radionuclides) of all the current and future receptors evaluated

Future Ecological Researcher A future onsite ecological researcher, assumed to perform specific field research projects involving contact with surface soil, surface water, and sediments was evaluated in AOC No 1 (10 acres) and AOC No 2 AOC No 3 and AOC No 4 each of which are about 50 acres Fifty acres was defined by parties to the IAG as an appropriate-sized area for evaluating potential exposure of ecological researchers (DOE 1994a)

Future Open Space Recreational User An onsite open space exposure scenario developed to estimate risks from recreational use of open space areas at RFETS, was evaluated in AOC No 1 (10 acres) and in AOC No 2 AOC No 3 and AOC No 4 each of which are about 50 acres

Future Construction Worker A future onsite construction worker, assumed to contact subsurface soil during excavation activities associated with construction of commercial buildings, was evaluated in AOC No 1 and AOC No 2

6 4 4 Exposure Pathways

Potentially complete exposure pathways for each receptor are listed in Table 6 4-2 and shown in the conceptual site model (CSM) in Figure 6 4-5

The CSM is a schematic representation of the chemical sources, chemical release mechanisms, environmental transport media, human intake routes, and human receptors for OU6 A complete exposure pathway requires a chemical source, chemical release mechanism, environmental release medium, exposure point, and human intake route If one of these elements is lacking, the pathway is incomplete and no human exposures can occur Incomplete pathways were not evaluated in the HHRA

Potentially complete pathways include all pathways for which human exposure is possible, no matter how trivial A potentially complete pathway was not assessed when, based on professional judgement and logic, the contribution of the pathway to overall exposure is likely to be orders of magnitude lower than exposure from other pathways These potentially complete pathways are unlikely to have any bearing on mathematical estimations of total risk to receptors and therefore were not evaluated in the HHRA. The following exposure pathways are incomplete or potentially complete but not assessed for all receptors

- Ingestion of fish in Walnut Creek (incomplete)
- Ingestion of livestock (potentially complete but not assessed)
- Ingestion of homegrown garden produce (incomplete)
- Groundwater ingestion and dermal contact (incomplete)
- Inhalation of VOCs released to outdoor air through volatilization from soil or groundwater (potentially complete but not assessed)

- Dermal uptake of metals and radionuclides from soil and sediment (potentially complete but not assessed)

Site-wide incomplete pathways and pathways that were potentially complete but not assessed are discussed further in Appendix J of this report and in the Exposure Assessment TM for OU6 (DOE 1995a)

6 5 EXPOSURE POINT CONCENTRATIONS

Exposure point concentrations of COCs were calculated for each exposure area and exposure medium (surface soil, subsurface soil, groundwater, air, pond sediment, pond surface water, stream/dry sediment) evaluated in the risk assessment. The exposure point concentration of a chemical in a sampled medium (soil groundwater sediment, or surface water) is usually the 95 percent upper confidence limit (95% UCL) on the arithmetic mean The 95% UCL on the mean is an estimate of the average concentration to which people could be exposed over time in the exposure area Sometimes the maximum detected concentration is used as the exposure concentration if the data set does not permit a good estimate of the mean This can occur with small data sets or in data sets with a high frequency of nondetects If the calculated 95% UCL concentration exceeded the maximum detected concentration, the maximum was used as the exposure concentration (EPA 1989a) For convenience in this report the 95% UCL or maximum concentration is referred to as the reasonable maximum exposure (RME) concentration RME concentrations of COCs were used in estimating risk for both the central tendency (CT) and RME exposure scenarios

6 5 1 Calculating the Concentration Term

Tables 6 5-1 through 6 5-6 summarize the exposure concentrations of COCs in surface soil, subsurface soil groundwater pond sediment, pond surface water and stream/dry sediment for each exposure area evaluated in the HHRA Attachment J1 to Appendix J shows the analytical results used in the calculations In calculating exposure concentrations from chemical analytical results one-half the sample quantitation limit (SQL) was used to represent the concentration in samples that were validated "nondetect" for a chemical provided that the chemical was detected in at least one other sample in the data set (EPA 1989a) An exception to this rule is when the SQL is unusually high due to sample dilution The SQL

for diluted samples can far exceed the measured concentrations of the chemical in other samples These samples were excluded from the data set if they caused the arithmetic mean concentrations to exceed the maximum detected concentration

The same principle was applied when a compound was detected in very few samples and only at estimated quantities below the CRQL If using one-half the CRQL for nondetects caused the arithmetic mean concentrations to exceed the maximum reported concentration, those nondetect samples were excluded from the data set

Attachment J1 to Appendix J contains tables showing all analytical results in the data sets and the calculation of 95% UCL concentrations for COCs in the sampled media The 95% UCL concentrations were calculated based on either a normal or lognormal distribution, as appropriate In some cases, the calculation of the 95% UCL based on a lognormal distribution gave an unreasonable result (e g, a value much higher than the maximum observation), even though the data appear to fit a lognormal distribution These cases were most common for small data sets and for larger data sets that had a range of several orders of magnitude between the minimum and maximum observations When unreasonable results were obtained, other values (either the maximum concentration or the 95% UCL based on a normal distribution) were used as the exposure concentration for risk assessment These cases were noted in Tables 6.5-1 through 6 5-6 and are discussed in Attachment J1

6.5.2 Surface Soil

Table 6 5-1 summarizes the RME concentrations of COCs in onsite surface soil in each exposure area COCs are antimony, silver, vanadium, zinc, Am-241, and Pu-239/240 Exposure point concentrations were calculated for AOC No 1, AOC No 2, and the 30-acre maximum exposure area in AOC No 2

6.5.3 Subsurface Soil

RME concentrations of COCs in subsurface soil are summarized in Table 6 5-2 The subsurface soil concentrations were used to estimate health risks associated with construction worker exposures Exposure concentrations were calculated for AOCs No 1 and No 2, where future construction activities were assumed to occur

6 5 4 Groundwater

Groundwater in OU6 is not ingested and is not expected to be used as a drinking water source in the future therefore, exposure concentrations for ingestion of groundwater were not calculated (except for COIs evaluated in Section 6 10 7) However exposure to groundwater COCs via inhalation of VOCs migrating into a future office building was evaluated in AOC No 2 (there is no measurable groundwater in AOC No 1) Maximum concentrations of volatile COCs in groundwater are summarized in Table 6 5-3 These concentrations were used as conservative source concentrations for soil gas modeling and estimating basement air concentrations in a building (future office worker exposure)

6 5.5 Pond Sediment

RME concentrations of COCs in pond sediment are summarized in Table 6 5-4 The pond sediment concentrations were used to estimate health effects associated with incidental ingestion and dermal contact by ecological workers and open space recreational users Exposure concentrations of antimony Am-241 and Pu-239/240 which are COCs in surface soil were modeled assuming transport from surface soil in storm runoff (see Table 6 5-13 and Section J5 10)

Additional pond sediment samples were collected in a separate sampling program in 1994 These data are evaluated in Attachment J5 to Appendix J

6 5 6 Pond Surface Water

RME concentrations of COCs in pond surface water are summarized in Table 6 5-5 The pond surface water concentrations were used to estimate health effects associated with incidental ingestion and dermal contact with surface water by ecological workers and open space recreational users In addition although they are not COCs in surface water concentrations of antimony Am-241 and Pu-239/240 transported from surface soil in storm runoff were also estimated (Table 6 5-13 and Section 6 5 10)

6.5 7 Stream/Dry Sediment

RME concentrations of COCs in stream/dry sediment are summarized in Table 6 5-6 The RME concentrations were used to estimate health risks associated with incidental ingestion, dermal contact, and inhalation of airborne particulates by ecological workers and open space recreational users RME concentrations were calculated for AOCs No 3 and No 4

6.5.8 Air Concentrations from Wind Erosion of Surface Soil

Tables 6 5-7 through 6 5-9 summarize the modeling results for onsite air concentrations of COCs associated with PM_{10} released by wind erosion of surface soil The air modeling approach and results are presented in detail in Appendix I Onsite air concentrations from wind erosion of surface soil were estimated using the Ventilated Valley Dispersion Model, a box model that is often used to estimate ambient air concentrations in the immediate vicinity of an emission source. The box model incorporates a site-specific wind erosion emission rate for PM_{10} and other site-specific variables

The modeling was performed using 5 years of meteorological data (1989 to 1993) to yield five different estimates of annual average PM_{10} concentrations Air concentrations of COCs were calculated by multiplying the PM_{10} concentration by the chemical concentration in surface soil The maximum of the five estimated annual average air concentrations was used as a conservative estimate of the exposure point concentration in the risk assessment

6.5 9 Onsite Air Concentrations from Construction Activities

Tables 6 5-10 and 6 5-11 summarize the estimated air concentrations of COCs adhered to airborne PM_{10} at potential future construction sites in AOC No 1 and AOC No 2 In the construction scenario, three air emission sources were evaluated (1) wind erosion of surface soil in the AOC, (2) wind erosion of subsurface soil in a 10-acre excavation site, and (3) emission during heavy construction (earth moving) Emissions from construction activities were estimated using a standard equation for heavy construction from AP-42 (EPA 1993), and wind erosion was evaluated using the box model described earlier The exposure point concentrations are the sum of air concentrations resulting from wind erosion of surface soil,

wind erosion of subsurface soil and heavy construction activities Wind erosion of surface soil has the largest effect on the estimated air concentrations

6 5 10 Basement Air

Table 6 5-12 summarizes the exposure point concentrations of COCs in basement air from migration of VOCs from groundwater through a building foundation The modeling approach and results are presented in detail in Appendix I Maximum detected concentrations were used as conservative source concentrations in the modeling

6 5 11 Modeled Surface Water and Sediment

Exposure concentrations of antimony, Am-241 and Pu-239/240 in pond sediment and pond surface water were modeled in order to evaluate future impacts of these surface soil COCs assuming they were transported from surface soil to the ponds in storm runoff A comprehensive mathematical model the Hydrological Simulation Program - FORTRAN (HSPF) (Bicknell et al 1993) was developed and applied to the Walnut Creek watershed OU6 potential contaminant sources in the watershed are surface soils and in-situ stream and pond sediment Groundwater loads were not considered a significant source and were not included in the model (see discussion in Section 5) VOCs detected in pond water samples were also not modeled because their concentrations are low and fate and transport processes such as volatilization, would render their concentration negligible over an exposure duration of several years Instead measured concentrations of VOCs in pond water were used as exposure point concentrations in risk assessment (see Section 6 5 6)

The potential for resuspension and migration of in-situ pond and stream sediment was estimated to be very low, even under extreme flow conditions, according to a conservative screening-level evaluation discussed in Attachment A of Appendix H Therefore migration of sediment out of the A- and B- series ponds is not expected Furthermore concentrations of sediment COCs will not increase in the future because chemical concentrations in OU6 soils are lower than current concentrations in pond sediment

Only future receptors (ecological researchers and open space recreational users) are assumed to be exposed to pond sediments To estimate future sediment concentrations following

migration from surface soil, migration, and deposition of the three potentially most hazardous COCs in surface soil (antimony, Am-241, and Pu-239/240) were modeled. For purposes of the HHRA, the model was used to generate 30 simulations of 30-year average concentrations of each modeled COC in newly deposited sediment and in surface water in each of the A- and B-series ponds and in selected stream segments The sediment concentration terms used in risk assessment were depth-weighted averages of RME concentrations in existing and newly deposited sediment, assuming 15 years of deposition (one-half the total deposition time evaluated) These concentrations represent the reasonable maximum estimates of the average concentrations during a 30-year exposure duration

Table 6 5-13 summarizes the depth-weighted exposure concentrations of antimony, Am-241, and Pu-239/240 in sediment and surface water in the A- and B-series ponds after 15 years of deposition For simplicity, the maximum concentrations derived from the model were used in the risk assessment The surface water and pond sediment concentrations were used to estimate health risk associated with surface water and sediment ingestion and dermal exposure by future ecological researchers and future open space recreational users Concentration terms for other COCs in pond sediment and surface water were derived from sampling results (i e, they were not modeled) and were described in Sections 6 5 4 and 6 5 5

6.6 ESTIMATING CHEMICAL INTAKES

Chemical intake is expressed in terms of milligram chemical ingested, inhaled, or dermally absorbed per kilogram body weight per day (mg/kg-day) Intake of radionuclides is expressed simply in terms of pCi total intake Intakes were estimated following guidance in Risk Assessment Guidance for Superfund (EPA 1989a), the Exposure Factors Handbook (EPA 1989b), other EPA guidance documents, relevant scientific literature, and professional judgement regarding probable site-specific exposure conditions Intakes were based on reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, frequency and duration of exposure, and chemical concentration.

6 6 1 General Intake Equation

The general equation for calculating chemical intake in terms of mg/kg-day is

$$\text{Intake} = \frac{\text{chemical concentration x intake rate x exposure frequency x exposure duration}}{\text{body weight x averaging time}}$$

with corresponding units of

$$\text{mg/kg-day} = \frac{\text{mg/volume or mass x volume or mass/day x day/year x year}}{\text{kg x day}}$$

The variable "averaging time" is expressed in days to calculate daily intake For noncarcinogenic chemicals the averaging time is equivalent to the exposure duration, expressed in days yielding an average daily dose during the exposure period For carcinogens the averaging time is a 70-year lifetime, expressed as 25 550 days, yielding "lifetime average daily intake" (EPA 1989a) Intake of carcinogens is averaged over a lifetime because according to some scientific opinion and EPA policy, a high dose received over a short period of time is equivalent to a corresponding low dose received over a lifetime, and even very low doses of carcinogens are assumed to have the potential to cause cancer (i e it is assumed that carcinogens do not have a threshold dose below which adverse effects do not occur) Therefore the lifetime daily intake of a carcinogen is estimated by averaging over a 70-year lifetime

Intake of radionuclides was calculated using equations similar to those for calculating intake of chemicals Intake of radionuclides by either ingestion or inhalation is a function of radionuclide activity concentration intake rate (or the amount of contaminated medium contacted per unit time or event) and exposure frequency and duration The only difference between calculating intake for radionuclides and nonradioactive substances is that averaging time and body weight are excluded from the intake equations for radionuclides

6 6.2 Pathway-Specific Intake Equations and Exposure Factors

Chemical intakes were estimated for CT and for RME conditions, as recommended by EPA (EPA 1992b) The CT is estimated by selecting average values for exposure variables The RME is estimated by selecting values for exposure variables so that the combination of all variables results in the maximum exposure that can reasonably be expected to occur at the site

The Exposure Factor Tables in Attachment J2 show the equations used to calculate intake for each exposure route and the numerical values for CT and RME exposure factors for each receptor and exposure pathway Exposure factors warranting further explanation are discussed below

6 6.3 Age-weighted Soil Ingestion Rate

Both child and adult soil ingestion rates were evaluated in the open space recreational use exposure scenario For noncarcinogens, child and adult soil ingestion were evaluated separately, using the equation and values listed in Attachment J2 This approach yields separate hazard indexes for children and adults for the soil ingestion exposure route The separate hazard index for children is a more protective estimate of potential noncarcinogenic hazard for this age group because it accounts for the greater amount of soil ingested by children relative to body weight and the possibility of toxic effects occurring from the higher dose

For carcinogens, a combined child and adult weighted ingestion rate was calculated, combining the soil ingestion rates, body weights, exposure frequency, and exposure duration for both age groups. Separate cancer risks for children are normally not calculated because it is thought that higher doses over a short exposure period have comparable carcinogenic potential to a lower dose received over a longer exposure period Age-adjusted soil ingestion rates for carcinogenic chemicals are explained in Table 6 6-1

6 6 4 Chemical-Specific Exposure Factors

Several exposure parameters listed in the Exposure Factors Tables in Attachment J2 are chemical-specific These are discussed below

Soil Matrix Effect The soil matrix effect describes the reduced bioavailability of a chemical constituent bound to a soil matrix (or other solid such as food) compared to the same chemical constituent in solution For COCs in soil whose toxicity factors were derived from studies in which the agent was administered in solution, a soil matrix factor of 0 5 was used in calculating chemical intake for risk assessment Chemical-specific soil matrix effects for COCs in soil are listed in Table 6 6-2 The matrix effect of 0 5 is a conservative value derived from a review of literature summarized in Table 6 6-3 Further discussion is provided in Appendix J Section J6 6 The matrix effects were applied to ingestion of COCs in soil and sediment

Absorption Factors The absorption factor is a chemical-specific value describing the fraction of organic chemical in soil that is absorbed by the skin Table 6 6-4 lists the values and sources for absorption factors used in this risk assessment Dermal absorption of radionuclides and metals (other than mercury) is considered negligible because they are not absorbed well across the skin (EPA 1989a, 1991b) Therefore dermal uptake of radionuclides and metals was considered negligible and was not evaluated in this risk assessment

Permeability Constants Permeability constants are chemical-specific factors that describe the rate at which dissolved (aqueous-phase) chemicals permeate the skin Absorption of metals and radionuclides adhered to suspended sediment was assumed to be negligible and was not evaluated Permeability constants for organic contaminants in surface water are listed in Table 6 6-4

6 7 TOXICITY ASSESSMENT

Tables 6 7-1 6 7-2 and 6 7-3 present the reference concentrations (RfCs), reference doses (RfDs) cancer slope factors (SFs) and radionuclide dose coefficients that were used to estimate noncarcinogenic health hazards cancer risks and annual radiation doses These factors are established by EPA for use in CERCLA risk assessments RfCs and RfDs can be

considered to be exposure levels or doses at which no adverse effects are expected to occur even to sensitive subpopulations under long-term exposure conditions RfCs and RfDs incorporate a number of safety factors to ensure that they are protective of the health of sensitive subgroups (e g , children and the elderly) For purposes of estimating cumulative risk from multiple exposure routes, RfCs (expressed as air concentrations in mg/m^3) were converted to RfDs (expressed as doses in terms of mg/kg body weight per day) SFs, expressed as risk per mg/kg-day intake, are upperbound estimates of the cancer dose-response relationship and are likely to overestimate actual carcinogenic potency Dose coefficients can be multiplied by radionuclide intake to estimate equivalent dose, which can then be compared to a radiation protection standard

Oral toxicity values were used to estimate effects from dermal absorption of organic chemicals Additional discussion regarding the derivation, conservative features, and use of EPA toxicity factors is available in Appendix J, Section J7 0

6.8 RISK CHARACTERIZATION

Risk characterization is the final step of the risk assessment process In this step, the toxicity factors (RfDs and SFs) for the COCs are applied in conjunction with estimated chemical intakes to predict noncarcinogenic and carcinogenic health risks to exposed individuals

6.8 1 Hazard Index for Noncarcinogenic Effects

The potential for noncarcinogenic effects is characterized by comparing estimated chemical intakes with chemical-specific RfDs The resulting ratio is called a hazard quotient (HQ) It is derived in the following manner

$$\text{Noncancer Hazard Quotient} = \frac{\text{Chemical Intake (mg/kg-day)}}{\text{RfD (mg/kg-day)}}$$

Use of the RfD assumes that there is a level of intake (the RfD) below which it is unlikely that even sensitive individuals will experience adverse health effects over a lifetime of exposure If the average daily intake exceeds the RfD (that is, if the HQ exceeds 1), there may be cause for concern for potential noncancer effects (EPA 1989a) It should be noted,

however that the level of concern does not increase linearly as the RfD is approached or exceeded This is because all RfDs are not assessed equally accurate and are not based on the same severity of toxic effects Since the HQ does not define a dose-response relationship, its numerical value cannot be construed as a direct estimate of risk (EPA 1986)

To assess exposures to multiple chemicals, the HQs for each chemical are summed to yield an HI per receptor per pathway The assumption of additive effects reflected in the HI is most properly applied to substances that induce the same effect by the same mechanism (EPA 1986) Consequently, summing HQs for substances that are not expected to induce the same type of effect could overestimate the potential for adverse effects The HI provides a measure of the potential for adverse effects but it is conservative and dependent on the quality of experimentally derived evidence

If an individual may be exposed by multiple pathways, the HIs from all relevant pathways are summed to obtain the total HI for that receptor If the total HI is less than or equal to 1 multiple-pathway exposures to COCs at the site are judged unlikely to result in an adverse effect If the sum is greater than 1 further evaluation of exposure assumptions and toxicity, including consideration of specific target organs affected and mechanisms of toxic actions of COCs is warranted to ascertain if the cumulative exposure would in fact be likely to harm exposed individuals

6 8 2 Carcinogenic Risk

Potential carcinogenic effects are characterized in terms of the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen Excess lifetime cancer risk is estimated from the projected lifetime daily average intake and the cancer SF, which represents an upperbound estimate of the dose-response relationship Excess lifetime cancer risk is calculated by multiplying the average daily chemical intake by the cancer SF as follows

$$\text{Cancer Risk} = \text{Chemical Intake (mg/kg-day)} \times \text{SF (mg/kg-day)}^{1}$$

EPA states that carcinogenic risks estimated using SFs are upperbound estimates This means that the actual risk is likely to be less than the predicted risk (EPA 1989a) RME cancer risks

could be significantly overestimated because they are generally calculated by multiplying together 95th percentile estimates of cancer potency, 95% UCLs of concentrations, and high-end estimates of several exposure parameters

The risks resulting from exposure to multiple carcinogens are assumed to be additive The total cancer risk is estimated by summing the risks estimated for each COC and for each pathway This is a highly conservative approach that results in an artificially elevated estimate of cancer risk, especially if several carcinogens are present, because 95th percentile estimates are not strictly additive (EPA 1989a)

EPA policy must be considered in order to interpret the significance of the cancer risk estimates In the National Oil and Hazardous Substances Pollution Contingency Plan (EPA 1990d), EPA states that "For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper-bound lifetime cancer risk of between 10^{-4} and 10^{-6}" Additionally, where cumulative carcinogenic risk to an individual based on RME exposure is less than 10^{-4} and the total HI does not exceed 1, action is generally not warranted for protection of public health (EPA 1991c)

6.8.3 AOC No 1

AOC No 1 is the North Spray Field Area (IHSS 167 1), which is less than 10 acres in areal extent Hazard/risk results for current and future receptors evaluated in AOC No 1 are summarized in Table 6 8-1 and detailed in Attachment J3 in Appendix J

Noncarcinogenic Hazard Index The cumulative HIs for noncarcinogenic health effects for current and future onsite receptors in AOC No 1 are 0 01 or less for the CT and RME conditions (Table 6 8-1) Because the HIs are less than 1, no adverse noncancer health effects are expected under the exposure conditions evaluated

Carcinogenic Risk Excess lifetime cancer risk estimates for current and future onsite receptors in AOC No 1 are summarized in Table 6 8-1 and detailed in Attachment J3 in Appendix J Excess lifetime cancer risk estimates for all receptors in AOC No 1 were 5E-08 or less, which is below EPA's target risk level of 1E-06 (1 in 1,000,000) to 1E-04 (1 in

10 000) for exposure to chemicals released from hazardous waste sites (EPA 1989a), indicating negligible risk for all receptors

6 8 4 AOC No 2

AOC No 2 includes the Sludge Dispersal Area, Triangle Area, and Soil Dump Area and is approximately 50 acres in areal extent Hazards/risks for future office workers were evaluated in a 30-acre maximum exposure area in AOC No 2, which includes all of the Sludge Dispersal Area, the Triangle Area, and approximately half of the Soil Dump Area All other receptors were assumed to be exposed to the entire area Hazard/risk results for all receptors in AOC No 2 are summarized in Table 6 8-2, and detailed in Attachment J3 in Appendix J

Noncarcinogenic Hazard Index For all current and future onsite receptors the cumulative HIs for noncarcinogenic health effects in AOC No 2 are 0 01 or less for the average and RME conditions indicating that no adverse noncancer health effects are expected under the exposure conditions evaluated

Carcinogenic Risk For current and future onsite receptors the estimated excess lifetime cancer risks in AOC No 2 are less than 1E-06 (Table 6 8-2) indicating that cancer risks are negligible for all receptors

6 8 5 AOC No 3

AOC No 3 includes Ponds A-1, A-2, and A-3 and the interconnecting stream segments AOC No 3 is approximately 50 acres in areal extent Hazard/risk results for the future receptors exposed to AOC No 3 are summarized in Table 6 8-3 and detailed in Attachment J3

Noncarcinogenic Hazard Index The cumulative HIs for noncarcinogenic health effects for future onsite receptors in AOC No 3 are 0 03 or less for the average and RME conditions (Table 6 8-3) therefore no adverse noncancer health effects are expected under the exposure conditions evaluated

Carcinogenic Risk Excess lifetime cancer risk estimates for future onsite receptors in AOC No 3 are summarized in Table 6 8-3 and detailed in Attachment J3 of Appendix J Estimated cancer risks did not exceed 1E-06 for either receptor, indicating negligible risk

6.8 6 AOC No 4

AOC No 4 includes Ponds B-1, B-2, B-3, and B-4 and the interconnecting stream segments. AOC No 4 is approximately 50 acres in areal extent Hazard/risk results for the future receptors exposed to AOC No 4 are summarized in Table 6.8-4 and detailed in Attachment J3

Noncarcinogenic Hazard Index The cumulative HIs for noncarcinogenic health effects for future onsite receptors in AOC No 4 are 0 1 or less for the average and RME conditions (Table 6 8-4) therefore, no adverse noncancer health effects are expected under the exposure conditions evaluated

Carcinogenic Risk Excess lifetime cancer risk estimates for future onsite receptors in AOC No 4 are summarized in Table 6 8-4 and detailed in Attachment J3 of Appendix J Estimated cancer risks were 6E-06 or less. These levels are within the EPA target cancer risk range of 1E-06 to 1E-04 for exposure to chemicals released from hazardous waste sites (EPA 1989a)

6.8 7 1994 Pond Sediment Samples

In a separate sampling program in 1994, pond sediment samples were collected from Ponds A-1, A-2, B-1, and B-2 (Attachment J5) A risk evaluation for exposure of ecological researchers and open space recreational users is presented in Attachment J5 to Appendix J Cumulative HIs were below 1 and RME cancer risks were 9E-06 or below for open space recreational users and ecological researchers exposed to sediments These estimates support previous risk results for AOC No 3 and AOC No 4, indicating no unacceptable risk for receptors exposed to pond sediment in OU6

6 8 8 Summary of Cumulative Hazard/Risk Results

Hazard/risk characterization was performed for five onsite receptors in four AOCs in RFETS OU6 Results are summarized in Tables 6 8-1 through 6 8-4 and detailed in Attachment J3 in Appendix J

Cumulative HIs were less than 1 and cancer risk estimates were below 6E-06 for all receptors and exposure scenarios Cancer risk estimates using 1994 pond sediment data from Ponds A-1 A-2 B-1 and B-2 were 9E-06 or below These levels are within EPA guidelines and suggest that further action to reduce risk may not be warranted

6 8 9 Evaluation of Health Hazards from Potential Exposure to Lead in OU6

Lead was detected in greater than 5 percent of surface soil, subsurface soil, and groundwater samples in OU6 Lead does not have an EPA-established toxicity factor so risks cannot be quantitatively evaluated In this section the potential for health hazards from exposure to lead in soil and groundwater are discussed

Surface Soil Concentration distributions of lead in surface soil in OU6 were not different from background distributions according to statistical background comparisons However, four sample results from surface soil exceeded the background $UTL_{95,95}$ of 61 4 mg/kg EPA's Revised Interim Soil Lead Guidance recommends a screening level of 400 ppm (400 mg/kg) for residential scenarios (EPA 1994b) The maximum detected concentration of lead in surface soil in OU6 (68 7 mg/kg) was far less than EPA's screening level for residential soil indicating that no further action is required based on lead in surface soil

Subsurface Soil Concentration distributions of lead in subsurface soil in OU6 were not different from background distributions according to statistical background comparisons However, two sample results from subsurface soil exceeded the background $UTL_{95,95}$ of 31 mg/kg The maximum detected concentration of lead in subsurface soil in OU6 (84 9 mg/kg) was far less than EPA's screening level for residential soil (400 mg/kg) indicating that no further action is required based on lead in subsurface soil (EPA 1994b)

Groundwater Statistical background comparison showed that lead was above background levels in unfiltered groundwater samples but not in filtered groundwater samples The maximum concentration of lead in filtered groundwater (3 4 µg/L) did not exceed the federal standard for tap water (15 µg/L) TSS in unfiltered groundwater samples were much higher than in background samples, and therefore unfiltered groundwater samples collected in OU6 had elevated levels of numerous metals, including lead, that are associated with suspended solids in the samples Based on comparing the concentrations of lead in unfiltered and filtered samples, lead in unfiltered groundwater in OU6 is not considered to be a site contaminant, but rather the result of high TSS in the samples This is consistent with the elimination of all metals in unfiltered groundwater as OU-wide COCs (see Section 6 3 1) In addition, exposure to lead in groundwater is an incomplete pathway for all receptors in OU6 because groundwater from OU6 is neither used nor is it expected to be used in the foreseeable future

6 9 RADIATION DOSE CALCULATIONS

Total radiation doses for one year of exposure (expressed as total effective dose equivalents, in mrem/year) were estimated for receptors exposed to radionuclides in soil, air, and other media by the ingestion, inhalation, and external irradiation pathways The estimated doses were compared to DOE radiation standards for protection of public health, also expressed in mrem/year (DOE 1990c)

6 9 1 Calculating Annual Radiation Doses

Ingestion and Inhalation Routes of Exposure For the inhalation and ingestion routes of exposure, annual intake of the radionuclide, expressed in pCi/year, is first calculated using the following equation

$$Intake_{ai} = C * IR * EF$$

where

$Intake_{int}$	=	Annual radionuclide intake via inhalation or ingestion (pCi/yr)
C	=	Activity concentration of a radionuclide at the exposure point (pCi/m^3 pCi/L or pCi/g)
IR	=	Intake rate (m^3/day, L/day, or kg/day)
EF	=	Exposure frequency (days/year)

Exposure factors used in calculating annual radionuclide intake for specific receptors and pathways are presented in Attachment J2 The annual intake of each radionuclide in pCi/year was multiplied by the committed effective dose coefficient (mrem/pCi) from Table 6 7-3 to estimate the committed effective dose equivalent (CEDE) for one year of exposure (mrem/year)

External Irradiation For the external irradiation route of exposure an areal activity concentration in soil (pCi/m^2) adjusted for a gamma shielding factor is first calculated

$$AC = C * \frac{10^3 g}{kg} * SD * D * (1-Se)$$

where

AC	=	Areal activity concentration in soil, adjusted for a gamma shielding factor (pCi/m^2)
C	=	Mass activity concentration of a radionuclide at the exposure point (pCi/g soil)
SD	=	Soil density at RFETS (1 84E+03 kg/m^3)
D	=	Soil depth (0 0508m) (2 inches)
Se	=	Gamma shielding factor (unitless)

Exposure factors used in calculating annual radionuclide intake for specific receptors and pathways are presented in Attachment J2 The areal activity concentration of each radionuclide in soil was multiplied by the number of hours of exposure per year to obtain the annual external irradiation exposure as indicated in the following equation

$$EI = AC * TE * EF * CF$$

where

EI	=	Annual external irradiation exposure (pCi-hr/m^2-year)
AC	=	Areal activity concentration (pCi/m^2)
Te	=	Gamma exposure time factor (fraction of day)
EF	=	Exposure frequency (days/year)
CF	=	Conversion factor (24 hr/day)

The annual irradiation exposure was then multiplied by the effective dose coefficient for external irradiation (mrem/hr per pCi/m^2) (Table 6.9-1) to estimate the effective dose equivalent (EDE) for each radionuclide for one year of exposure (mrem/year)

Estimating Annual Radiation Dose. Total effective dose equivalents (TEDEs) are equal to the sum of CEDEs and EDEs for all radionuclides and all exposure pathways. Total annual radiation dose is equal to the TEDE for one year of exposure and can be compared to annual radiation protection standards

Annual radiation doses were estimated for all receptors and exposure areas (Attachment J4), results are summarized and compared to radiation protection standards in the following subsections

6 9 2 Radiation Protection Standards

The DOE occupational limit for radiological workers is 50 mSv/year (5,000 mrem/year) (DOE 1993g) The DOE annual radiation dose limit for members of the public is 1 mSv/year (100 mrem/year) for all routes of exposure (DOE 1990c) The occupational limit for general employees (i e, those not considered to be radiological workers) may be 100 or 5,000 mrem/year depending on employment circumstances These values are for radiation doses received in addition to that from natural background radiation (estimated in the Denver area to range from 350 to 700 mrem/year, NCRP 1987) and that received from routine medical treatments (U S average is approximately 50 mrem/year, NCRP 1987) The 100 mrem/year

limit for members of the public is the level used for comparison to radiation doses estimated for receptors evaluated in OU6

6 9.3 Radiation Dose Estimates

Annual radiation doses, in terms of TEDE for one year of exposure, were estimated for five onsite receptors in four AOCs in RFETS OU6 Onsite receptors are current workers future office workers, future ecological workers, future open space users, and future construction workers Results are summarized in Table 6 9-1 through 6 9-4 and detailed in Section J9 0 and Attachment J4

Exposure pathways included ingestion of soil, surface water and sediments inhalation of airborne particulates and external irradiation

Radiation dose calculations for AOC No 1 are summarized in Table 6 9-1 Estimated annual radiation doses were 0 02 mrem or lower for all receptors evaluated in AOC No 1 These doses are below the DOE limit of 100 mrem/year for protection of public health and 5 000 mrem/year for radiological worker exposure

Radiation dose calculations for AOC No 2 are summarized in Table 6 9-2 Total annual radiation doses were 0 1 mrem/year or less for all onsite receptors in AOC No 2, indicating that exposure to radionuclides in AOC No 2 is negligible

Radiation dose calculations for AOC No 3 are summarized in Table 6 9-3 Total annual radiation doses were 0 06 mrem/year or less for both future onsite receptors in AOC No 3, indicating that exposure to radionuclides in AOC No 3 is negligible

Radiation dose calculations for AOC No 4 are summarized in Table 6 9-4 Total annual radiation doses were 0 6 mrem/year or less for both future onsite receptors in AOC No 4 indicating that exposure to radionuclides in AOC No 4 is negligible

6 10 UNCERTAINTIES AND LIMITATIONS

Uncertainties and limitations are inherent in the risk assessment process The level of certainty associated with the conclusions of the risk assessment are conditional upon the quality of data and models used to identify COCs and estimate chemical concentrations, the assumptions made in estimating exposure conditions, the conservatism of the methods used to develop toxicity values, and the conservatism of methods used to characterize risk At all stages of this risk assessment, reasonable conservative assumptions were made that tend to result in an overestimate of potential risk

Uncertainties specific to the human health risk assessment for OU6 lie chiefly in the identification of COCs, the estimation of exposure point concentrations, the media not evaluated, the assumptions regarding human exposure scenarios at RFETS, and toxicity assessment Each of these are discussed below

6 10.1 Identification of COCs

The screening process used to select a subset of chemicals for evaluation in the risk assessment was intended to include all compounds with concentrations high enough to cause a concern for potential health hazards The screening process included a background comparison for inorganic analytes, a frequency test (analytes detected at less than 5 percent frequency were excluded as OU-wide contaminants because exposure potential is minimal), and concentration/toxicity screens that evaluate relative contribution to overall risk based on maximum detected concentrations

Concentration/toxicity screens have the potential for eliminating chemicals that could contribute significantly to overall risk if the relative magnitude of maximum concentrations differs from the relative magnitude of exposure concentrations (95% UCLs of the mean) However, the selection process was sufficiently conservative so that potentially significant sources of health risk were not overlooked, as illustrated in the following examples In subsurface soil, barium was the only analyte identified as a noncarcinogenic COC based on the results of the concentration/toxicity screen Of those potential COCs excluded by the screen, vanadium had the highest combination of maximum concentration and toxicity However, at its maximum concentration, vanadium would result in an RME HI of only 0 005,

indicating that vanadium and other compounds excluded by the screen would have contributed insignificantly to overall noncarcinogenic risk from exposure to potential COCs in subsurface soil Similarly in pond sediment benzo(a)anthracene was excluded by the screen but the incremental cancer risk associated with the maximum concentration of benzo(a)anthracene (5E-08) is insignificant compared to overall cancer risk from ingestion of pond sediment (3E-06)

6 10 2 Exposure Point Concentrations

The chief uncertainties in estimating exposure point concentrations of COCs lie in the numerical estimate of an average exposure concentration and in the modeling assumptions used to estimate concentrations in air surface water, and sediment The uncertainties can result in either an underestimate or overestimate of the concentration terms for risk assessment however conservative approaches were taken so as not to underestimate average exposure concentrations for the exposure scenarios being evaluated in risk assessment

For example concentration terms were either the 95% UCLs of the mean (normal or lognormal distribution) or the maximum detected concentrations The 95% UCL is used rather than the arithmetic mean concentration to provide an additional level of conservatism in accounting for the uncertainties involved in estimating the true mean from a relatively small data set Uncertainty related to small sample size variability in sample results extreme values and accounting for negative or zero values usually results in a high rather than a low bias to the estimate and therefore is not expected to result in an underestimation of exposure or risk

Modeling input parameters were based on conservative assumptions that were expected to result in conservative (protective) estimates of exposure concentrations for risk assessment Examples of conservative modeling parameters include (1) conservative estimates of mixing heights for onsite box models conservative estimates of emission rates during construction and use of maximum annual average air concentrations for COCs as exposure point concentrations for air modeling (2) use of maximum modeled concentrations for pond sediment and surface water concentrations and (3) use of maximum VOC concentrations in groundwater and conservative estimates of transport through soil and building foundations for estimating "basement air" concentrations of VOCs

6 10.3 Media Not Evaluated

As discussed in Section J1 4, IHSSs Evaluated in the HHRA, and in Section J3 4 2, Groundwater COCs Evaluated in the HHRA, groundwater near Trenches A, B, and C that appears to contain constituents related to potential releases from the Landfill (OU7) were not evaluated in the OU6 HHRA because potential groundwater contamination in this area is expected to be evaluated in OU7 and OU6 IHSSs are not the source of the detected analytes in groundwater In addition, nitrates detected in some wells upgradient of the A-series ponds were not evaluated in the HHRA, primarily because the source of the plume is in OU4 (Solar Ponds) Therefore, potential migration of nitrates cannot be quantitatively evaluated because source concentrations necessary for modeling cannot be defined based on OU6 sampling data. Furthermore, ingestion of groundwater was not a complete exposure pathway for any exposure scenario evaluated under current or future use conditions

6 10 4 Exposure Scenarios and Pathways

The chief uncertainty in the exposure assessment is future land use at RFETS Because of the uncertainty in future land use, several possible scenarios were developed, including onsite commercial ecological research, open space recreational, and construction scenarios Therefore, the uncertainty in future land use and exposure conditions is addressed by the range of scenarios evaluated.

6 10.5 Toxicity Assessment

Toxicity values derived by EPA are conservative upperbound estimates of potential toxicity or carcinogenicity of chemicals, and their use in risk assessment tends to result in an overestimate of potential risk Several detected chemicals do not have EPA-established toxicity factors and could not be evaluated quantitatively in the risk assessment Some of the chemicals were detected at low frequency and many were detected at low concentrations Lead, copper, dibenzofuran, and a few PAHs were detected at high frequency or at high concentrations in various media but do not have EPA established toxicity values Each were evaluated qualitatively and are not expected to contribute to underestimation of risk

For example concentrations of lead in surface and subsurface soil were lower than EPA's screening level of 400 mg/kg for residential scenarios indicating that lead in surface soil would not be expected to pose a health risk Maximum copper concentrations in surface soil were comparable to maximum concentrations of other metals in surface soil Because inorganic COCs in surface soil did not result in unacceptable risk and because copper is generally considered to have relatively low toxicity in humans, it is unlikely that exposure to copper in surface soil would result in unacceptable risk PAHs in subsurface soil, pond sediment and stream/dry sediment that did not have toxicity values are probably less toxic than benzo(a)pyrene Because benzo(a)pyrene did not pose an unacceptable risk to any receptors in these media, it is unlikely that PAHs without toxicity values would pose an unacceptable risk

6 10 6 Evaluation of Risk Associated with Special-Case COCs

Special-case COCs are compounds that were infrequently detected (<5 percent) but that exceeded 1 000 times the RBC Vinyl chloride in groundwater was the only special-case COC in OU6 Cancer risk that would be associated with ingestion of vinyl chloride in groundwater was evaluated using residential exposure assumptions even though residential development is not a reasonable or expected future use scenario Cancer risks were estimated using vinyl chloride concentrations in the only well where vinyl chloride was detected (well 3586) Cancer risk estimates were 4E-04 (CT) and 1E-02 (RME), which exceed the EPA target risk range of 1E-06 to 1E-04 Vinyl chloride in that well would pose unacceptable risk to humans if ingested daily for many years However vinyl chloride was not detected in any other well nor in any medium such as surface water that is downgradient of the contaminated well Since onsite use of groundwater is unlikely under any of the assumed exposure scenarios current and future receptors will not likely be exposed to vinyl chloride in groundwater

6 10 7 Evaluation of Risk Associated with Chemical of Interest (COIs)

Chemicals of interest (COIs) are compounds that are probably not environmental contaminants (i e the are probably naturally occurring) but were retained for separate consideration because of their potential toxicity at environmental levels

Metals in groundwater in OU6 Hazard/risk results for hypothetical residential ingestion of COIs in OU6 groundwater are shown in Table 6 10-1 The HIs were 1 (CT) and 9 (RME) Manganese contributed most to the total HIs HQs for other metals were near or less than 1 Cancer risk estimates were 4E-06 (CT) and 1E-04 (RME) These estimates are within EPA's target risk range of 1E-06 to 1E-04 (1 in 1 million to 1 in 10,000) Both arsenic and beryllium contributed significantly to the total cancer risk estimates

As a comparison to risk estimates for metals in unfiltered OU6 groundwater samples and to help support the conclusion drawn in the COC TM (DOE 1994c) that metals in OU6 groundwater are naturally occurring, hazard/risk levels were also estimated for hypothetical residential ingestion of background levels of arsenic, antimony, beryllium, and manganese in unfiltered groundwater Total HIs for noncarcinogenic health effects were 0 3 and 3 0 for the CT exposure and RME conditions respectively (Table 6 10-1) HQs for antimony, arsenic, and beryllium in background are very similar to those in OU6, whereas HQs for manganese were lower in background samples than in OU6 However, differences in manganese concentrations in groundwater from OU6 and background wells are attributable to geochemical differences, not environmental contamination, because OU6 groundwater wells were located in areas with high concentrations of natural manganese and iron, whereas background wells were located in areas with relatively low concentrations of manganese and iron

The lifetime excess cancer risks associated with ingesting background concentrations of arsenic and beryllium in groundwater are 8E-06 (8 in 1 million) and 2E-04 (2 in 10,000) for the CT exposure and RME conditions, respectively Thus, RME cancer risk from exposure to COIs in groundwater at background levels exceeds that from exposure to COIs in OU6 groundwater

Hazard/risk estimates from hypothetical residential exposure to naturally occurring (background) levels of metals in groundwater exceed EPA target levels for health hazard indexes and cancer risk Similar hazard/risk levels were estimated for COIs in groundwater in OU6, suggesting that COIs in groundwater samples in OU6 are naturally occurring and are not due to environmental contamination

Arsenic in stream/dry sediment Arsenic in stream/dry sediment occurs in concentrations comparable to background levels and appears to be naturally occurring (DOE 1994a) Nevertheless because of special concerns regarding arsenic toxicity, hazard indexes and cancer risk associated with exposure to arsenic in stream/dry sediment were evaluated for the open space recreational use exposure scenario The total HI for exposure to arsenic in OU6 stream/dry sediment was well below 1, and the cancer risk estimate was 3E-07, indicating negligible risk to recreational users Hazard/risks were also calculated for exposure to background levels of arsenic The total HI at background concentrations was also well below 1 and the cancer risk estimate was 2E-07 In conclusion, arsenic concentrations in OU6 stream/dry sediment and background locations are similar and hazard/risk results are similar Arsenic is not considered a site contaminant in OU6

6 11 SUMMARY AND CONCLUSIONS

6 11 1 Summary

The HHRA for RFETS OU6 estimated health risks and annual radiation doses for current and future onsite receptors who could be exposed directly or indirectly to COCs at or released from sources in OU6 COCs were identified as the chemicals metals or radionuclides in soil or groundwater that were likely to contribute at least 1 percent of overall risk The COCs with the largest contribution to risk were Am-241 and Pu-239/240 in surface and pond sediment and Aroclor-1254 in pond sediment

Exposure scenarios evaluated were a current worker (security patrol), a future office worker a future ecological researcher, a construction worker, and a future open space recreational user

Exposure media evaluated were surface soil, subsurface soil (construction worker only), outdoor and indoor air pond sediment pond surface water and stream/dry sediment

Risks were estimated for four AOCs in OU6 AOC No 1 is the North Spray Field Area AOC No 2 includes the Sludge Dispersal Area Triangle Area and Soil Dump Area AOC No 3 includes Ponds A-1 A-2 and A-3 AOC No 4 includes Ponds B-1 through B-4 In addition risks for the future office worker were evaluated in a 30-acre maximum exposure

area in AOC No 2 and risks for the future open space recreational user and ecological worker exposed to sediment in Ponds A-1, A-2, B-1, and B-2 were evaluated using 1994 pond sediment sampling data.

Annual radiation doses in terms of mrem/year were also estimated for comparison to national radiation standards.

The risk characterization process combines average and reasonable maximum estimates of exposure with upperbound estimates of toxicity to yield conservative (protective) estimates of health risk Estimates of health risk for average (CT) and RME conditions are provided so that risk management decisions can be based on a range of potential risk for different exposure scenarios

Results of the risk assessment can be described as follows

- AOC No 1 and AOC No 2 Cumulative HIs were below 1 and RME cancer risk estimates were below EPA's target risk range 1E-06 to 1E-04 for all receptors These results indicate that no adverse noncarcinogenic health hazards and negligible cancer risks are expected for all receptors evaluated

- AOC No 3 and AOC No 4 Cumulative HIs were below 1 and RME cancer risk estimates were 6E-06 or below for both receptors The maximum cancer risk estimate of 6E-06 for the open space user is within EPA's acceptable risk range of 1E-06 to 1E-04 Ingestion of maximum modeled concentrations of Am-241 and Pu-239/240 in pond sediment over a 30-year exposure duration for open space use is the chief contributor to this estimate of cancer risk Given the conservatism of using maximum concentrations and a 30-year exposure duration, the RME cancer risk estimates for recreational open space exposure to the ponds very likely overestimate potential risk The results indicate that there is negligible risk for these receptors

- 1994 pond sediment samples Cumulative HIs were below 1 and RME cancer risk estimates were 9E-06 or below for both receptors These estimates

support risk results for AOC No 3 and AOC No 4 indicating no unacceptable risk for receptors exposed to pond sediment in OU6

- Estimates of annual radiation doses for onsite receptors were less than 0 6 mrem/year, well below the DOE standard of 100 mrem/year for protection of the public

- Background and OU6 levels of COIs in unfiltered groundwater (antimony arsenic beryllium and manganese) would pose unacceptable risk if directly ingested

- Vinyl chloride in groundwater in well 3586 (evaluated as a special-case COC) would pose unacceptable risk if directly ingested

6 11 2 Conclusions

The maximum RME cancer risk estimates were 6E-06 for a future open space recreational user in AOC No 4 and 9E-06 for a future open space recreational user exposed to Ponds B-1 and B-2 (1994 pond sediment samples Attachment J5) Cancer risk estimates for all other receptors and exposure areas were at or below 1E-06 HIs were below 1 for all receptors

Estimated annual radiation doses for onsite receptors were less than 0 6 mrem/year well below the DOE standard of 100 mrem/year for protection of the public

In general cancer risk levels that do not exceed 1E-04 combined with HIs that do not exceed 1 may be used to support a decision that remediation is not warranted for the protection of public health (EPA 1991c) These results suggest that remediation of exposure media evaluated in the OU6 HHRA (surface soil subsurface soil A- and B-series ponds and adjacent stream segments) may not be necessary for protection of public health

TABLE 6 3-1
SUMMARY OF CHEMICALS OF CONCERN

	Surface Soil	Subsurface Soil	Groundwater	Pond Sediment	Pond Surface Water	Stream/Dry Sediment
Aroclor-1254				X		
Benzo(a)anthracene						X
Benzo(a)pyrene		X		X		X
Benzo(b)fluoranthene		X		X		X
Bis(2-ethylhexyl)phthalate				X		
Chloroform			X		X	
1,2-Dichloroethene					X	
Di-n-butylphthalate					X	
Indeno(1,2 3-cd)pyrene						X
Methylene chloride			X			
Tetrachloroethene			X			
Trichloroethene			X		X	
Nitrate			X			
Antimony	X			X		
Barium		X				
Cobalt						X
Silver	X			X		
Strontium						X
Vanadium	X			X		X
Zinc	X			X		X
Americium-241	X	X	X	X		X
Plutonium-239/240	X	X	X	X		X
Radium-226			X			
Uranium-233/234		X				
Uranium-238		X				
Special-Case Chemicals						
Vinyl chloride			X			
Chemicals of Interest						
Antimony			X			
Arsenic			X			X
Beryllium			X			
Manganese			X			

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TABLE 6 3-2
METALS DETECTED AT
5% OR GREATER FREQUENCY
SURFACE SOIL[1]

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency[2] %	> Background [3]?
Aluminum	24 100	100	No
Antimony	43 6	47	Yes
Arsenic	11	100	No
Barium	272	100	No
Beryllium	1 5	90	No
Cadmium	6 4	41	No
Cesium	35 4	86	No
Chromium	35 1	99	Yes
Cobalt	20 3	100	Yes
Copper	61 6	100	Yes
Lead	68 7	100	Yes
Lithium	18 1	95	No
Manganese	823	100	No
Mercury	0 34	41	Yes
Nickel	22 5	95	Yes
Selenium	1 3	35	No
Silver	52 7	8	Yes
Strontium	255	100	Yes
Thallium	0 55	44	No
Tin	38 7	5	No
Vanadium	75 9	100	Yes
Zinc	650	100	Yes

[1] Excluding data from Old Outfall (IHSS 143) which was removed from evaluation in OU6

[2] Detection frequency calculated without QA/QC duplicate samples

[3] Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

TABLE 6.3-3
CONCENTRATION/TOXICITY SCREEN
SURFACE SOIL[1]
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Antimony	43 6	n/a	4 0E-04	1 1E+05	8 0E-01	80 4
Vanadium	75 9	n/a	7 0E-03	1 1E+04	8 0E-02	8 0
Silver	52 7	n/a	5 0E-03	1 1E+04	7 8E-02	7 8
Zinc	650	n/a	3 0E-01	2 2E+03	1 6E-02	1 6
Mercury	0 34	n/a	3 0E-04	1 1E+03	8 4E-03	0 8
Nickel	22 5	n/a	2 0E-02	1 1E+03	8 3E-03	0 8
Strontium	255	n/a	6 0E-01	4 3E+02	3 1E-03	0 3
Cobalt	20 3	n/a	6 1E-02	3 3E+02	2 5E-03	0 2
Chromium	35 1	n/a	1 0E+00	3 5E+01	2 6E-04	0 0
Total Risk Factor				1 4E+05		

[1] Excluding data from Old Outfall (IHSS 143) which was removed from evaluation in OU6
RfDs are in units of mg/kg-day
n/a = not available

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TABLE 6 3-4
CONCENTRATION/TOXICITY SCREEN
SURFACE SOIL[1]
RADIONUCLIDES

Chemical	Maximum Detected Conc (pCi/g)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium 239/240	15 22	2 8E-08	3 2E-10	4 3E-07	7 7E-01	77 1
Americium-241	3 243	3 9E-08	3 3E-10	1 3E-07	2 3E-01	22 9
Total Risk Factor				5 5E-07		

[1] Excluding data from Old Outfall (IHSS 143) which was removed from evaluation in OU6
Slope factors are in units of risk/pCi

TABLE 6 3-5
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY SUBSURFACE SOIL [1]

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency[2] %	> Background [3]?
Organic Compounds			
2-Butanone	3 7	22	
2-Chlorophenol	0 055	8	
Acetone	5 1	88	
Benzo(a)pyrene	0 13	8	
Benzo(b)fluoranthene	0 17	12	
Benzoic acid	0 26	19	
Bis(2-ethylhexyl)phthalate	0 11	27	
Fluoranthene	0 45	27	
Phenanthrene	0 17	12	
Pyrene	0 19	23	
Toluene	1 1	90	
Metals			
Aluminum	24100	100	No
Antimony	21 65	7	No
Arsenic	10 9	99	No
Barium	2970	100	Yes
Beryllium	2.1	86	No
Cadmium	1.8	7	No
Cesium	33 7	71	No
Chromium	217	98	Yes
Cobalt	21 4	95	No
Copper	52 1	100	No
Lead	84 9	100	Yes
Lithium	29 8	89	No
Manganese	907	100	No
Mercury	0 93	28	No
Nickel	41 5	64	No
Selenium	1 3	8	No
Strontium	506	100	Yes
Thallium	0 69	34	No
Vanadium	118	100	Yes
Zinc	706	100	Yes

[1] Excluding data from Old Outfall (IHSS 143), which was removed from evaluation in OU6
[2] Detection frequency calculated without QA/QC duplicate samples
[3] Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

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TABLE 6 3-6
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL[1]
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Barium	2 970	1 4E-04	7 0E-02	2 1E+07	1 0E+00	99 9
Vanadium	118	n/a	7 0E-03	1 7E+04	7 9E-04	0 1
Zinc	706	n/a	3 0E 01	2 4E+03	1 1E-04	0 0
Strontium	506	n/a	6 0E 01	8 4E+02	4 0E-05	0 0
Chromium	217	n/a	1 0E+00	2 2E+02	1 0E-05	0 0
Acetone	5 1	n/a	1 0E-01	5 1E+01	2 4E-06	0 0
2 Butanone	3 7	3 0E-01	6 0E-01	1 2E+01	5 8E-07	0 0
Fluoranthene	0 45	n/a	4 0E-02	1 1E+01	5 3E-07	0 0
2-Chlorophenol	0 055	n/a	5 0E 03	1 1E+01	5 2E-07	0 0
Toluene	1 1	1 1E-01	2 0E-01	1 0E+01	4 7E-07	0 0
Pyrene	0 19	n/a	3 0E-02	6 3E+00	3 0E-07	0 0
Bis(2-ethylhexyl)phthalate	0 11	n/a	2 0E-02	5 5E+00	2 6E-07	0 0
Benzoic acid	0 26	n/a	4 0E+00	6 5E-02	3 1E-09	0 0
Total Risk Factor				2 1E+07		

[1] Excluding data from Old Outfall (IHSS 143) which was removed from evaluation in OU6
RfDs are in units of mg/kg-day
n/a = not available

TABLE 6 3-7
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL[1]
CARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Benzo(a)pyrene	0 13	n/a	7 3E+00	9 5E-01	8 8E-01	88 3
Benzo(b)fluoranthene	0 17	n/a	7 3E-01	1.2E-01	1 2E-01	11 5
Bis(2-ethylhexyl)phthalate	0 11	n/a	1 4E-02	1 5E-03	1 4E-03	0 1
Total Risk Factor				1 1E+00		

[1] Excluding data from Old Outfall (IHSS 143) which was removed from evaluation in OU6
Slope factors are in units of risk/(mg/kg-day)
n/a = not available

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TABLE 6 3-8
CONCENTRATION/TOXICITY SCREEN
SUBSURFACE SOIL
RADIONUCLIDES

Chemical	Maximum Activity (pCi/g)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Uranium-238	141	1 2E-08	6 2E-11	1 7E-06	9 5E-01	95 1
Uranium-233/234	3 05	1 4E-08	4 4E-11	4 3E-08	2 4E-02	2 4
Plutonium-239/24	0 88	2 8E-08	3 2E-10	2 5E-08	1 4E-02	1 4
Americium-241	0 44	3 9E-08	3 3E-10	1 7E-08	9 6E-03	1 0
Uranium-235	0 16	1 3E-08	4 7E-11	2 1E-09	1 2E-03	0 1
Total Risk Factor				1 8E-06		

Slope factors are in units of risk/pCi

TABLE 6.3-9
ORGANIC COMPOUNDS AND TOTAL METALS DETECTED AT 5% OR GREATER FREQUENCY GROUNDWATER

Chemical	Maximum Detected Concentration (mg/L)	Detection Frequency[1] %	> Background [2]?
Organic Compounds			
1 1 1-Trichloroethane	0 012	9	
1 1-Dichloroethane	0 062	9	
1,2-Dichloroethene	0 074	11	
1 2-Dichloroethene, cis	0 0007	6	
Acetone	0 027	5	
Bis(2-ethylhexyl)phthalate (total)	0 008	21	
Chloroform	0 008	9	
Diethyl phthalate	0 002	7	
Methylene chloride	0 032	12	
Tetrachloroethene	0 013	15	
Toluene	0 016	6	
Trichloroethene	0.15	14	
Metals			
Aluminum	456	95	Yes
Antimony	0 194	16	Yes
Arsenic	0 018	52	Yes
Barium	5 06	98	Yes
Beryllium	0 032	30	Yes
Cadmium	0 0329	26	Yes
Chromium	0 58	75	Yes
Cobalt	0 228	45	Yes
Copper	6 43	54	Yes
Lead	0 254	73	Yes
Lithium	0 456	93	Yes
Manganese	6 2	94	Yes
Mercury	0 0015	10	Yes
Molybdenum	0 0295	27	No
Nickel	1 07	66	Yes
Selenium	0 475	58	Yes
Silver	3 04	20	Yes
Strontium	6 96	100	Yes
Thallium	0 0027	5	No
Tin	0 267	19	No
Vanadium	0 754	74	Yes
Zinc	8	83	Yes

[1] Detection frequency calculated without QA/QC duplicate samples
[2] Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

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TABLE 6 3-10
CONCENTRATION/TOXICITY SCREEN
GROUNDWATER
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/L)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Nitrate	1 760	n/a	1 6E+00	1 1E+03	9 9E-01	98 9
1 2-Dichloroethene (total)	0 074	n/a	9 0E-03	8.2E+00	7 4E-03	0 7
Tetrachloroethene	0 013	n/a	1 0E-02	1 3E+00	1 2E-03	0 1
Chloroform	0 008	n/a	1 0E-02	8 0E-01	7 2E-04	0 1
1 1-Dichloroethane	0 062	1 4E-01	1 0E-01	6 2E-01	5 6E-04	0 1
Methylene chloride	0 032	9 0E-01	6 0E-02	5 3E-01	4 8E-04	0 0
Acetone	0 027	n/a	1 0E-01	2 7E-01	2 4E-04	0 0
Toluene	0 016	1 1E-01	2 0E-01	1 5E-01	1 3E-04	0 0
cis-1 2-Dichloroethene	0 0007	n/a	1 0E-02	7 0E-02	6 3E-05	0 0
Diethyl phthalate	0 002	n/a	8 0E-01	2 5E-03	2 2E-06	0 0
Total Risk Factor				1 1E+03		

RfDs are in units of mg/kg-day
n/a = not available

TABLE 6.3-11
CONCENTRATION/TOXICITY SCREEN
GROUNDWATER CARCINOGENS

Chemical	Maximum Detected Conc (mg/L)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Trichloroethene	0 15	6 0E-03	1 1E-02	1 7E-03	5 1E-01	51 5
Tetrachloroethene	0 013	2 0E-03	5 2E-02	6 8E-04	2 1E-01	21 1
Chloroform	0 008	8.0E-02	6 1E-03	6 4E-04	2 0E-01	20 0
Methylene chloride	0 032	1.6E-03	7 5E-03	2 4E-04	7 5E-02	7 5
Total Risk Factor				3.2E-03		

Slope factors are in units of risk/mg (kg-day)
n/a = not available

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TABLE 6 3-12
CONCENTRATION/TOXICITY SCREEN
GROUNDWATER RADIONUCLIDES

Chemical	Maximum Activity (pCi/L)	Inhalation Slope Factor		Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Radium-226[1]	8 8	2 8E-09	*	3 0E-10	2 6E-09	5 4E-01	54 3
Plutonium 239/240	3 65	2 8E-08	*	3 2E-10	1 2E-09	2 4E-01	24 0
Americium 241	3 2	3 9E-08	*	3 3E 10	1 1E-09	2 2E-01	21 7
Total Risk Factor					4 9E-09		

Slope factors are in units of risk/pCi

* Inhalation of radionuclides from groundwater is an incomplete pathway Therefore oral toxicity factors were used in the screen

[1] The maximum concentration of Radium 226 occurred at the Old Outfall (IHSS 143) Radium 226 was only analyzed for in two samples outside of the Old Outfall and the maximum concentration was 1 2 pCi/L

TABLE 6 3-13
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY POND SEDIMENT[1]

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency[2] %	> Background [3]?
Organic Compounds			
2-Butanone	0 13	53	
Acenaphthene	0 59	9	
Acetone	0 81	25	
Anthracene	0 8	20	
Aroclor-1254	10	44	
Benzene	0 01	6	
Benzo(a)anthracene	1 1	38	
Benzo(a)pyrene	0 87	41	
Benzo(b)fluoranthene	3 1	45	
Benzo(g,h,i)perylene	0 66	11	
Benzo(k)fluoranthene	1	32	
Benzoic acid	4 6	27	
Bis(2-ethylhexyl)phthalate	88	80	
Butyl benzylphthalate	0 12	5	
Chrysene	1 9	52	
Di-n-octyl phthalate	0 25	11	
Fluoranthene	3.5	66	
Indeno(1,2,3-cd)pyrene	0 66	14	
Phenanthrene	2.6	54	
Pyrene	3 8	66	
Toluene	1.1	90	
Metals			
Aluminum	27,400	100	No
Antimony	68 5	39	Yes
Arsenic	10 2	100	No
Barium	254	100	No
Beryllium	15 2	98	No
Cadmium	9 9	39	No
Cesium	5 8	93	No
Chromium	96 1	100	Yes
Cobalt	15 5	100	Yes
Copper	125	100	Yes
Lead	155	100	No
Lithium	16 6	98	No
Manganese	558	100	Yes
Mercury	1 5	43	No
Nickel	58 1	70	No
Selenium	1 9	5	No
Silver	345	39	Yes
Strontium	307	100	No
Thallium	0 85	39	No
Vanadium	62.7	100	Yes
Zinc	1 270	100	Yes

(1) Based on pond sediment samples collected in 1992

(2) Detection frequency calculated without QA/QC duplicate samples.

(3) Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

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TABLE 6 3-14
CONCENTRATION/TOXICITY SCREEN
POND SEDIMENT
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation RfD		Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Aroclor 1254	10	n/a		2 0E-05	5 0E+05	6 6E-01	65 9
Antimony	68 5	n/a		4 0E-04	1 7E+05	2 3E-01	22 6
Silver	345	n/a		5 0E-03	6 9E+04	9 1E-02	9 1
Vanadium	62 7	n/a		7 0E-03	9 0E+03	1 2E-02	1 2
Bis(2-ethylhexyl)phthal	88	n/a		2 0E-02	4 4E+03	5 8E-03	0 6
Zinc	1 270	n/a		3 0E 01	4 2E+03	5 6E-03	0 6
Cobalt	15 5	n/a		6 0E-02	2 6E+02	3 4E-04	0 0
Methylene chloride	8 3	9 0E-01	*	6 0E-02	1 4E+02	1 8E-04	0 0
Pyrene	3 8	n/a		3 0E-02	1 3E+02	1 7E-04	0 0
Chromium	96 1	n/a		1 0E+00	9 6E+01	1 3E-04	0 0
Fluoranthene	3 5	n/a		4 0E-02	8 8E+01	1 2E-04	0 0
Di-n-octylphthalate	0 25	n/a		2 0E-02	1 3E+01	1 6E-05	0 0
Acenaphthene	0 59	n/a		6 0E-02	9 8E+00	1 3E-05	0 0
Acetone	0 81	n/a		1 0E-01	8 1E+00	1 1E-05	0 0
Toluene	1 1	1 1E-01	*	2.0E-01	5 5E+00	7 3E-06	0 0
Anthracene	0 8	n/a		3 0E-01	2 7E+00	3 5E-06	0 0
Benzoic acid	4 6	n/a		4 0E+00	1 2E+00	1 5E-06	0 0
Butyl benzylphthalate	0 12	n/a		2 0E 01	6 0E-01	7 9E-07	0 0
2-Butanone	0 13	3 0E-01	*	6 0E-01	2 2E-01	2 9E-07	0 0
Total Risk Factor					7 6E+05		

RfDs are in units of mg/kg-day

n/a = not available

* Inhalation is an incomplete pathway because pond sediments are assumed to remain saturated and contaminants are not released to air Therefore oral toxicity factors were used in this screen

(1) Based on pond sediment samples collected in 1992

TABLE 6.3-15
CONCENTRATION/TOXICITY SCREEN
POND SEDIMENT
CARCINOGENS(1)

Chemical	Maximum Detected Conc. (mg/kg)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Aroclor-1254	10	n/a	7 7E+00	7.7E+01	8 7E-01	87.2
Benzo(a)pyrene	0 87	n/a	7.3E+00	6 4E+00	7.2E-02	7 2
Benzo(b)fluoranthene	3 1	n/a	7 3E-01	2.3E+00	2 6E-02	2 6
Bis(2-ethylhexyl)phthalate	88	n/a	1.4E-02	1.2E+00	1.4E-02	1 4
Benzo(a)anthracene	1 1	n/a	7 3E-01	8 0E-01	9 1E-03	0 9
Indeno(1,2 3-cd)pyrene	0 66	n/a	7 3E-01	4 8E-01	5 5E-03	0 5
Chrysene	1 9	n/a	7 3E-02	1 4E-01	1 6E-03	0 2
Benzo(k)fluoranthene	1	n/a	7 3E-02	7 3E-02	8 3E-04	0 1
Benzene	0 01	2 9E-02 *	2.9E-02	2 9E-04	3 3E-06	0 0
Total Risk Factor				8 8E+01		

Slope factors are in units of risk/(mg/kg-day)

n/a = not available

* Inhalation is an incomplete pathway because pond sediments are assumed to remain saturated and contaminants are not released to air Therefore oral toxicity factors were used in this screen

(1) Based on pond sediment samples collected in 1992

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TABLE 6 3-16
CONCENTRATION/TOXICITY SCREEN
POND SEDIMEN[T(1)]
RADIONUCLIDES

Chemical	Maximum Activity (pCi/g)	Inhalation Slope Factor		Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium-239/240	1174	2 8E-08	*	3 2E-10	3 8E-07	8 3E-01	82 5
Americium 241	230 53	3 9E-08	*	3 3E-10	7 6E-08	1 7E-01	16 7
Uranium 238	26 445	1 2E-08	*	6 2E 11	1 6E-09	3 6E-03	0 4
Uranium-233/234	15 935	1 4E-08	*	4 4E-11	7 0E-10	1 5E-03	0 2
Radium-228	2 3	9 9E-10	*	2 5E-10	5 8E-10	1 3E-03	0 1
Radium-226	1 25	2 8E-09	*	3 0E-10	3 8E 10	8 2E-04	0 1
Strontium 89 90	1 8	6 9E-11	*	5 6E 11	1 0E-10	2 2E-04	0 0
Uranium-235	0 854	1 3E-08	*	4 7E-11	4 0E 11	8 8E-05	0 0
Total Risk Factor					4 6E-07		

Slope factors are in units of risk/pCi

* Inhalation is an incomplete pathway because pond sediments are assumed to remain saturated and contaminants are not released to air Therefore oral toxicity factors were used in the screen

(1) Based on pond sediment samples collected in 1992

TABLE 6 3-17
ORGANIC COMPOUNDS AND TOTAL METALS DETECTED AT 5% OR GREATER FREQUENCY POND SURFACE WATER

Chemical	Maximum Detected Concentration (mg/L)	Detection Frequency[1] %	> Background [2]?
Organic Compounds			
1 2-Dichloroethene	0 003	8	
Chloroform	0 002	20	
Di-n-butylphthalate	0 002	12	
Trichloroethene	0 006	12	
Metals			
Aluminum	1 02	98	No
Antimony	0 0205	6	No
Arsenic	0 0066	41	No
Barium	0 12	100	No
Cadmium	0 0022	22	No
Cesium	0.06	12	No
Chromium	0 0043	16	No
Cobalt	0.0036	35	No
Copper	0 0047	19	No
Lead	0 0158	78	No
Lithium	0 0545	100	No
Manganese	0 293	100	No
Mercury	0 00096	33	No
Molybdenum	0.0176	75	No
Nickel	0 0063	47	No
Selenium	0 0083	22	No
Silver	0 0027	6	No
Strontium	0.568	100	No
Tin	0 0119	20	No
Vanadium	0 0056	49	No
Zinc	0 0748	76	No

[1] Detection frequency calculated without QA/QC duplicate samples
[2] Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

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TABLE 6 3-18
CONCENTRATION/TOXICITY SCREEN
POND SURFACE WATER
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/L)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
1 2 Dichloroethene	0 003	n/a	9 0E-03	3 3E-01	6 0E-01	60 2
Chloroform	0 002	n/a	1 0E-02	2 0E-01	3 6E-01	36 1
Di-n-butylphthalate	0 002	n/a	1 0E-01	2 0E-02	3 6E-02	3 6
Total Risk Factor				5 5E-01		

RfDs are in units of mg/kg-day
n/a = not available

TABLE 6.3-19
CONCENTRATION/TOXICITY SCREEN
POND SURFACE WATER
CARCINOGENS

Chemical	Maximum Detected Conc. (mg/L)	Inhalation Slope Factor		Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Trichloroethene	0 006	6 0E-03	*	1 1E-02	6 6E-05	8 4E-01	84 4
Chloroform	0 002	8 0E-02	*	6 1E-03	1 2E-05	1 6E-01	15 6
Total Risk Factor					7.8E-05		

Slope factors are in units of risk/(mg/kg-day)

n/a = not available

* Inhalation of volatile organic compounds released to air in the outdoors is a negligible pathway Therefore oral toxicity factors were used in the screen

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TABLE 6 3-20
ORGANIC COMPOUNDS AND METALS DETECTED AT 5% OR GREATER FREQUENCY[1]
STREAM SEDIMENT

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency[2] %	> Background? [3]
Organic Compounds			
Acenaphthene	0 13	7	
Acetone	0 063	7	
Anthracene	0 15	20	
Benzo(a)anthracene	0 43	27	
Benzo(a)pyrene	0 48	33	
Benzo(b)fluoranthene	0 65	27	
Benzo(g h i)perylene	0 16	13	
Benzo(k)fluoranthene	0 23	20	
Benzoic acid	0 51	33	
Benzyl alcohol	0 041	7	
Bis(2-ethylhexyl)phthalate	0 19	27	
Butyl benzylphthalate	0 12	7	
Chrysene	0 51	33	
Di-n-butyl phthalate	0 075	33	
Dibenzofuran	0 037	7	
Fluoranthene	1	47	
Fluorene	0 089	7	
Indeno(1 2 3-cd)pyrene	0 18	20	
Methylene chloride	0 007	7	
Naphthalene	0 046	7	
Phenanthrene	0 75	33	
Pyrene	0 96	33	
Metals			
Aluminum	11,600	100	No
Antimony	26 3	13	No
Arsenic	5 8	93	Yes
Barium	177	100	Yes
Beryllium	1	53	No
Cadmium	0 8	7	No
Cesium	18 1	47	No
Chromium	12 3	100	No
Cobalt	12 4	100	Yes
Copper	17 7	60	No
Lead	94 8	100	No
Lithium	15 2	93	No
Manganese	1 000	100	Yes
Mercury	0 13	27	No
Nickel	19 2	47	No
Selenium	0 45	13	No
Silver	1 4	7	No
Strontium	95 8	100	Yes
Thallium	0 46	33	No
Vanadium	33 9	100	Yes
Zinc	178	100	Yes

[1] All detected analytes were detected at a frequency greater than 5 percent

[2] Detection frequency calculated without QA/QC duplicate samples

[3] Background comparison is detailed in Appendix A of Technical Memorandum No 4 (DOE 1994c)

TABLE 6.3-21
CONCENTRATION/TOXICITY SCREEN
STREAM SEDIMENT
NONCARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation RfD	Oral RfD	Risk Factor	Risk Index	% of Total Risk Factor
Vanadium	33 9	n/a	7 0E-03	4 8E+03	8 2E-01	82 4
Zinc	178	n/a	3 0E-01	5 9E+02	1 0E-01	10 1
Cobalt	12 4	n/a	6 0E-02	2 1E+02	3 5E-02	3 5
Strontium	95 8	n/a	6 0E-01	1 6E+02	2 7E-02	2 7
Pyrene	0 96	n/a	3 0E-02	3 2E+01	5 4E-03	0 5
Fluoranthene	1	n/a	4 0E-02	2 5E+01	4 3E-03	0 4
Bis(2-ethylhexyl)phthalate	0 19	n/a	2 0E-02	9 5E+00	1 6E-03	0 2
Fluorene	0 089	n/a	4 0E-02	2.2E+00	3 8E-04	0 0
Acenaphthene	0 13	n/a	6 0E-02	2 2E+00	3.7E-04	0 0
Naphthalene	0 046	n/a	4 0E-02	1 2E+00	2 0E-04	0.0
Di-n-butylphthalate	0 075	n/a	1.0E-01	7 5E-01	1 3E-04	0 0
Acetone	0 063	n/a	1 0E-01	6 3E-01	1 1E-04	0 0
Butyl benzylphthalate	0 12	n/a	2 0E-01	6 0E-01	1 0E-04	0 0
Anthracene	0 15	n/a	3 0E-01	5 0E-01	8 5E-05	0 0
Benzyl alcohol	0 041	n/a	3 0E-01	1 4E-01	2 3E-05	0 0
Benzoic acid	0 51	n/a	4 0E+00	1 3E-01	2.2E-05	0 0
Methylene chloride	0 007	9 0E-01	6 0E-02	1 2E-01	2 0E-05	0 0
Total Risk Factor				5 9E+03		

RfDs are in units of mg/kg-day
n/a = not available

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TABLE 6 3-22
CONCENTRATION/TOXICITY SCREEN
STREAM SEDIMENT
CARCINOGENS

Chemical	Maximum Detected Conc (mg/kg)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Benzo(a)pyrene	0 48	n/a	7 3E+00	3 5E+00	7 8E-01	78 2
Benzo(b)fluoranthene	0 65	n/a	7 3E-01	4.7E-01	1 1E-01	10 6
Benzo(a)anthracene	0 43	n/a	7 3E-01	3 1E-01	7 0E-02	7 0
Indeno(1 2 3-cd)pyrene	0 18	n/a	7 3E-01	1 3E-01	2 9E-02	2 9
Chrysene	0 51	n/a	7 3E-02	3 7E-02	8 3E-03	0 8
Benzo(k)fluoranthene	0 23	n/a	7 3E-02	1 7E-02	3 7E-03	0 4
Bis(2-ethylhexyl)phthalate	0 19	n/a	1 4E-02	2 7E-03	5 9E-04	0 1
Methylene chloride	0 007	1 6E-03	7 5E-03	5 3E-05	1 2E-05	0 0
Total Risk Factor				4 5E+00		

Slope factors are in units of risk/(mg/kg-day)
n/a = not available

TABLE 6.3-23
CONCENTRATION/TOXICITY SCREEN
STREAM SEDIMENT
RADIONUCLIDES

Chemical	Maximum Activity (pCi/g)	Inhalation Slope Factor	Oral Slope Factor	Risk Factor	Risk Index	% of Total Risk Factor
Plutonium-239/240	1 95	2 8E-08	3 2E-10	5 5E-08	6 5E-01	65 1
Americium-241	0 75	3 9E-08	3 3E-10	2 9E-08	3 5E-01	34 9
Total Risk Factor				8.4E-08		

Slope factors are in units of risk/pCi

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TABLE 6 4-1
SUMMARY OF CURRENT AND FUTURE LAND USES

	Current		Future	
Land Use Category	**Offsite**	**Onsite**	**Offsite**	**Onsite**
Residential	Yes	No	Credible[a]	Improbable[b]
Commercial/Industrial	Yes	Yes	Credible	Credible[c]
Recreational/Open Space	Yes	No	Credible	Credible[d]
Ecological Reserve	No	No	Improbable	Credible[d]
Agricultural	Yes	No	Credible	Improbable

Credible is used to indicate scenarios that could reasonably occur
[b] Improbable is used to indicate scenarios that are unlikely to occur
Expected in the currently developed area of the plant site
[d] Expected in the buffer zone

TABLE 6 4-2
POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Onsite worker	Current	Inhalation of airborne particulates from OU6 surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
Onsite office worker	Future	Inhalation of airborne particulates from OU6 surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Inhalation of indoor VOCs (from migration through foundation)
Onsite open space recreational user	Future	Inhalation of airborne particulates from OU6 surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Inhalation of airborne particulates from sediment Ingestion of sediment Dermal contact with sediment External irradiation from sediment Ingestion of surface water Dermal contact with surface water
Onsite ecological worker	Future	Ingestion of surface water Dermal contact with surface water Ingestion of sediment Dermal contact with sediment Inhalation of airborne particulates from sediment External irradiation from sediment Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
Onsite construction worker	Future	Inhalation of airborne particulates from subsurface soil Ingestion of subsurface soil Dermal contact with subsurface soil External irradiation from subsurface soil

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TABLE 6 5-1
MAXIMUM AND RME CONCENTRATIONS FOR CHEMICALS OF CONCERN SURFACE SOIL

Analyte	Maximum Concentration (mg/kg or pCi/g)	RME Concentration (mg/kg or pCi/g)	
AOC No 1			
Antimony	24 15	16 50	n
Vanadium	40 1	33 39	n
Zinc	60 2	48 38	n
Americium-241	1 147	0 151	n
Plutonium-239/240	1 849	0 284	n
AOC No 2, 30-acre maximum exposure area			
Antimony	38 9	14 09	ln
Silver	52 7	2 64	ln
Vanadium	75 9	34 31	ln
Zinc	650	85 66	ln
Americium-241	3 243	1 27	ln
Plutonium-239/240	15 22	3 10	ln
AOC No 2			
Antimony	43 6	16 49	ln
Silver	52 7	2 31	ln
Vanadium	75 9	36 13	ln
Zinc	650	80 46	ln
Americium-241	3 243	1 24	ln
Plutonium-239/240	15 22	2 78	ln

Note Analytical results used in the calculation of the RME concentrations are shown in Attachment J1

RME Reasonable maximum exposure

n - Based on normal distribution

ln -Based on lognormal distribution

TABLE 6.5-2
MAXIMUM AND RME CONCENTRATIONS FOR CHEMICALS OF CONCERN SUBSURFACE SOIL

Analyte	Maximum Concentration (mg/kg or pCi/g)	RME Concentration (mg/kg or pCi/g)	
AOC No. 1			
Barium	866	129 33	ln
Americium-241	0 025	0 013	ln
Plutonium-239/240	0 072	0 021	ln
Uranium-233/234	3 05	0 8	ln
Uranium-238	141	1 54	ln
AOC No. 2			
Benzo(a)pyrene	0 13	0 13	m
Benzo(b)fluoranthene	0 17	0 17	m
Barium	1050	159 7	ln
Americium-241	0 44	0 025	ln
Plutonium-239/240	0 88	0 138	ln
Uranium-233/234	1 3	0 785	n
Uranium-238	1 6	0 793	ln

Note Analytical results used in the calculation of RME concentrations are shown in Attachment J1

RME - Reasonable maximum exposure
n - Based on normal distribution
ln - Based on lognormal distribution
m - Maximum detected concentration

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TABLE 6 5-3
MAXIMUM CONCENTRATIONS
FOR CHEMICALS OF CONCERN
GROUNDWATER

Analyte	Maximum Concentration (1) (µg/l)
AOC No 2, 30-acre maximum exposure area	
Chloroform	1
Methylene chloride	14
Tetrachoroethene	3
Trichloroethene	6

(1) For simplicity and as a conservative approach maximum concentrations of COCs in groundwater were used to model soil gas to indoor air

TABLE 6.5-4
MAXIMUM AND RME CONCENTRATIONS FOR CHEMICALS OF CONCERN POND SEDIMENTS (0-2 ft)

Analyte	Maximum Concentration (mg/kg or pCi/g)	RME Concentration (mg/kg or pCi/g)	
AOC No. 3			
Aroclor-1254	0 59	0 392	n
Benzo(a)pyrene	0 31	0 274	n
Benzo(b)fluoranthene	0 42	0 319	n
Bis(2-ethylhexyl)phthalate	7 8	2 637	ln
Antimony [1]	30 4	22 9	m
Silver	3 9	1 65	n
Vanadium	62 7	42.2	ln
Zinc	409	158 4	ln
Americium-241[1]	13 23	5 98	n,d
Plutonium-239/240 [1]	36 2	15 95	n,d
AOC No. 4			
Aroclor-1254	6 6	2 424	n
Benzo(a)pyrene	0.45	0 383	n
Benzo(b)fluoranthene	2	0 861	n
Bis(2-ethylhexyl)phthalate	46	30 26	ln
Antimony [1]	68.5	68 5	m
Silver	240	95 86	n,d
Vanadium	46 2	30.59	n
Zinc	346	220 79	n
Americium-241[1]	194 5	54 5	n,d
Plutonium-239/240 [1]	180 2	60 91	n

Note Analytical results used in the calculation of the RME concentrations are shown in Attachment J1

[1] The RME sediment concentrations for antimony, Am-241 and Pu-239/240 shown in this table were calculated using sediment sample results, they represent current concentrations in the 2-foot sediment sampling interval in each AOC These current concentrations were used in estimating depth-weighted future pond sediment concentrations following deposition of these COCs transported from surface soil in storm runoff (Table 6.5-13) The depth-weighted values were used in risk assessment to assess exposure of future receptors

RME- Reasonable maximum exposure

n - Based on normal distribution

ln - Based on lognormal distribution

m - Maximum detected concentration

d - See discussion in Attachment J1

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TABLE 6 5-5
MAXIMUM AND RME CONCENTRATIONS FOR CHEMICALS OF CONCERN POND SURFACE WATER

Analyte	Maximum Concentration (µg/l)	RME Concentration (µg/l)	
AOC No. 3			
Di-n-butylphthalate	2	2 00	m
AOC No 4			
1 2-Dichloroethene	3	2 53	n,d
Chloroform	2	2 00	m
Di-n-butylphthalate	1	1 00	m
Trichloroethene	6	2 96	n d

Note Analytical results used in the calculation of RME concentrations are shown in Attachment J1

RME - Reasonable maximum exposure

n - Based on normal distribution

m - maximum detected concentration

d - See discussion in Attachment J1

TABLE 6 5-6
MAXIMUM AND RME CONCENTRATIONS FOR CHEMICALS OF CONCERN STREAM/DRY SEDIMENTS

Analyte	Maximum Concentration (mg/kg or pCi/g)	RME Concentration (mg/kg or pCi/g)	
AOC No. 3			
Benzo(a)anthracene	0 19	0 19	m
Benzo(a)pyrene	0 26	0.26	m
Benzo(b)fluoranthene	0 40	0.297	n
Indeno(1,2 3-cd)pyrene	0 11	0 11	m
Cobalt	12 6	10 98	n
Strontium	95 40	69 7	n
Vanadium	34 4	31 24	n
Zinc	293	180 58	n
Americium-241	0.327	0 311	n
Plutonium-239/240	4 444	2 519	n,d
AOC No. 4			
Benzo(a)anthracene	0 43	0 302	n
Benzo(a)pyrene	0.48	0 48	m
Benzo(b)fluoranthene	0.65	0 41	n
Indeno(1 2 3-cd)pyrene	0 19	0 19	m
Cobalt	11 5	8 77	n
Strontium	95.8	74 49	n
Vanadium	31 3	26 66	n
Zinc	286	152 6	ln
Americium-241	1 293	0 660	n
Plutonium-239/240	3 095	1 392	n

Note Analytical results used in the calculation of RME concentrations are shown in Attachment J1

RME - Reasonable maximum exposure

n - Based on normal distribution

ln - Based on lognormal distribution

m - Maximum detected concentrations

d - See discussion in Attachment J1

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TABLE 6 5-7
FIVE YEAR AIR CONCENTRATIONS
FROM WIND EROSION OF SURFACE SOIL
AOC NO 1

Chemical	Annual Average Air Concentration (µg/m³) for Year[1] 1989	1990	1991	1992	1993	Five-year Maximum (µg/m³)	Specific Activity Conversion (pCi/µg)	Five-year Maximum (pCi/m³)
Antimony	1 57E-06	1 78E-04	8 38E-06	3 71E-06	1 00E-05	1 78E-04		-
Vanadium	3 18E-06	3 61E-04	1 70E-05	7 50E-06	2 03E-05	3 61E-04	-	
Zinc	4 61E-06	5 22E-04	2 46E-05	1 09E-05	2 94E-05	5 22E-04	-	
Americium-241	4 19E-15	4 74E 13	2 23E 14	9 86E-15	2 67E-14	4 74E-13	3 44E+06	1 63E-06
Plutonium 239/240	3 71E-13	4 20E 11	1 98E-12	8 74E 13	2 37E 12	4 20E 11	7 32E+04	3 07E-06

[1] From Tables in Appendix I
No specific activity conversion is necessary for nonradionuclides.

TABLE 6 5-8
FIVE YEAR AIR CONCENTRATIONS
FROM WIND EROSION OF SURFACE SOIL
AOC NO 2, 30-ACRE AREA

Chemical	Annual Average Air Concentration (µg/m³) for Year[1] 1989	1990	1991	1992	1993	Five-year Maximum (µg/m³)	Specific Activity Conversion (pCi/µg)	Five-year Maximum (pCi/m³)
Antimony	1 49E-06	1 69E-04	7 93E-06	3 51E-06	9 50E-06	1 69E-04	-	-
Silver	2 79E-07	3 16E-05	1 49E-06	6 57E-07	1 78E-06	3 16E-05	-	-
Vanadium	3 63E-06	4 10E-04	1 93E-05	8 54E-06	2 31E-05	4 10E-04	-	-
Zinc	9 05E-06	1 02E-03	4 82E-05	2 13E-05	5 77E-05	1 02E-03	-	-
Americium-241	3 91E-14	4 43E-12	2.08E-13	9 21E-14	2 49E-13	4 43E-12	3 44E+06	1 52E-05
Plutonium-239/240	4 49E-12	5 08E-10	2.39E-11	1 06E-11	2 86E-11	5.08E-10	7 32E+04	3 72E-05

[1] From Tables in Appendix I

- No specific activity conversion is necessary for nonradionuclides

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TABLE 6 5-9
FIVE YEAR AIR CONCENTRATIONS
FROM WIND EROSION OF SURFACE SOIL
AOC NO 2

Chemical	Annual Average Air Concentration ($\mu g/m^3$) for Year[1] 1989	1990	1991	1992	1993	Five-year Maximum ($\mu g/m^3$)	Specific Activity Conversion ($pCi/\mu g$)	Five-year Maximum (pCi/m^3)
Antimony	1 80E-08	2 04E-06	9 59E-08	4 24E-08	1 15E-07	2 04E-06		-
Silver	2 52E-09	2 86E-07	1 34E-08	5 94E-09	1 61E-08	2 86E-07		-
Vanadium	3 95E-08	4 47E-06	2 10E-07	9 29E-08	2 52E-07	4 47E-06		-
Zinc	8 79E-08	9 95E-06	4 68E-07	2 07E-07	5 61E-07	9 95E-06		-
Americium-241	3 94E 16	4 46E-14	2 10E 15	9 29E-16	2 52E-15	4 46E 14	3 44E+06	1 53E-07
Plutonium 239/240	4 16E-14	4 71E-12	2 22E-13	9 80E-14	2 65E-13	4 71E 12	7 32E+04	3 45E-07

[1] From Tables in Appendix I
No specific activity conversion is necessary for nonradionuclides.

TABLE 6 5-11
SUMMARY OF ANNUAL AVERAGE AIR CONCENTRATIONS FROM WIND EROSION AND CONSTRUCTION ACTIVITIES
AOC NO 2

Analyte	Surface Soil Wind Erosion 5-Year Maximum Annual Average Air Concentrations (µg/m³)	Subsurface Soil Wind Erosion[1] Annual Average Air Concentrations (µg/m³)	Heavy Construction Activities[1] Annual Average Air Concentrations (µg/m³)	Total Annual Average Air Concentrations (µg/m³)	Conversion Factor (pCi/µg)	Total Annual Average Air Concentrations (pCi/m³)
Semi-volatiles						
Benzo(a)pyrene	(2)	1 56E-10	1 31E-09	1 47E-09	(4)	(4)
Benzo(b)fluoranthene	(2)	2 04E-10	1 72E-09	1 92E-09	(4)	(4)
Metals						
Antimony	2 04E-06	(3)	(3)	2.04E-06	(4)	(4)
Barium	(2)	1 91E-07	1 61E-06	1 81E-06	(4)	(4)
Silver	2.86E-07	(3)	(3)	2.86E-07	(4)	(4)
Vanadium	4 47E-06	(3)	(3)	4 47E-06	(4)	(4)
Zinc	9 95E-06	(3)	(3)	9 95E-06	(4)	(4)
Radionuclides						
Americium-241	4 46E-14	8 68E-18	7.83E-17	4 47E-14	3 44E+06	1 54E-07
Plutonium-239/240	4 71E-12	2 26E-15	1 91E-14	4 73E-12	7 32E+04	3 46E-07
Uranium-233/234	(2)	1 52E-13	1 29E-12	1.44E-12	6.19E+03	8 91E-09
Uranium-238	(2)	2.85E-09	2.40E-08	2 69E-08	3.33E-01	8 96E-09

(1) At a 10-acre construction site.
(2) Substance is not a COC in surface soil
(3) Substance is not a COC in subsurface soil
(4) No specific activity conversion is necessary for nonradionuclides

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TABLE 6 5-10
SUMMARY OF ANNUAL AVERAGE AIR CONCENTRATIONS FROM WIND EROSION AND CONSTRUCTION ACTIVITIES
AOC NO 1

Analyte	Surface Soil Wind Erosion 5 Year Maximum Annual Average Air Concentrations ($\mu g/m^3$)	Subsurface Soil Wind Erosion[1] Annual Average Air Concentrations ($\mu g/m^3$)	Heavy Construction Activities[1] Annual Average Air Concentrations ($\mu g/m^3$)	Total Annual Average Air Concentrations ($\mu g/m^3$)	Conversion Factor ($pCi/\mu g$)	Total Annual Average Air Concentrations (pCi/m^3)
Metals						
Antimony	1 78E-04	(3)	(3)	1 78E-04	(4)	(4)
Barium	(2)	1 55E-07	1 31E-06	1 46E-06	(4)	(4)
Vanadium	3 61E-04	(3)	(3)	3 61E-04	(4)	(4)
Zinc	5 22E-04	(3)	(3)	5 22E-04	(4)	(4)
Radionuclides						
Americium-241	4 74E-13	4 48E-18	3 78E-17	4 74E-13	3 44E+06	1 63E-06
Plutonium-239/240	4 20E-11	3 40E-16	2 87E-15	4 20E-11	7 32E+04	3 07E-06
Uranium-233/234	(2)	1 55E-13	1 31E-12	1 47E-12	6 19E+03	9 10E-09
Uranium-238	(2)	5 53E-09	4 67E-08	5 22E-08	3 33E-01	1 74E-08

(1) At a 10-acre construction site

(2) Substance is not a COC in surface soil

(3) Substance is not a COC in subsurface soil

(4) No specific activity conversion is necessary for nonradionuclides.

TABLE 6 5-12
INDOOR AIR CONCENTRATIONS OF VOCs FROM SOIL GAS TRANSPORT

Analyte	Indoor Air Concentration[1] ($\mu g/m^3$)
AOC No. 2, 30-acre Maximum Exposure Area	
Chloroform	6.22E-09
Methylene chloride	5.42E-08
Tetrachloroethene	8.22E-08
Trichloroethene	1.07E-07

[1]Maximum modeled concentration (from Tables in Appendix I)

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TABLE 6 5-13
ESTIMATED FUTURE SEDIMENT AND SURFACE WATER CONCENTRATIONS FROM SURFACE RUNOFF AOC NO 3 AND AOC NO 4

	RME Concentration in Sediment at 15 years			RME Concentration in Surface Water		
Pond	Americium-241 (pCi/g)	Plutonium 239/240 (pCi/g)	Antimony (mg/kg)	Americium 241 (pCi/L)	Plutonium 239/240 (pCi/L)	Antimony (mg/L)
AOC No 3						
A 1	9 28E+00	2 89E+01	2 05E+01	1 40E-02	4 30E-02	4 42E-08
A 2	1 01E+00	3 17E+00	1 19E+01	1 30E-02	4 20E-02	1 21E-08
A 3	2 30E-02	4 70E-02	3 17E-01	2 04E-05	4 65E-05	1 92E-07
Maximum	9 28E+00	2 89E+01	2 05E+01	1 40E-02	4 30E-02	1 92E-07
AOC No 4						
B 1	9 93E+01	5 56E+01	1 19E+01	1 67E-01	3 80E-02	6 08E 11
B 2	1 14E+01	2 67E+01	1 20E+01	2 90E-02	6 90E-02	3 37E-08
B 3	2 35E+01	7 83E+01	4 70E+01	3.26E-05	1 10E-04	3 02E-09
B-4	4 00E-03	8 00E-03	1 62E-01	1 03E-04	3 41E-04	9 69E-08
Maximum	9 93E+01	7 83E+01	4 70E+01	1 67E-01	6 90E-02	9 69E-08

Note Sediment concentrations at 15 years represent the mean concentration over 30 years of runoff and deposition. Sediment concentrations are depth-weighted averages of COC concentrations in current and future deposits Surface water concentrations represent suspended sediment in the water column (95% UCLs on the means of multiple 30-year average modeled concentrations)

TABLE 6.6-1
AGE-WEIGHTED SOIL AND SEDIMENT INGESTION RATES FOR CARCINOGENS AND RADIONUCLIDES

For carcinogens age-weighted soil and sediment ingestion rates for child and adult open space use were calculated using the following formula.

$$IRadj = \frac{IRc \times EDc \times FCc}{BWc} + \frac{IRa \times EDa \times FCa}{BWa}$$

where

IRadj = Age and time-weighted soil or sediment ingestion rate, mg-years/day-kg
IRc = Childhood soil ingestion rate
EDc = Childhood exposure duration
FCc = Fraction ingested from contaminated source (child)
BWc = Child body weight
IRa = Adult soil ingestion rate
EDa = Adult exposure duration
FCa = Fraction ingested from contaminated source (adult)
BWa = Adult body weight

Applying exposure factors from Attachment J2 for open space use, soil ingestion, and sediment ingestion yields the following weighted IRs for chemical intake

		Open Space Use
CT	IRadj =	9 2 mg-years/day-kg
RME	IRadj =	57 mg-years/day-kg

For radionuclides. For radionuclides, BW is not included in the equation. IRadj for radionuclides

		Open Space Use
CT	IRadj =	175 mg-years/day
RME	IRadj =	1800 mg-years/day

CT = Central tendency
RME = Reasonable maximum exposure

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TABLE 6 6-2
SOIL MATRIX EFFECTS

Chemical of Concern	Type of Critical Study (1)		Soil Matrix Effect (2)
	Oral Reference Dose	Oral Slope Factor	
Antimony	Drinking water (rats)		0 5
Aroclor 1254	Glycerol & corn oil vehicle (monkeys)	Corn oil vehicle stirred in food (rats) (3)	0 5
Barium	Drinking water (humans)		0 5
Benzo(a)pyrene (4)		Dietary vehicle not specified (rats mice dogs)	1
Bis(2-ethylhexyl)phthalate	Dietary vehicle not specified (guinea pigs)	Dietary vehicle not specified (rats mice)	1
Cobalt	Inhalation (humans) (5)		1
Silver	Intravenous (humans)		0 5
Strontium	Dietary vehicle not specified (rats)		1
Vanadium	Drinking water (rats)		0 5
Zinc	Dietary supplements (human) (6)		0 5
Americium-241		Soluble form in food or water (7)	1
Plutonium 239/240		Soluble form in food or water (7)	1
Uranium 233/234		Soluble form in food or water (7)	1
Uranium 238		Soluble form in food or water (7)	1

(1) Source IRIS unless otherwise noted
(2) A soil matrix effect of 0 5 is supported by literature review see text and Table 6 6-3
(3) Study done for Aroclor-1260 used by analogy
(4) Adopted for all carcinogenic PAHs that are chemicals of concern in sediment
(5) In the absence of information on the critical study supporting the provisional oral RfD for cobalt, a default matrix effect of 1 is adopted This may overestimate absorption of cobalt from soil
(6) Dietary supplements are designed to be readily absorbed in the gastrointestinal tract therefore a soil matrix effect is appropriate
(7) Personal communication (Nelson, 1995) Slope factors were derived using gastrointestinal absorption factors for soluble forms of each radionuclide Retardation of radionuclide intake from soil matrix is appropriate to consider but cannot be quantified using a simple soil matrix effect because the adjustment must account for differential effects on target organs Therefore a matrix effect of 1 is adopted, even though it probably overestimates bioavailability of mineralized forms of radionuclides in soils at Rocky Flats

TABLE 6 6-3
DERIVATION OF 0.5 SOIL MATRIX EFFECT

Compound (Species)	Fraction Absorbed from Food or Soil (Fm)	Fraction Absorbed from Water (Fw)	Matrix Effect	Source
Cadmium (in adults)	0 025	0 05	0 50 (1)	EPA 1995a, Kjellstrom and Nordberg, 1978
Manganese (adults)	–	–	0 04 (2)	EPA 1995a
Cyanide (rats)	–	0 5	0 20 (3)	EPA 1995a
Lead (children)	0 3	0 6	0 60 (1)	EPA 1994c
Lead (adults)	0 03	–	0 05 (1)	Heard and Chamberlain (1982)
Lead (rats)	–	0 28	0 08 - 0 20 (4)	Freeman et al 1992
Nickel (adults)	0.007	0.59	0 03 (1)	Sunderland et al 1989
Arsenic (rabbits)	0.28	–	0.47 (1)	Freeman et al 1993
TCDD (guinea pigs)	–	–	0 10 (5)	McConnell et al 1984
Benzo(a) pyrene (rats)	–	–	0 34-0.51 (6)	Goon et al 1991
Matrix Effect Selected for Use in HHRA			0 5	

(1) Based on Fm/Fw
(2) Based on relative toxicity of manganese in water vs food (RfD water = 5E-03 mg/kg-d, RfD food = 1 4E-01 mg/kg-d, ratio = 0 04)
(3) Based on relative toxicity of cyanide in food and water; see text.
(4) Based on relative retention of lead in blood, bone, and liver
(5) Based on relative retention of TCDD in liver
(6) Based on relative bioavailability from soil compared to water

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TABLE 6 6-4
DERMAL ABSORPTION FRACTIONS AND DERMAL PERMEABILITY CONSTANTS FOR COCs IN SOIL AND SURFACE WATER

Chemical	Soil Absorbed Fraction	Dermal Permeability Constant (cm/hr)	Source
1 2-Dichloroethene	-	0 01	1
Aroclor 1254	0 06	-	2
Bis(2-ethylhexyl)phthalate	0 01		3
Chloroform		0 13	4
Di-n-butylphthalate		0 07	5
Trichloroethene		0 23	4
Vinyl Chloride	-	0 0073	6

Source
1 EPA 1992c Table 5-8 Estimated Kp value for trans-1 2-dichloroethene
2 EPA 1992c Experimentally measured Table 6-3
3 EPA 1992f New Interim Region IV Guidance recommending 1 percent absorption for all organics
4 EPA 1992c Table 5 8 Measured K_p pressure similar to benzene
5 EPA 1992c Calculated using Equation 5 8
6 EPA 1992c Table 5-8 Estimated K_p

Chemical not evaluated in this medium

TABLE 6 7-1
TOXICITY FACTORS FOR CHEMICALS OF CONCERN ORGANIC COMPOUNDS AND METALS

Analyte	Slope Factors Oral	Slope Factors Inhalation	EPA Cancer Weight of Evidence	Reference Doses Oral	Reference Doses Inhalation (*)	RfC
Antimony	-	-	-	4 0E-04 (1)	-	-
Aroclor-1254	7 7E+00 (1)	-	B2	2.0E-05 (1)	-	-
Arsenic	1 7E+00 **	1 5E+01 **	A	3 0E-04 (1)	-	-
Barium	-	-	-	7.0E-02 (1)	1 41E-04	5 0E-04 (2)
Benzo(a)anthracene	7 3E-01 (3)	-	B2	-	-	-
Benzo(a)pyrene	7 3E+00 (3)	-	B2	-	-	-
Benzo(b)fluoranthene	7 3E-01 (3)	-	B2	-	-	-
Beryllium	4 3E+00 (1)	8 4E+00 (1)	B2	5 0E-03 (1)	-	-
Bis(2-ethylhexyl)phthalate	1.4E-02 (1)	-	B2	2.0E-02 (1)	-	-
Chloroform	6 1E-03 (1)	8 0E-02 (1)	B2	1 0E-02 (1)	-	-
Cobalt	-	-	-	6 0E-02(4)	-	-
1 2-Dichloroethene	-	-	-	9 0E-03 (5)	-	-
Di-n-butylphthalate	-	-	D	1.0E-01(1)	-	-
Indeno(1 2 3-cd)pyrene	7 3E-01 (3)	-	B2	-	-	-
Manganese (food)	-	-	D	1 4E-01 (1)	1 4E-05	5 0E-05 (1)
Manganese (water)	-	-	D	5 0E-03 (1)	-	-
Methylene chloride	7 5E-03 (1)	1 6E-03 (1)	B2	6 0E-02 (1)	9 0E-01	3.0E+00 (5)
Nitrate	-	-	-	1 6E+00 (1)	-	-
Silver	-	-	-	5 0E-03 (1)	-	-
Strontium	-	-	-	6 0E-01 (1)	-	-
Tetrachloroethene	5 2E-02 (6)	2 0E-03 (6)	B2	1 0E-02 (1)	-	-
Trichloroethene	1 1E-02 (6)	6 0E-03 (6)	B2	-	-	-
Vanadium	-	-	-	7 0E-03 (5)	-	-
Vinyl chloride	1 9E+00 (5)	3.0E-01 (5)	A	-	-	-
Zinc	-	-	D	3 0E-01 (1)	-	-

Sources

1 = IRIS (EPA 1995a)
2 = HEAST (EPA 1994a) Table 2
3 = EPA 1993
4 = Provisional value for cobalt. USEPA. ECAO
5 = HEAST (EPA 1994a)
6 = Joan S Dollarhide Superfund Health Risk Technical Support Center "Carcinogenicity Characterization of Perchloroethylene (PERC) and Trichloroethylene (TCE) (Luke Air Force Base Arizona)" ECAO

Notes

* Calculated from RfC RfD = RfC x 20m^3/day/70kg

** Converted from IRIS unit risks (U R.) Oral proposed U R. = 5E-05/µg/L Inhalation U R. = 4 3E-03/µg/m^3
Oral SF = 5E-05 x 1000µg/mg x 70kg/2L Inhalation SF = 4 3E-03/µg/m^{3}x1000µg/mgx70kg/20m^3

EPA Cancer Weight of Evidence

A = Human carcinogen
B1 = Probable human carcinogen (limited human data)
B2 = Probable human carcinogen (animal data only)
C = Possible human carcinogen
D = Noncarcinogenic (inadequate evidence)
E = Not classifiable or not carcinogenic

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TABLE 6 7-2
SLOPE FACTORS
FOR RADIONUCLIDES

Analyte	GI Absorption Factor (F_1)[1]	Oral (Risk/pCi)	ICRP Lung Class [2]	Inhalation (Risk/pCi)	External (Risk per pCi-year/g)	EPA Cancer Weight of Evidence
Americium 241	1E-03	3 28E 10	W	3 85E-08	4 59E-09	A
Plutonium-239[3]	1E-03	3 16E 10	Y	2 78E-08	1 26E 11[4]	A
Plutonium 240[3]	1E-03	3 15E-10	Y	2 78E-08	1 87E 11[4]	A
Uranium 233/234[5]	5E-02	4 44E 11	Y	1 40E-08	2 14E 11	A
Uranium 238 +D	5E-02	6 20E 11	Y	1 24E-08	5 25E-08	A

Source HEAST Supplement No 2 (EPA 1994a)

[1]Gastrointestinal (GI) absorption factors are the fractional amounts of each radionuclide absorbed across the GI tract into the bloodstream

[2]Lung clearance classification recommended by the International Commission on Radiological Protection (ICRP) Y=year W=week

[3]The external irradiaition slope factor for plutonium-239/240 at RFETS was calculated using the slope factors for each isotope weighted for site specific activities at RFETS (see Section J7 4)

[4]A site specific external irradiation SF for RFETS Pu 239/240 (1 37E-11 per pCi-year/g) based on the specific activity weighted average of the slope factors for Pu 239 and Pu-240 was used as a site-specific estimate of the potential for RFETS Pu 239/240 to produce cancer risk

[5]Slope factors shown are for U 234

A = Class A (human) carcinogen

+D = Risks from radioactive decay products are included

TABLE 6 7-3
EFFECTIVE DOSE COEFFICIENTS FOR RADIONUCLIDES

Radionuclide	f_1 [1]	Ingestion (Sv/Bq)	Class [2]	Inhalation (Sv/Bq)	External [3]
Americium-241	1 00E-03	9 84E-07	W	1 20E-04	2 99E+00
Plutonium-239	1 00E-03	9 56E-07	W	1 16E-04	3 78E-02
	1 00E-04	9 96E-08	Y	8 33E-05	
	1 00E-05	1 40E-08			
Uranium-234[4]	5 00E-02	7 66E-08	D	7 37E-07	8 07E-02
	2 00E-03	7 06E-09	W	2.13E-06	
			Y	3 58E-05	
Uranium-238	5 00E-02	6 88E-08	D	6.62E-07	6 46E-02
	2 00E-03	6 42E-09	W	1 90E-06	
			Y	3 20E-05	

[1] Fractional uptake from small intestine to blood.
[2] Lung clearance class D = days W = weeks Y = years
[3] In units of millirem/yr per microcurie/square meters
[4] Used to evaluate U-233/234

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TABLE 6 8-1
SUMMARY OF ESTIMATED HEALTH RISK
AOC NO 1

	Central Tendency		Reasonable Maximum	
Pathway	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
Current Worker				
Ingestion of surface soil	1 78E-03	1 10E 09	1 13E 02	4 35E 08
Inhalation of particulates from surface soil		6 59E 10		5 22E-09
Dermal contact with surface soil*				
External irradiation		2 51E 10		2 84E-09
Total	1 78E-03	2 01E-09	1 13E-02	5 16E-08
Future Office Worker				
Ingestion of surface soil	8 91E-04	5 49E 10	1 13E-02	4 35E-08
Inhalation of particulates from surface soil		5 00E-10		5 22E-09
Dermal contact with surface soil *				
External irradiation		2 51E 10		2 93E-09
Total	8 91E-04	1 30E-09	1 13E 02	5 17E-08
Future Ecological Worker				
Ingestion of surface soil	1 74E-03	6 72E 10	6 21E-03	2 40E-09
Inhalation of particulates from surface soil		1 22E 10		2 29E 10
Dermal contact with surface soil *				
External irradiation		8 36E 11		1 05E 10
Total	1 74E 03	8 78E 10	6 21E-03	2 73E-09
Future Open Space Recreational Use				
Ingestion of surface soil by a child	2 11E 03		1 05E-02	
Ingestion of surface soil by an adult	2 26E-04		1 13E-03	
Carcinogenic effects of ingestion of surface soil		3 83E 10		6 27E 09
Inhalation of particulates from surface soil		1 41E 11		6 61E 10
Dermal contact with surface soil*				
External irradiation		1 51E 11		2 93E 10
Total	2 34E-03	4 12E 10	1 17E 02	7 22E-09
Future Construction Worker				
Ingestion of subsurface soil	9 27E-05	3 64E 10	5 21E-04	2 04E 09
Inhalation of particulates from surface and subsurface soil	9 37E-08	3 41E 11	1 17E-07	4 24E 11
Dermal contact with subsurface soil*				
External irradiation		1 55E 09		1 94E 09
Total	9 28E-05	1 95E 09	5 21E-04	4 03E-09

Dermal absorption of metals and radionuclides is considered insignificant

Exposure pathway is not relevant for COCs (e g COCs do not have carcinogenic effects)

TABLE 6.8-2
SUMMARY OF ESTIMATED HEALTH RISK
AOC NO. 2

Pathway	Central Tendency		Reasonable Maximum	
	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
Future Office Worker 30-acre area				
Ingestion of surface soil	7 90E-04	5 50E-09	1 00E-02	4 36E-07
Inhalation of particulates from surface soil		5 47E-09		5 71E-08
Dermal contact with surface soil *		-		
External irradiation	-	2 11E-09		2 47E-08
Inhalation of VOCs from infiltration	2 34E-12	3.09E-15	2 45E-11	3 23E-14
Total	7 90E-04	1 31E-08	1 00E-02	5 18E-07
Current Worker				
Ingestion of surface soil	1 82E-03	1 01E-08	1.15E-02	4 02E-07
Inhalation of particulates from surface soil		6 89E-11		5 46E-10
Dermal contact with surface soil*				
External irradiation		2.06E-09		2 41E-08
Total	1 82E-03	1.23E-08	1 15E-02	4 26E-07
Future Ecological Worker				
Ingestion of surface soil	1 78E-03	6 20E-09	6 34E-03	2.21E-08
Inhalation of particulates from surface soil		1.28E-11		2 82E-11
Dermal contact with surface soil *		-		
External Irradiation		6 88E-10		8 59E-10
Total	1.78E-03	6 90E-09	6 34E-03	2 30E-08
Future Open Space Recreational Use				
Ingestion of surface soil by a child	2.15E-03	-	1 08E-02	
Ingestion of surface soil by an adult	2 31E-04	-	1 15E-03	
Carcinogenic effects of ingestion of surface soil		3 53E-09		5 78E-08
Inhalation of particulates from surface soil		1 47E-12		6 91E-11
Dermal contact with surface soil*				
External irradiation		1 24E-10		2 41E-09
Total	2 38E-03	3 66E-09	1 19E-02	6.03E-08
Future Construction Worker				
Ingestion of subsurface soil	1 15E-04	1 89E-09	6 43E-04	1 06E-08
Inhalation of particulates from surface and subsurface soil	1 16E-07	3 62E-12	1.45E-07	4 51E-12
Dermal contact with subsurface soil*				
External irradiation		8 02E-10		1 00E-09
Total	1 15E-04	2 69E-09	6 43E-04	1 16E-08

* Dermal contact with metals and radionuclides is considered insignificant.

Exposure pathway is not relevant for COCs (e g. COCs do not have carcinogenic effects)

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TABLE 6 8-3
SUMMARY OF ESTIMATED HEALTH RISK
AOC NO 3

	Central Tendency		Reasonable Maximum	
Pathway	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
Future Ecological Worker				
Ingestion of pond sediment	7 32E 05	1 79E-09	8 71E-04	2 13E-08
Ingestion of stream/drv sediment	5 57E 06	2 78E 10	6 63E 05	3 30E-09
Inhalation of particulates from stream/dry sediment		5 27E 13		9 03E 13
Dermal contact with pond sediment	4 55E 04	2 51E-09	4 33E-03	2 39E-08
Dermal contact with stream/drv sediment*				
Ingestion of surface water	5 60E-08	3 18E 12	4 80E-07	2 73E 11
Dermal contact with surface water	3 55E-06		6 08E 06	
External irradiation from stream/dry sediment		1.67E 11		3 62E 11
Total	5 37E 04	4 59E-09	5 28E-03	4 85E-08
Future Open Space Recreational Use				
Ingestion of pond sediment by a child	3 40E-03		1 70E 02	
Ingestion of pond sediment bv an adult	3 66E-04		1 82E 03	
Carcinogenic effects of ingestion of pond sediment		4 62E 08		7 47E 07
Ingestion of stream/drv sediment bv a child	2 59E 04		1 29E-03	
Ingestion of stream/dry sediment bv an adult	2 77E-05		1 39E-04	
Carcinogenic effects of ingestion of stream/drv sediment		1 08E-08		1 71E 07
Inhalation of particulates from stream/drv sediment		1 69E-12		7 90E 11
Dermal contact with pond sediment	7 81E-05	1 55E-09	5 17E-03	3 42E-07
Dermal contact with stream/drv sediment*				
Ingestion of surface water	5 01E-08	1 02E 11	6 01E-07	4 09E 10
Dermal contact with surface water	6 23E 07		7 62E-06	
External irradiation from stream/drv sediment		3 16E 11		6 14E 10
Total	4 13E-03	5 86E-08	2 54E-02	1 26E-06

* PAHs metals and radionuclides are the only COCs in stream/drv sediment Dermal absorption of metals and radionuclides is considered insignificant EPA has stated that it is inappropriate to assess dermal absorption of PAHs using the oral slope factor (EPA 1989a)

Exposure pathwav is not relevant for COCs (e g , COCs do not have carcinogenic effects)

TABLE 6.8-4
SUMMARY OF ESTIMATED HEALTH RISK
AOC NO 4

Pathway	Central Tendency		Reasonable Maximum	
	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
Future Ecological Worker				
Ingestion of pond sediment	2 61E-04	8 15E-09	3 11E-03	9 70E-08
Ingestion of stream/dry sediment	4 78E-06	3 49E-10	5 69E-05	4 48E-09
Inhalation of particulates from stream/dry sediment		4 12E-13		7 06E-13
Dermal contact with pond sediment	3 32E-03	1 84E-09	3 17E-02	1 75E-07
Dermal contact with stream/dry sediment*				
Ingestion of surface water	1 34E-06	4 65E-11	1 15E-05	1 52E-10
Dermal contact with surface water	7 48E-05	8 24E-10	1 28E-04	1 41E-09
External irradiation from stream/dry sediment		3 48E-11		7 54E-11
Total	3 67E-03	2 78E-08	3 30E-02	2 78E-07
Future Open Space Recreational Use				
Ingestion of pond sediment by a child	1 21E-02		6 06E-02	
Ingestion of pond sediment by an adult	1 30E-03		6 49E-03	
Carcinogenic effects of ingestion of pond sediment		2.05E-07	-	3 32E-06
Ingestion of stream/dry sediment by a child	2 22E-04		1 11E-03	
Ingestion of stream/dry sediment by an adult	2 38E-05		1 19E-04	-
Carcinogenic effects of ingestion of stream/dry sediment		1 67E-08		2 62E-07
Inhalation of particulates from stream/dry sediment		1 32E-12		6 18E-11
Dermal contact with pond sediment	5 70E-04	1 13E-08	3 78E-02	2 50E-06
Dermal contact with stream/dry sediment*				-
Ingestion of surface water	1 20E-06	5 72E-11	1 44E-05	2 29E-09
Dermal contact with surface water	1 31E-05	5 19E-10	1 61E-04	2 12E-08
External irradiation from stream/dry sediment		6 58E-11		1 28E-09
Total	1 42E-02	2 34E-07	1 06E-01	6 10E-06

*PAHs, metals and radionuclides are the only COCs in stream/dry sediment. Dermal absorption of metals and radionuclides is considered insignificant. EPA has stated that it is inappropriate to assess dermal absorption of PAHs using the oral slope factor (EPA 1989a).

Exposure pathway is not relevant for COCs (e.g. COCs do not have carcinogenic effects)

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TABLE 6 9-1
SUMMARY OF ANNUAL RADIATION DOSE
AOC NO 1

Pathway	Annual Radiation Dose Central Tendency (mrem/year)	Annual Radiation Dose Reasonable Maximum (mrem/year)
Current Worker		
Ingestion of surface soil	1 11E-03	7 05E-03
Inhalation of particulates from surface soil	1 86E-03	2 36E-03
External irradiation from surface soil	3 90E-03	7 12E-03
Total	6 87E-03	1 65E-02
Future Office Worker		
Ingestion of surface soil	5 56E-04	7 05E-03
Inhalation of particulates from surface soil	1 41E-03	2 36E-03
External irradiation from surface soil	3 90E-03	7 12E-03
Total	5 87E-03	1 65E-02
Future Ecological Worker		
Ingestion of surface soil	1.09E-03	3 89E-03
Inhalation of particulates from surface soil	5 51E-04	1 03E-03
External irradiation from surface soil	1 85E-03	2 32E 03
Total	3 49E-03	7 24E-03
Future Open Space Recreational Use		
Ingestion of surface soil	1 72E-04	8 47E-04
Inhalation of particulates from surface soil	1 77E-05	2 48E-04
External irradiation from surface soil	4 75E-05	2 85E-04
Total	2 37E-04	1 38E-03
Future Construction Worker		
Ingestion of subsurface soil	2 72E-04	1 53E-03
Inhalation of particulates from surface and subsurface soil	3 84E-04	4 78E-04
External irradiation from subsurface soil	3 76E-04	4 70E-04
Total Annual Radiation Exposure (mrem/yr)	1 03E 03	2 47E-03

TABLE 6.9-2
SUMMARY OF ANNUAL RADIATION DOSE
AOC NO 2

Pathway	Annual Radiation Dose Central Tendency (mrem/year)	Annual Radiation Dose Reasonable Maximum (mrem/year)
Future Office Worker, 30-acre area		
Ingestion of surface soil	4 71E-03	5 98E-02
Inhalation of particulates from surface soil	1 54E-02	2 57E-02
External irradiation from surface soil	3 30E-02	6 03E-02
Total	5 31E-02	1 46E-01
Current Worker		
Ingestion of surface soil	9 18E-03	5 82E-02
Inhalation of particulates from surface soil	1 94E-04	2 46E-04
External irradiation from surface soil	3 22E-02	5 88E-02
Total	4 15E-02	1 17E-01
Future Ecological Worker		
Ingestion of surface soil	8 99E-03	3 21E-02
Inhalation of particulates from surface soil	5 75E-05	1 08E-04
External irradiation from surface soil	1 53E-02	1 91E-02
Total	2 43E-02	5 13E-02
Future Open Space Recreational Use		
Ingestion of surface soil	1 42E-03	6 99E-03
Inhalation of particulates from surface soil	1.84E-06	2.59E-05
External irradiation from surface soil	3 92E-04	2 35E-03
Total	1 81E-03	9 36E-03
Future Construction Worker		
Ingestion of subsurface soil	3 53E-04	1 98E-03
Inhalation of particulates from surface and subsurface soil	4 05E-05	5 04E-05
External irradiation from subsurface soil	3 60E-04	4 50E-04
Total	7 53E-04	2 48E-03

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TABLE 6 9-3
SUMMARY OF ANNUAL RADIATION DOSE
AOC NO 3

Pathway	Annual Radiation Dose Central Tendency (mrem/year)	Annual Radiation Dose Reasonable Maximum (mrem/year)
Future Ecological Worker		
Ingestion of pond sediment	1 78E-03	2 12E-02
Ingestion of stream/dry sediment	6 36E-05	7 58E-04
Inhalation of particulates from stream/dry sediment	8 47E-07	1 45E-06
Ingestion of surface water	3 72E-06	3 19E-05
External irradiation from stream/dry sediment	4.42E-04	9 48E-04
Total	2 29E-03	2.29E-02
Future Open Space Recreational Use		
Ingestion of pond sediment	1 08E-02	5 29E-02
Ingestion of stream/dry sediment	3 85E-04	1 89E-03
Inhalation of particulates from stream/dry sediment	7 52E-07	1 06E-05
Ingestion of surface water	3 32E-05	3 99E-05
External irradiation from stream/dry sediment	1.05E-04	7 90E-04
Total	1 13E-02	5 57E-02

TABLE 6.9-4
SUMMARY OF ANNUAL RADIATION DOSE
AOC NO. 4

Pathway	Annual Radiation Dose Central Tendency (mrem/year)	Annual Radiation Dose Reasonable Maximum (mrem/year)
Future Ecological Worker		
Ingestion of pond sediment	1 84E-02	2 19E-01
Ingestion of stream/dry sediment	3 76E-04	1 48E-03
Inhalation of particulates from stream/dry sediment	6 68E-07	1 14E-06
Ingestion of surface water	4 28E-05	3 67E-04
External irradiation from stream/dry sediment	8.94E-04	1.09E-03
Total	1 97E-02	2.22E-01
Future Open Space Recreational Use		
Ingestion of pond sediment	1.12E-01	5 48E-01
Ingestion of stream/dry sediment	2 28E-03	1 48E-03
Inhalation of particulates from stream/dry sediment	5.94E-07	8 35E-06
Ingestion of surface water	3 82E-04	4 59E-04
External irradiation from stream/dry sediment	2.08E-04	1.56E-03
Total	1 15E-01	5 52E-01

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TABLE 6 10-1
SUMMARY OF HEALTH RISKS FOR SPECIAL-CASE CHEMICALS OF CONCERN AND CHEMICALS OF INTEREST (COIs)

Exposure Pathway/Receptor	Central Tendency Hazard Index	Central Tendency Carcinogenic Risk	Reasonable Maximum Exposure Hazard Index	Reasonable Maximum Exposure Carcinogenic Risk
Special-Case COC				
Residential Ingestion of Vinyl Chloride in Groundwater				
AOC No. 2				
Vinyl Chloride		4 33E-04		1 03E-02
Chemicals of Interest (COIs)				
Residential Ingestion of Metals in Groundwater				
AOC No. 2				
Antimony	1 59E-01		1 13E+00	
Arsenic	3 18E-02	2 09E-06	2 26E-01	4 95E-05
Beryllium	7 69E-04	2 13E-06	5 48E-03	5 05E-05
Manganese	1 10E+00		7 93E+00	
Total	1 31E+00	4 21E-06	9 30E+00	1 00E-04
Background				
Antimony	3.08E-01		2 19E+00	
Arsenic	2 56E-02	1 68E-06	1 83E-01	3 99E-05
Beryllium	2.31E-03	6 38E-06	1 64E-02	1 51E-04
Manganese	8 23E-02		5 86E-01	
Total	4 18E-01	8 06E-06	2 98E+00	1 91E-04
Ingestion of Arsenic In Stream/Dry Sediment (Open Space Recreational User)				
AOC No 3				
Arsenic (Child)	1.92E-03		4 94E-03	
Arsenic (Adult)	3 39E-05		5 29E-04	
Arsenic (Carcinogenic)		6 05E-09		3 08E-07
Total	1 95E-03	6 05E-09	5 47E-03	3 08E-07
AOC No. 4				
Arsenic (Child)	1 09E-03		3 71E-03	
Arsenic (Adult)	2 55E-05		3 98E-04	
Arsenic (Carcinogenic)		4 55E-09		2 32E-07
	1 12E-03	4 55E-09	4 11E-03	2 32E-07
Background				
Arsenic (Child)	1 10E-03		3 73E-03	
Arsenic (Adult)	2 46E-05		4 00E-04	
Arsenic (Carcinogenic)		4 56E-09		2 33E-07
Total	1 13E-03	4 56E-09	4 13E-03	2 33E-07

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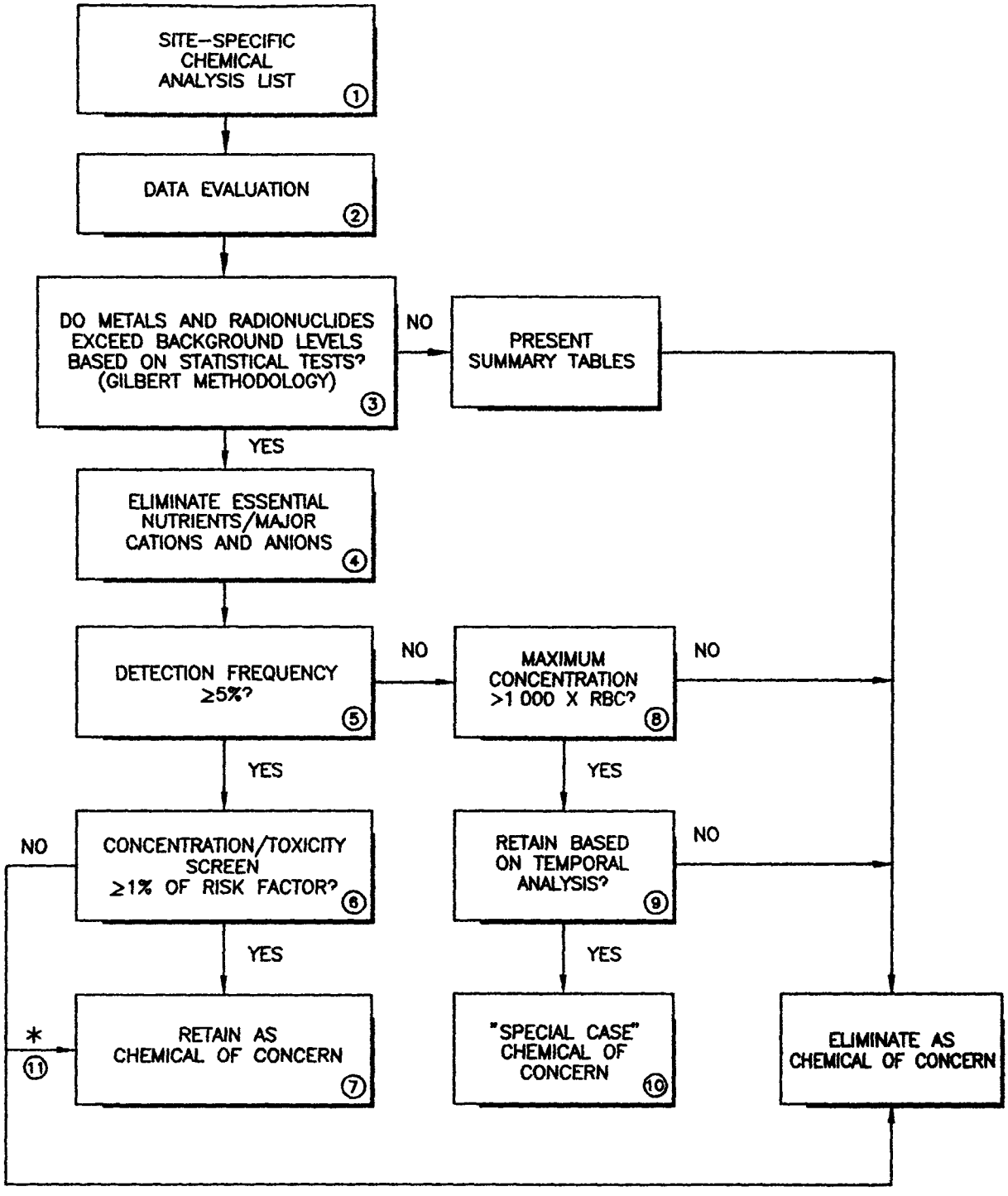

* PROFESSIONAL JUDGEMENT
RBC RISK-BASED CONCENTRATION

U S DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden Colorado

OPERABLE UNIT NO 6
PHASE I RFI/RI REPORT

PROCESS FOR IDENTIFYING CHEMICALS OF CONCERN

FIGURE 6 3 1 MARCH 1995

OU6R297 1-1

SUMMARY OF ECOLOGICAL RISK ASSESSMENT FOR THE WOMAN CREEK WATERSHED AT RFETS

The ecological risk assessment (ERA) for the Walnut Creek watershed is summarized in this section ERAs for the Walnut Creek and Woman Creek watersheds were combined and results presented in a single report (Appendix F) The ERAs represent the ecological portions of the baseline risk assessments associated with the RCRA Facility Investigation/Remedial Investigations (RFI/RIs) for OUs 1, 2, 4 (in part), 5, 6, 7, 10 (in part) and 11 ERAs were formerly planned for each OU, and preliminary ecological field investigations were conducted on that basis

The combined ERA was conducted based on recent agreements among the U S Environmental Protection Agency (EPA) Colorado Department of Public Health and Environment (CDPHE), and U S Department of Energy (DOE) The agencies agreed that it is ecologically more appropriate to conduct the ERAs for each watershed this scale is more relevant to ecological receptors because they are not constrained by the administrative boundaries associated with the OUs ERAs are now required for four areas (1) the industrial area/protected area (IA/PA) (2) the Walnut Creek watershed, (3) the Woman Creek watershed~~, and~~ (4) offsite areas, including Great Western Reservoir, Standley Lake, and Mower Reservoir The ERA accompanying this report addresses ecological risks from contaminant sources in the Walnut Creek and Woman Creek watersheds with the RFETS boundaries but outside of the IA/PA

An ERA is required to support the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Record of Decision or the Resource Conservation and Recovery Act (RCRA) Corrective Action Decision for any of the OUs within these areas Sections within CERCLA include statements that both human health and the environment must be considered when assessing risks associated with releases from hazardous waste sites Also, the National Contingency Plan (NCP) specifically states that an environmental evaluation must be performed to assess threats to the environment (40 CFR Part 300 430 [e][2][i][G]) during the overall process of assessing the need to remediate a hazardous waste site The Interagency Agreement (IAG) negotiated among DOE EPA, and CDPHE states that one

objective of the RFI/RI is to provide data to establish the baseline risk assessment for human health and the environment for the OU The methodology used here evaluates the likelihood that adverse ecological effects are occurring or may occur as a result of exposure to one or more chemical stressors (EPA 1992a)

7 1 SUMMARY OF RFETS ECOLOGICAL RISK ASSESSMENT METHODOLOGY

An ecological risk assessment methodology (ERAM) for RFETS was developed to support risk management decisions for individual OUs The approach used is consistent with a screening-level risk assessment appropriate for sites where ecological effects have not been observed but contaminant levels have been measured and can be compared with concentrations considered protective of ecological receptors. The RFETS ERAM draws from DOE and EPA guidance and ERA tools developed at Oak Ridge National Laboratory (ORNL) and the Savannah River Site (DOE 1993a, 1993b, EPA 1992, 1994, Norton *et al* 1992, Opresko *et al* 1994)

The ERAM is documented in three technical memoranda (TMs)

- TM1 - Assessment Endpoints (in preparation)
- TM2 - Sitewide Conceptual Model
- TM3 - Ecological Chemicals of Concern (ECOCs) Screening Methodology

TM1 is currently in preparation and will provide sitewide guidance on developing assessment endpoints the ecological resources to be protected and the objectives of the assessments Specific assessment endpoints and objectives for the Walnut Creek and Woman Creek ERA are identified in Appendix (Section F4)

TM2 (DOE 1995a) describes ecological components of the site that are potentially affected by contamination and presents baseline assumptions and parameter values used in exposure estimates and risk characterization The following information was included in TM2

- Descriptions of the key ecological features of RFETS, including vegetation, wildlife, aquatic organisms, and protected species

- Summaries of existing sitewide monitoring programs

- Exposure pathway models which describe the contaminant transport and exposure mechanisms important in evaluating exposure of ecological receptors to the chemical stressors at RFETS

- Selection criteria for the identification of key ecological receptors

- General exposure parameters for key receptor species

TM3 (DOE 1995b) describes a phased approach to identify ECOCs___the environmental contaminants that are the focus of risk characterization Tier 1 consisted of identifying chemicals detected within each source area that were above background concentrations This was done using a statistical methodology developed specifically for RFETS The result of Tier 1 was a list of PCOCs that was further screened in Tier 2 and Tier 3 using ecotoxicity criteria Tier 2 and Tier 3 screens each required estimates of exposure for the key ecological receptors at RFETS Methods used in Tiers 1, 2 and 3 are explained in detail in Appendix F (Section F3) The watershed ERAs focus on identification and characterization of ECOCs because chemical stressors are usually of greatest concern for ERAs conducted as part of CERCLA investigations (EPA 1994)

7 2 PRELIMINARY EXPOSURE AND RISK SCREEN

An initial step in conducting the watershed ERAs was to evaluate contaminant distribution and identify ECOCs This evaluation required screening-level exposure and risk estimations using data collected during RFI/RI activities and sitewide environmental monitoring programs The screen corresponds to the preliminary exposure and risk calculation step of the EPA procedure for conducting ERAs at Superfund sites (EPA 1994)

The purpose of the sitewide ERA is to provide information that is useful for both evaluating ecological risk on a watershed basis and making decisions regarding remedial actions associated with the individual OUs and IHSSs within them Therefore, ecological risks were estimated for distinct subareas of each watershed called ERA source areas which were identified by grouping IHSSs based on OU location and contaminant sources (Figure 7 2-1)

Source area boundaries were determined based on abiotic and biotic sampling locations Risks were quantified for each source area separately and their contribution to overall risk in the watershed was determined

The primary objective of the ecotoxicity screen is to evaluate exposures to determine if the chemical concentrations represent an ecotoxicological threat. The risk was evaluated by comparing site exposures to toxicity reference values (TRVs) or benchmark exposures that, if exceeded, could result in adverse effects TRVs were derived to represent the No-Observed-Adverse-Effects Level (NOAEL) for sublethal systemic and reproductive effects The approach to derivation of TRVs is described in TM3 Specific uses of TRVs for the watershed ERAs is presented in Appendix F (Section F3 2 6)

Assistance in developing TRVs was solicited from other sites in the DOE complex and associated academic institutions Site-specific ecotoxicological benchmarks were derived using methods developed at Oak Ridge National Laboratories (ORNL) (Opresko *et al.* 1994) Toxicologists from Clemson University and radioecologists from Oregon State University and Argonne National Laboratory conducted extensive literature searches for the remaining PCOCs and developed preliminary benchmarks Life history information on representative species found at RFETS was obtained from EPA (1993) or scientific literature and documented by in TM2 (DOE 1995a)

Risk was estimated by comparing the site exposures to TRVs using the hazard quotient (HQ) approach (EPA 1994) The HQ is the ratio of the site exposure versus the TRV (exposure – TRV) The hazard index (HI) is the sum of individual HQs for individual chemicals and was used to approximate cumulative risk in an area (DOE 1995b) TRVs and exposures were based on calculating effects on individual organisms This approach was taken because the most reliable methods for estimating exposure and effects are individual-based Extrapolation to populations or communities was qualitative and based on area of affected habitat, quality of resources, and species-specific behaviors

ECOC screens were conducted for three wide-ranging species (coyote, mule deer, and red-tailed hawk) and four receptors with more restricted home ranges (limiting species). Risk for wide-ranging species was negligible no HQs or HIs were greater than 1 ECOCs were identified for limiting species and aquatic receptors that may spend all or most of their time

in small areas and therefore, are in more frequent contact with contaminants ECOCs were identified by source area and receptor type and included metals, radionuclides and organic compounds (Table 7 2-1) Cumulative risks were identified based on HIs (Figure 7 2-2)

7 3 PROBLEM FORMULATION AND RISK CHARACTERIZATION

The preliminary risk screen identified ECOCs based on chemical concentrations in abiotic and biotic media and conservative assumptions concerning exposure and toxicity The remainder of the ERA focuses on further characterization of ecological risk from exposure to the ECOCs Specific objectives and approach for risk characterization are described in problem formulation (EPA 1994)

7 3 1 Problem Formulation

The risk characterization has two main goals (1) refine risk estimates through use of less conservative and more realistic assumptions and characterize remaining uncertainty and (2) identify areas, chemicals and media contributing most to risk Where feasible, guidance for developing cleanup criteria protective of assessment endpoints was also provided Where appropriate exposures and risk were summarized by watershed OU, and IHSS to aid in risk management and remediation decisions

Conservative assumptions were used in the Tier 3 screen to improve efficiency of the screen or to account for uncertainty in exposure or toxicity estimates Conservative assumptions were selected to minimize the probability of underestimating risk so that uncertainty would be biased in only one direction (EPA 1994) Refinement of risk estimates involved use of less conservative assumptions and/or site data on direct measurement of toxic effects to reduce uncertainty In most cases a combination of data types was used in a weight-of-evidence approach to risk characterization

The risk characterization for each of the ECOCs included the following activities (1) refine exposure estimates to more accurately reflect site conditions including bioavailability contaminant distribution and frequency and duration of exposures (2) refine toxicity estimates based on more specific evaluation of contaminant forms and potential toxicity (3) review site data to determine if predicted effects were manifested (4) if appropriate

extrapolate effects on individuals to estimate effects to RFETS populations or communities, and (5) identify, characterize, and rank sources of uncertainty and identify data needed to further refine estimates

The risk characterization focused on potential toxic effects of ECOCs to five ecological receptor groups

1 Aquatic life
2 Aquatic-feeding birds
3 Terrestrial-feeding raptors
4 Small mammals
5 Vegetation communities

These receptor groups were selected based on results of the ECOC screen presented in Appendix F (Section F3), either because potential toxicity from ECOCs was identified or because available data were inadequate to conclude that risk was negligible

Assessment endpoints and specific objectives of the risk characterization were identified for each resource category (Appendix F, Table F4-1) Assessment endpoints are explicit expressions of the environmental values to be protected (Suter 1989, EPA 1992a) The purpose of assessment endpoints in this phase of the watershed ERAs was to focus the risk characterization on potential exposures to ECOCs and the specific effects that may result The potential for exposure and toxicity was established in the Tier 3 screen In most cases, the specific effect is defined by the toxicological endpoints on which the TRVs were based. Most of these endpoints were based on chronic sublethal or reproductive effects that were not measured at RFETS Results of toxicity testing or other measurements of effects were available for some groups and were used where appropriate

For each receptor group, assessment endpoints, exposure pathways, and specific goals and objectives are identified and described in Appendix F (Section F4) Where appropriate, a working null hypothesis (H_0) was defined to help guide analysis and evaluation of uncertainty

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7 3 2 Risk Characterization

The risk characterization was completed using qualitative and quantitative approaches described in the problem formulation step In some cases the evaluation focused on assessing the adequacy of data used in exposure calculations In other cases more accurate or quantitative methods were used to estimate frequency or duration of exposures

Specific measurements of metals radionuclides and PCBs in biota were available for evaluating exposures and food-web transfers These data were reliable indicators of exposure (Suter 1993) and also used to evaluate potential impacts to upper level consumers from ECOCs accumulated in forage or prey However, for other ECOCs the risk characterization was largely conducted without the benefit of sampling and analysis specifically designed to evaluate effects of ECOCs Results of risk characterization are presented in detail in sections summarized in the following subsections Risks are also summarized by receptor group, ECOC and ERA source areas in Table 7 3-1

7 3 2 1 Summary of Risks to Aquatic Life

The preliminary risk screen was based on comparisons of chemical concentrations in sediments and surface water to TRVs derived from the literature or calculated using methods recommended by EPA (EPA 1992a) The screen identified several ECOCs in sediments but none for surface water Sediment ECOCs included volatile and semivolatile organics PCBs and metals

The magnitude of sediment HQ and HI values for some sites in Walnut Creek suggested a high level of toxicity to benthic organisms especially in the A- and B-series ponds furthest upstream and closest to the IA of RFETS HQs exceeded 100 for some chemicals at these sites (Appendix F, Figure F5-5) PAHs were the main contributors to risk estimates at most sites in Walnut Creek, accounting for 90 percent or more of the HI in ponds A-1 and B-1 Risk estimates were much lower in the Woman Creek watershed where HIs were below 3, no HQ exceeded 2 6

The risk levels predicted by the HQ and HI calculations were verified using results of sediment toxicity tests and site data on benthic community structure If estimates of potential

toxicity (i e , TRVs) and exposures were relatively accurate, then the extremely wide range of HI and HQ values should correspond to varying levels of toxicity to test organisms and impacts on benthic communities Physical stress such as fluctuating water levels and the presence of organisms in upper trophic levels (e g , fish) represent confounding factors in this analysis However, if toxicity is an important factor in controlling benthic community structure, then results should indicate some level of correlation between predicted toxicity (i e , HIs or HQs) and level of impacts

Correlations were evaluated using cluster analysis and regression methods. Cluster analyses (Ludwig and Reynolds 1988) were conducted to determine whether groups of sites with similar community composition (e g , total organism density and species richness) also had similar HIs or HQs Regression methods (Sokal and Rholf 1968) were used to estimate if the proportion of variation in community structure could be explained by differences in HIs

Results indicate that predicted toxicity accounts for some of the variation in community composition, but other factors are clearly important. Groups that were identified by cluster analysis based on density, richness, and pollution tolerance were not similar to those identified when the same analysis was conducted using HIs However, differences in HIs did account for about 50 percent of the variation in rank order of ponds with respect to richness Results of sediment toxicity testing did not indicate significant toxicity in any of the ponds except Pond B-2, which did not have the highest HIs

These results suggest that although toxicity tests do not show robust toxicity, effects of sediment contamination may be manifested in the benthic community structure of the detention ponds However, other factors such as size, fluctuating water levels, and the presence or absence of upper trophic levels are also important Potential toxicity of sediment contaminants particularly PAHs, may be important factors in limiting aquatic communities if physical stress was reduced through a change in management of the ponds

It should be noted that the ponds were constructed to minimize offsite transport of contaminants especially radionuclides, in sediments and surface water The presence of PAHs and metals in sediments are in part, a result of runoff from industrial areas and input from the wastewater treatment plant The fact that sediment contaminant concentrations

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decrease dramatically with distance downstream indicates that the ponds are effective in attenuating offsite transport of sediment-bound contaminants

7 3 2 2 Summary of Risks to Aquatic-Feeding Birds

Sediment contamination may also affect wildlife that feed in contaminated areas ECOCs identified for aquatic-feeding wildlife included PCBs (Aroclor-1254) DBP, and mercury Great blue herons and mallards were identified as representative receptors because birds are more sensitive to many contaminants than mammals

Aroclor-1254 was detected in sediments of the A- and B-series ponds with the highest concentrations in ponds B-1 and B-2 Available data on PCB content of aquatic biota indicated negligible levels for birds feeding on fish, amphibians or invertebrates from the ponds However biological tissue data were not available to evaluate the potential risk from all the ponds for which PCBs were detected in sediments Therefore, site-specific data on uptake of PCBs by aquatic species were used to estimate the maximum concentration in sediments that would ultimately result in exposures of herons and mallards that are equal to or less than the TRV Estimates were based on the organic carbon content of sediments and calculated for a range of levels of site use by the birds

Risk estimates also accounted for the effects of food chain length on biomagnification Accumulation of PCBs in upper level consumers is proportional to the length of the food chain through which PCBs are transferred from sediments to top consumers (Rassmussen *et al* 1990) Calculations were made for two hypothetical food chains (1) one in which a species such as fathead minnows that feed primarily on zooplankton and algae is the primary prey of aquatic-feeding birds and (2) one in which the main food source is a piscivorous species such as largemouth bass

Results indicate that risks to herons or mallards are negligible if they feed on fish or invertebrates from lower trophic levels However, herons may experience toxic exposures if they feed on upper level consumers from ponds B-1 B-2 or B-3 more than about 40 percent of the time The communities in these ponds currently lack the upper trophic levels but possible future introduction of predaceous fish or other upper level consumers could result in increased exposure to aquatic birds The sediment criteria calculated for evaluating risk

can also be used by risk managers in making decisions concerning management of pond sediments

7.3.2.3 Summary of Risks to Terrestrial-Feeding Raptors

Chromium, lead, mercury, and vanadium were detected in terrestrial arthropods from OU2 and small mammals from OU4 and OU6 source areas (OU4/6 area) at concentrations that could be toxic to raptors feeding extensively in the areas. American kestrels were selected to represent ecological receptors because they have relatively small home ranges and are known to breed at RFETS

The preliminary risk estimate for chromium in terrestrial arthropods from OU2 was based on the maximum detected concentration from the East Trenches source area. Chromium concentrations in terrestrial arthropods from the 903 Pad area were estimated based on data from the East Trenches Thus, data were inadequate to accurately estimate exposures However, review of the OU2 data suggests that the maximum concentration was anomolously high and its use overestimates risk The mean chromium concentration in OU2 soils was not elevated compared to background, and chromium was included in the PCOCs because of two samples that exceeded the background $UTL_{99/99}$ The OU2 source areas represent a small portion of the mesic and xeric mixed grassland habitat type at RFETS Thus, exposure to chromium in OU2 does not appear to represent a significant ecological risk to kestrels given the low magnitude of the exposures, probable overestimate of exposure, and relatively small area involved

Preliminary risk estimates indicated that chromium, lead, mercury, and vanadium could also present a risk to raptors feeding extensively in the areas around the A- and B-series ponds Review of data revealed that vanadium and mercury were detected with low frequency and at relatively low concentrations and probably do not represent an ecological risk However, chromium and mercury concentrations were consistently elevated in small mammal samples collected from the pond margins The source of the elevated concentrations in small mammals is not clear because neither metal was consistently elevated in soils or dry sediments They were both included in the PCOCs because of samples that exceeded the $UTL_{99/99}$ for soils and sediments Few small mammals collected from sites further from the ponds contained detectable quantities of either metal

Probabilistic exposure estimates indicate that kestrels feeding primarily on small mammals in the OU4/6 areas are likely to ingest chromium and lead at rates that exceed background intakes and TRVs These estimates must be considered conservative because they assume that kestrels feed only on small mammals and small mammal samples from the pond areas are probably over-represented in the data set Further sampling would be required to more accurately evaluate exposures and identify the source of chromium and lead in small mammals

7 3 2 4 Summary of Risks to Small Mammals

Preliminary risk estimates indicated little risk to small mammals from ingestion of contaminants in RFETS source areas Barium and selenium were identified as ECOCs in the (OU6) North Spray Field and OU7 Downgradient source areas, respectively Both metals were detected at potentially ecotoxic concentrations in vegetation Risk was evaluated for populations of more common species and individuals of Preble s meadow jumping mouse, a species of special concern at RFETS

Exposure to barium in the North Spray Field appears to represent little risk to small mammal populations at RFETS The North Spray Field includes about 0 64 percent of the mesic mixed grassland habitat type in the Walnut Creek watershed and does not appear to contain resources that are not common in other grassland areas of the site Thus, a negligible proportion of populations of common grassland species are likely to be affected However this source area includes areas identified as potential habitat for the jumping mouse and exposure of individuals of this species is of concern

The HQ for barium ingestion from the site was 1 05 The TRV for barium was based on concentrations that produced hypertension in laboratory rats (Perry *et al* 1983 as cited in Opresko *et al* 1994) The concentration on which the NOAEL was based was the maximum dose in the study and did not affect growth or food or water consumption in experimental animals Therefore the level of risk associated with exceeding the TRV is unclear Thus the barium concentration in vegetation in this source area may produce some adverse effects in individual animals but the potential for long-term effects on growth or reproduction is unclear but appears to be minimal

The source of selenium in vegetation from the OU7 downgradient area is not clear This area was not subject to spray evaporation of water from the landfill pond (DOE 1995c) The vegetation samples from the area may have included selenium accumulators (such as *Astragalus* sp) that are common at RFETS The area represents an insignificant proportion of the total mesic grassland habitat at RFETS However, the source area is located within areas identified as probable habitat for the jumping mouse.

The TRV for selenium was based on intakes calculated for background areas of RFETS (0 32 mg/kg/day) because it exceeded the literature-based ecotoxicological benchmark (0 075 mg/kg/day) This suggests that small mammals inhabiting RFETS may be adapted to high ambient concentrations of selenium that are common in semi-arid areas of the Rocky Mountain west However, intakes from the OU7 area are more than twice those estimated for background areas and may represent a risk to individuals that spend all of their time there

The presence of Preble's meadow jumping mouse in the OU7 Downgradient area has not been confirmed However, confirmed captures have been recorded for areas approximately 2 2 km to the east in riparian habitat along Walnut Creek The OU7 Downgradient area does not include the well-developed riparian vegetation of these other areas; therefore, it is probably not critical habitat for the jumping mouse However, it is possible that individuals dispersing from currently inhabited areas could contact vegetation and soils in the OU7 Downgradient area

7.3.2.5 Summary of Risks to Vegetation Communities

HQs for several inorganic contaminants and metals exceeded 1 in subsurface soils and sediments in various source areas The highest HQ for soils was due to nitrates in the OU7 Downgradient area and for silver in sediments of the B-ponds The risks associated with the PCOCs are uncertain As noted previously, no obvious areas of vegetation stress were observed during field investigations. It is possible that concentrations for most ECOC metals in soils are within the range tolerated by plant species at RFETS However, the potential phytotoxicity is not known because soil toxicity tests were not conducted during RFI/RIs

TRVs were not available for most organic soil or sediment PCOCs HQs were well below 1 for organic PCOCs for which TRVs were available However as with metals the potential phytotoxicity of most organic PCOCs was not quantified with plant toxicity tests

7 3 2 6 Summary of Risks from Radionuclides

Transuranic radionuclides were identified as PCOCs for most OUs The ECOC screen indicated relatively few areas with radionuclide concentrations (activities) in soils that exceeded TRVs Plutonium-239/240 and americium-241 concentrations in soils exceeded TRVs in two locations in the 903 Pad source areas, and uranium-233/234 and uranium-238 concentrations in soils of the Old Landfill exceeded TRVs at two locations Radionuclides were also elevated in vegetation and small mammals collected from ERA source areas

The potential risks from radionuclide uptake by biota were evaluated by calculating the internal radiological dose and comparing it to the TRV. The TRV was based on a benchmark value of 0 1 rad/day, which was identified by IAEA (1992) as protective of biological receptors Results indicated that maximum radionuclide concentrations measured in small mammal resulted in dose rates at least 1 000 times less than the TRV The potential uptake by predators was also evaluated and indicated that risks to predators were also not significant Thus although abiotic media and biota contain elevated concentrations of transuranic radionuclides risks of adverse effects appear to be negligible

7 4 CONCLUSIONS

Ecotoxic risks to terrestrial plants and animals at RFETS are restricted to very localized areas and do not appear to be of sufficient magnitude to affect population community or systemic functions Physical factors especially disturbance due to construction or other plant activities appear to be far more important in determining community structure and habitat suitability around the industrialized areas of the site

Elevated levels of chromium and lead in small mammals may represent a risk to individual kestrels or other raptors that feed exclusively around the A- and B-ponds However exposures probably would not result in effects on the kestrel population at RFETS The exposure estimate probably overestimates risk to individuals because (1) TRVs are based on

chronic sublethal effects, (2) 100 percent bioavailability was assumed, and (3) site use was assumed to be 100 percent Further characterization of the contaminant sources and exposures should be conducted before decisions to remediate soils or sediments are based on this endpoint

Risks to aquatic life and aquatic-feeding wildlife are primarily due to sediment contaminants in the B-ponds HQs and HIs indicate that PAHs are the most important contaminant in evaluating risk to aquatic biota. However, results of preliminary toxicity tests do not indicate the level of toxicity predicted by risk estimates PCBs in sediments of ponds B-1, B-2, and B-3 could represent a risk to aquatic-feeding birds if aquatic communities in those ponds were more fully developed and include substantial populations of upper-level consumers such as largemouth bass However, under current biological conditions, toxic exposure to PCBs does not appear to represent an ecotoxicological risk.

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Table 7 3 1
Summary of Risk Estimates for ECOCs by Source Area
Walnut Creek Watershed

Source Areas	Receptors at Risk	Exposure Points Contributing the Most Risk	ECOC	HQ
North Walnut Creek	Aquatic Species	Sediments	Anthracene	110
			Chrysene	32
			Benzo(b)fluoranthene	15
			Methylene chloride	9 5
			Benzoic acid	8 2
			Magnesium	1 6
			Barium	1 4
			Cobalt	1 4
			Vanadium	1 2
			Manganese	1 2
			Strontium	1 1
	Wetland Vegetation Communities	Sediments	Zinc	1 3
			Vanadium	1 3
			Strontium	1 1
South Walnut Creek	Aquatic Species	Sediments	Naphthalene	1 100
			Anthracene	140
			Chrysene	38
			Benzo(b)fluoranthene	19
			Methylene chloride	17
			Zinc	1 8
			Benzo(k)fluoranthene	1 5
			Magnesium	1 3
			Benzoic acid	1 3
			Vanadium	1 3
			Barium	1 3
			Strontium	1 3
			Cobalt	1 0
OU2 903 Pad	American Kestrel	Terrestrial Arthropods	Chromium	5 56
	Aquatic Species	Surface Water	Barium	39
	Great Blue Heron	Fish	Aroclor 1254	5 78
	Small Mammals	Sediments	Toluene	1 900
	Small Mammals	Surface Soils	Plutonium 239/240	1 92
	Vegetation Communities	Subsurface Soil	Zinc	1 2
OU2 East Trenches	American Kestrel	Terrestrial Arthropods	Chromium	4 36
	Small Mammals	Subsurface Soil	Toluene	20 0
OU2 Mound Area	American Kestrel	Terrestrial Arthropods	Chromium	2 53
	Vegetation Communities	Subsurface Soil	Zinc	1 4
OU4 Downgradient	American Kestrel	Small Mammals	Mercury	1 36
	Vegetation Communities	Subsurface Soil	Nitrate/Nitrite	4 8
			Zinc	1 4
			Lead	1 3
OU6 A Ponds	American Kestrel	Small Mammals	Lead	1 76
			Chromium	1 33
	Great Blue Heron	Fish	Di N butyl phthalate	16 56
	Mallard	Benthic Macroinvertebrates	Di N butyl phthalate	2 00
	Vegetation Communities	Subsurface Soil	Zinc	1 0
	Great Blue Heron	Sediments	PCBs	NA
	Mallard	Sediments	PCBs	NA

Table 7 3-1
Summary of Risk Estimates for ECOCs by Source Area
Walnut Creek Watershed

Source Areas	Receptors at Risk	Exposure Points Contributing the Most Risk	ECOC	HQ
Pond A 1	Aquatic Species	Sediments	Anthracene	88
			Chrysene	34
			Benzo(b)fluoranthene	18
			Antimony	3 7
			Magnesium	2 4
			Toluene	2.2
			Cobalt	1.8
			Vanadium	1 7
			Aroclor 1254	1 3
			Benzo(k)fluoranthene	1 2
	Wetland Vegetation Communities	Sediments	Antimony	3 8
			Chromium	1.9
			Vanadium	1 7
			Zinc	1 5
Pond A 2	Aquatic Species	Sediments	Aldrin	35,000
			Chrysene	3 9
			Magnesium	2 3
			Zinc	1 9
			Benzoic acid	1 7
			Acetone	1 5
			Cobalt	1 5
			Vanadium	1 4
	Wetland Vegetation Communities	Sediments	Zinc	3 9
			Vanadium	1 4
			Chromium	1 0
Pond A-3	Aquatic Species	Sediments	Chrysene	29
			Benzo(b)fluoranthene	18
			Antimony	3 0
			Magnesium	3 0
			Vanadium	2 8
			Cobalt	2 1
			Zinc	1 0
	Wetland Vegetation Communities	Sediments	Antimony	3 0
			Chromium	2 8
			Vanadium	2 8
			Zinc	2 1
Pond A-4	Aquatic Species	Sediments	Antimony	5 2
			Magnesium	2.6
			Vanadium	2 3
			Cobalt	2 0
	Wetland Vegetation Communities	Sediments	Antimony	5 2
			Vanadium	2 4
			Zinc	1 9
			Chromium	1 6
Pond A 5	Aquatic Species	Sediments	Benzoic acid	7 7
			Acetone	2 9
			Cobalt	1 8
			Magnesium	1 7
			Vanadium	1 6
	Wetland Vegetation Communities	Sediments	Vanadium	1 6
			Chromium	1 3
			Zinc	1 0

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Table 7 3 1
Summary of Risk Estimates for ECOCs by Source Area
Walnut Creek Watershed

Source Areas	Receptors at Risk	Exposure Points Contributing the Most Risk	ECOC	HQ
OU6 B Ponds	American Kestrel	Small Mammals	Lead	1 25
			Vanadium	2 86
	Great Blue Heron	Fish	Mercury	2 40
			Di N butyl phthalate	8 27
	Great Blue Heron	Sediments	PCBs	NA
	Mallard	Sediments	PCBs	NA
Pond B 1	Aquatic Species	Sediments	Naphthalene	3 500
			Fluorene	1 400
			Anthracene	270
			Heptachlor	230
			Chrysene	94
			Silver	90
			Benzo(b)fluoranthene	61
			Aroclor 1254	8 9
			Zinc	4 8
			Methylene chloride	4 3
			Benzo(k)fluoranthene	2 8
			Copper	2 6
			Acetone	2 2
			Magnesium	2 0
			Cobalt	1 6
			Vanadium	1 4
			Dibenzo(ah)anthracene	1 4
	Wetland Vegetation Communities	Sediments	Silver	88 0
			Zinc	10 0
			Chromium	6 6
			Vanadium	1 4
Pond B-2	Aquatic Species	Sediments	Silver	52
			Chrysene	7 7
			Aroclor 1254	4 3
			Magnesium	3 1
			Acetone	3 1
			Cobalt	1 7
			Manganese	1 2
			Vanadium	1 1
	Wetland Vegetation Communities	Sediments	Silver	51 0
			Chromium	2 0
			Zinc	1 7
			Vanadium	1 1
Pond B 3	Aquatic Species	Sediments	Silver	64
			Aroclor 1260	48
			Chrysene	32
			Benzo(b)fluoranthene	18
			Antimony	8 9
			Aroclor 1254	4 0
			Copper	1 9
			Magnesium	1 8
			Cobalt	1 7
			Zinc	1 6
			Vanadium	1 4

Table 7 3-1
Summary of Risk Estimates for ECOCs by Source Area
Walnut Creek Watershed

Source Areas	Receptors at Risk	Exposure Points Contributing the Most Risk	ECOC	HQ
Pond B 3	Wetland Vegetation Communities	Sediments	Silver	63 0
			Antimony	8 9
			Zinc	3 3
			Chromium	2 9
			Vanadium	1 4
Pond B-4	Aquatic Species	Sediments	Anthracene	110
			Chrysene	62
			Benzo(b)fluoranthene	51
			Silver	15
			gamma-BHC (Lindane)	12
			Antimony	3 3
			Magnesium	2 3
			Benzo(k)fluoranthene	2 1
			Vanadium	1 8
			Zinc	1 7
			Aroclor-1254	1 7
			Cobalt	1 5
	Wetland Vegetation Communities	Sediments	Silver	16 0
			Zinc	3 5
			Antimony	3 3
			Vanadium	1 8
			Chromium	1 8
Pond B-5	Aquatic Species	Sediments	Magnesium	2 5
			Vanadium	2 1
			Cobalt	1 6
	Wetland Vegetation Communities	Sediments	Vanadium	2 2
			Zinc	2 0
			Chromium	2 0
OU6 North Spray Fields	Preble s Meadow Jumping Mouse	Vegetation	Barium	1 05
	Vegetation Communities	Subsurface Soil	Chromium	1 2
			Zinc	1 0
OU6 Burial Trenches	Vegetation Communities	Subsurface Soil	Strontium	1 5
OU6 Soil Dump Area	American Kestrel	Small Mammals	Mercury	3 14
	Vegetation Communities	Subsurface Soil	Strontium	1 6
			Zinc	1 0
OU7 Downgradient	Aquatic Species	Surface Water	Barium	45
			Manganese	2 4
			Strontium	1 5
			Barium	45
	Preble's Meadow Jumping Mouse	Vegetation	Selenium	2 36
	Vegetation Communities	Subsurface Soil	Nitrate/Nitrite	170
			Strontium	1 6
			Zinc	1 5

[1]Radionuclide benchmarks use small mammals as the limiting species but Preble s meadow jumping mouse can be substituted because it represents our small mammal receptor
Two significant figures were presented for all receptors except wildlife receptors

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Table 7 3 1
Summary of Ecological Risks for Walnut Creek Watershed

Receptor Group	ECOCs	ERA Source Area	Media/Exposure Point	Conclusions
Wide Ranging Wildlife	None	Not Applicable	Not Applicable	The Tier 3 ECOC screen did not identify ECOCs
Aquatic Life	Metals and Organics in Sediments	OU6 A Ponds OU6 B Ponds	Sediments	Risks are primarily due to PAHs in sediments However no toxicity was detected in sediment toxicity tests with *Hyalella azteca* Importance of sediment contamination is unclear but does not appear to be the to be the primary factor controlling benthic community structure
Aquatic-Feeding Birds	Aroclor 1254	OU6 A-Ponds OU6 B Ponds	Pond Sediments	Aroclor 1254 concentrations in sediment exceeded risk based criteria for ponds B 1 B-2 and B-3 only if top aquatic predators were present Ponds currently do not support this type of community but could if pond management changed
	Mercury	OU6 A Ponds OU6 B Ponds	Fish Tissue	Mercury was detected in 75% of fish from B-ponds However the maximum concentration was detected in B-5 which has the lowest contaminant content The maximum HQ was 2 Mercury does not appear to represent risk to herons
	Di N butyl phthalate	OU6 A Ponds OU6 B-Ponds	Sediments	All samples with detectable DBP concentrations were J qualified Only one sample corresponds to an HQ of 2 all other HQs are ≤ 1 DBP does not appear to represent risk to herons or mallards
Terrestrial Feeding Raptors	Chromium	OU2 903 Pad OU2 East Trenches	Terrestrial Arthropods	Mean chromium concentration in soils was not greater than the background mean No clear contaminant source exists Chromium is not a risk to the kestrel population at RFETS
	Chromium Lead	OU4 Downgradient OU6 A Ponds OU6 B-Ponds	Small Mammals	Chromium and lead were elevated in small mammals from pond areas The source is unclear because soils and sediments contain low levels Risks are possible to individual birds feeding in the area but effects to RFETS population are minimal
	Mercury Vanadium	OU4 Downgradient OU6 A Ponds OU6 B-Ponds	Small Mammals	Mercury and vanadium were detected at low frequency and some concentrations were J qualified Risks appear to be minimal
Small Mammals	Plutonium-239/240 Americium 241	OU2 903 Pad OU2 East Trenches	Soils	Radionuclides do not present significant risk to terrestrial receptors Maximum tissue concentrations do not result in dose rates that exceed the TRV (0 1 rad/day)
	Barium	OU6 North Spray Field	Vegetation	The barium HQ of 1 05 indicates that exposures are very close to the NOAEL Risks to small mammal populations are negligible Some individual jumping mice might be exposed but adverse effects would be minimal
	Selenium	OU7 Downgradient	Vegetation	Selenium exposure exists in a small area but includes habitat for jumping mouse The source of selenium is not clear Levels in vegetation were twice that of background Possible adverse effects to individuals exist but population effects were negligible due to the small area
Vegetation	Metals and Organics	Most Source Areas	Soils Sediments	Nitrates in OU7 and OU4 and silver in B-ponds have the highest risk estimates However ecological risk is unclear because vegetation in these areas does not appear stressed

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8 1 CONCLUSIONS

A Phase I RFI/RI of OU6 was conducted as directed by the Interagency Agreement of 1991 The purpose was to assess the site physical characteristics characterize contaminant sources and the nature and extent of potential contamination in surface soil, subsurface soil groundwater surface water, sediment and air, assess fate and transport of environmental constituents, and estimate potential risks to human health and the environment Field investigations indicate that the site physical characteristics are complex Site meteorologic and hydrogeologic processes combine interactively to provide mechanisms and pathways for surface and subsurface constituents to migrate through the environment

The nature and extent of environmental contamination within OU6 were characterized through the collection, analysis, and assessment of hundreds of samples of various environmental media Environmental samples were analyzed for a comprehensive suite of chemicals to help characterize potential contamination associated with waste handling and disposal practices conducted during the operating history of the Rocky Flats Plant The OU6 data assessment process including rigorous data validation, was designed to be conservative to ensure an accurate and comprehensive understanding of potential contamination conditions in OU6

The results of the OU6 data assessment process indicated the presence of PCOCs in surface soil subsurface soil, groundwater pond and stream surface water, and pond and stream/dry sediments PCOCs identified in one or more of these environmental media include VOCs SVOCs, PCBs/pesticides, metals and other inorganic constituents, and radionuclides The list of PCOCs for each medium was then screened using risk-based and other screening methods to identify COCs for both the HHRA and the ERA The HHRA COCs were selected on an OU-wide basis, for the ERA, COCs were selected on a Walnut Creek watershed basis Primary HHRA COCs were Am-241 and Pu-239/240 in all media, except groundwater, metals in surface and subsurface soil pond sediment, and stream/dry sediment, and Aroclor-1254 in pond sediment The primary ERA COCs were PAHs, PCBs silver, di-n-butyl phthalate chromium lead mercury vanadium selenium and barium in all media analyzed

The presence of COCs in all media is a result of historical releases to the environment Though unlikely under current conditions, COCs in each particular medium have the potential to migrate from locally affected areas to larger areas within the affected medium or to other media via various migration pathways Migration could occur through air, surface water, the vadose zone, and groundwater

The presence of COCs in pond sediments is a result of historical discharges to the ponds and runoff from plant facilities to North and South Walnut creeks. Surface water modeling results indicate that the chemical concentrations in pond sediment will not increase in the future from source loads in OU6, which are insignificant compared to existing pond sediment concentrations Furthermore, little potential exists for contaminated pond sediment transport beyond the ponds themselves, even under extreme precipitation events. Because the model simulation indicates that no net erosion occurs at any of the detention ponds, there is little likelihood for contaminated sediments to migrate out of the system past Indiana Street.

Results of the OU6 Phase I groundwater assessment have shown that groundwater underlying the OU6 study area has been impacted by contaminant migration from source areas within other OUs VOCs were detected in groundwater samples collected from monitoring wells beneath the OU6 trenches south of the Present Landfill (OU7). These compounds are probably derived from either OU10 (PUD Yard) or the Present Landfill and were evaluated as part of the OU7 landfill closure process. A nitrate plume emanating from the Solar Ponds (OU4) was detected in the UHSU groundwater between the Solar Ponds and North Walnut Creek, upstream of Pond A-1, and will be characterized as part of a sitewide groundwater assessment Consistent high concentrations of vinyl chloride and other solvents have been detected in the Valley Fill Alluvium near monitoring Well 3586 located upstream of IHSS 141 and Pond B-1 The similarity between constituents detected in this well and those detected upgradient in OU2 wells suggests that OU2 is the likely source of these solvents Modeling results suggest that vinyl chloride present in Well 3586 is not migrating at significant concentrations as far as the inlet to Pond B-1 and is not expected to affect areas further downgradient under normal conditions Evidence from groundwater sampling and modeling indicates that no contaminants are currently migrating offsite along the Walnut Creek drainage

The OU6 HHRA estimated health risks and annual radiation doses for current and future onsite receptors who could potentially be exposed directly or indirectly to COCs at or released from sources in OU6 Exposure scenarios that were evaluated involved a current industrial worker (security guard), a future industrial/office worker, a future ecological researcher a future open space recreational user, and a future construction worker Future onsite residential receptors were not considered in the HHRA because future land-use plans do not include residential use It was determined during HHRA negotiations with the regulatory agencies that health risks to offsite receptors would not be addressed on an OU-specific basis but would best be examined on a sitewide basis

For the HHRA exposure media evaluated were surface soil, subsurface soil (construction worker only) outdoor and indoor air, and stream and pond surface water and sediments Groundwater was not evaluated as an exposure medium because there are no current or future receptors Risks were evaluated for four AOCs AOC No 1 is the North Spray Field Area AOC No 2 includes the Sludge Dispersal Area, Triangle Area, and Soil Dump Area AOC No 3 includes Ponds A-1, A-2, and A-3 AOC No 4 includes Ponds B-1 through B-4 In addition, risks for the future office worker were evaluated in a 30-acre maximum exposure area in AOC No 2

The risk characterization process combines average and reasonable maximum estimates of exposure with upperbound estimates of toxicity to yield conservative (protective) estimates of health risk Estimates of health risk for average (CT) and reasonable maximum exposure (RME) conditions were provided so that risk management decisions can be based on a range of potential risks for different exposure scenarios

The following are the major conclusions of the HHRA

- AOC No 1 and AOC No 2 Cumulative HIs were below 1 and the RME cancer risk estimates were below EPA's "point of departure" of 1E-06 for all receptors These results indicate that no adverse noncarcinogenic health hazards and negligible cancer risk are expected for all receptors evaluated (current and future workers construction worker open space recreation user and ecological researcher)

- AOC No 3 and AOC No 4 Cumulative HIs were below 1 and RME cancer risk estimates were 5E-06 or below for both receptors The maximum cancer risk estimate of 5E-06 for the open space user is near the lower end of EPA's target risk range of 1E-06 to 1E-04 Ingestion of maximum modeled concentrations of Am-241 and Pu-239/240 in pond sediment over a 30-year exposure duration for open space use is the chief contributor to this estimate of cancer risk Given the conservatism of using maximum concentrations and a 30-year exposure duration, the RME cancer risks estimates for recreational open space exposure to the ponds probably overestimate potential risk The results indicate that there is no unacceptable the risk for the receptors evaluated (open space recreational user and ecological researcher)

- Estimates of annual radiation doses for onsite receptors were less than 0 6 mrem/year, well below the DOE standard of 100 mrem/year for protection of the public

- Vinyl chloride in groundwater in well 3586 (evaluated as a special-case COC) would pose unacceptable risk if directly ingested

The ERA for OU6, the Walnut Creek Watershed, estimated ecological risks associated with current and future effects of contaminants found in the watershed Future impacts from groundwater, which may emerge to surface waters from sources in the Industrial Area, were not addressed, however The conclusions are based on the implementation of the sitewide ERA methodology as approved by the regulatory agencies This methodology stipulated the PCOC screening approach, the site conceptual model, and the relevant ecological receptors

The conclusions of the ERA are summarized in Appendix F, Table F6-1, where ECOCs are identified for each receptor (wide-ranging wildlife, aquatic-feeding birds, terrestrial-feeding raptors, small mammals and vegetation) and contaminated medium in each ERA source area. Potential risks were identified and evaluated through a conservative ECOC screen, the ecological evidence of effects, and the results of toxicity tests Where potential risks were identified, the data supporting the results were evaluated in a weight of evidence approach using professional judgment to make the final assessment of risk

For the Walnut Creek watershed, potential risks from the ECOCs varied by receptor No ecological risks to wide-ranging wildlife were identified Vegetation showed no evidence of stress in field sampling whereas the ECOC screen suggested that adverse effects on vegetation from some contaminants are possible Models suggested that birds that consume fish may be at risk from PCBs in pond sediments if predatory fish such as large-mouth bass are added to ponds B-1, B-2, and B-3 Under the present ecosystem structure these receptors are not at risk Mercury and di-n-butyl-phthalate pose only a nominal risk to aquatic-feeding birds based on data evaluation Terrestrial-feeding raptors may be exposed to metals through consumption of contaminated prey (insects and small mammals), but the data suggest that the sources of metals in the prey are uncertain and that while there may be a potential threat to individual birds populations are not likely to be affected when assumptions about restricted feeding ranges are relaxed Small mammals are not at risk from radionuclides and risk from barium are close to a no-effects threshold Of some concern are the possible effects of selenium in plants to individual small mammals feeding in the ERA source area downgradient of OU7 While small mammal populations are not at risk, individuals may experience adverse effects A further evaluation of this risk may be warranted in order to ensure protection of the Prebles Meadow Jumping Mouse (PMJM) if it is found in this area Field efforts are underway to validate the presence or absence of PMJM in the OU7 downgradient area and "natural" selenium accumulation in plants will be evaluated as the likely source of this contaminant exposure to mice

In summary, ecological risk to receptors as determined by the ECOC screening methodology, ecological monitoring data and toxicity testing have identified few potential threats and no actual negative impacts to RFETS ecosystems from site contaminants In the absence of demonstrated environmental injury the site ecosystems are most likely at risk from future contaminated groundwater emergence and physical disturbance associated with remediation activities

8 2 RECOMMENDATIONS

The results of the Phase I RFI/RI and BRA support the conclusion that environmental contamination within OU6 does not pose a threat to public health or the environment, and that remediation of environmental media to address public health issues is not warranted

Because OU6 contains the Walnut Creek watershed, it will continue to be a potential pathway for contaminants to migrate offsite, either through groundwater or surface water These media should be managed on a sitewide level As long as the RFETS plant is an industrial facility or in the process of decontamination and decommissioning, active monitoring and management of the Walnut Creek watershed should continue. As a best management practice, the ponds should be retained for protection of offsite surface water and continue to provide storm water quality improvement

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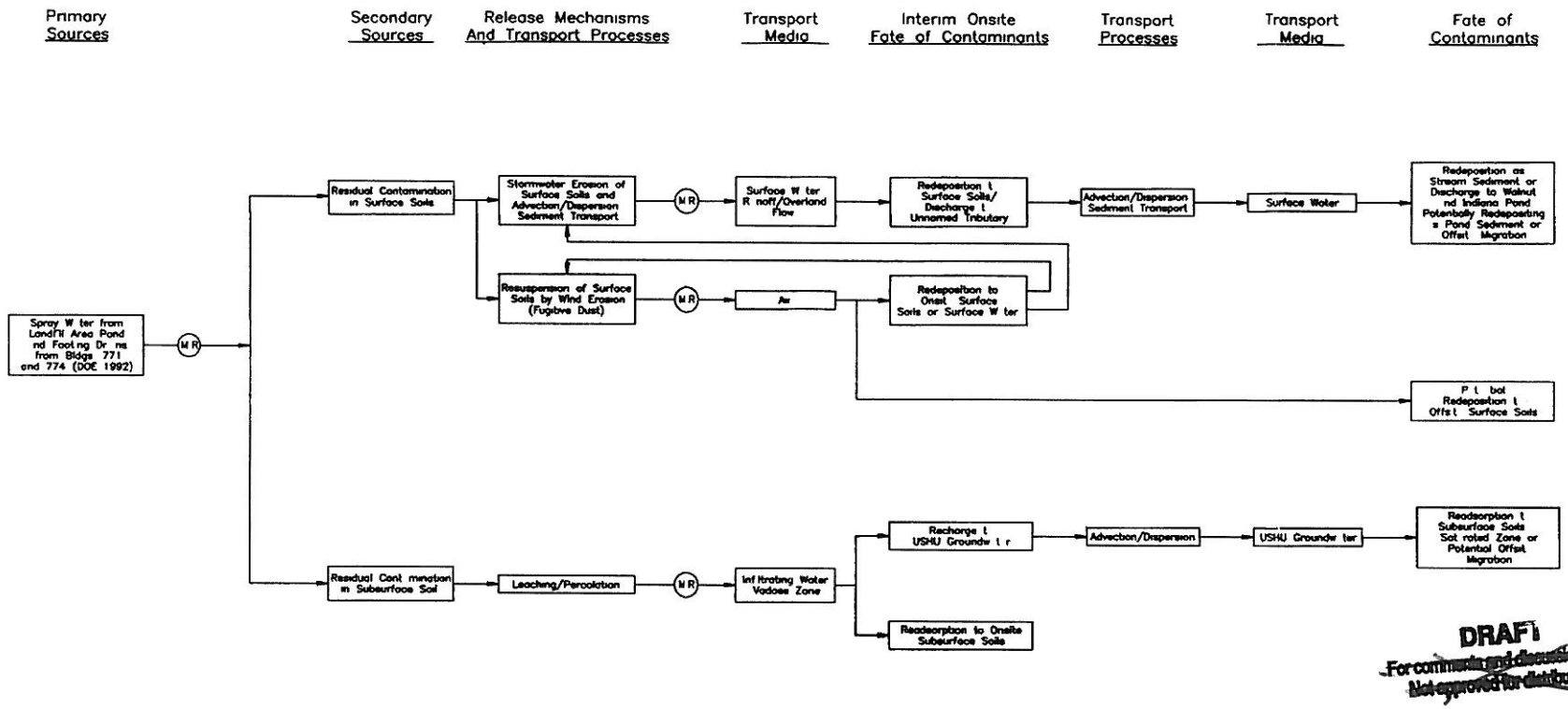

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Legend

M R Analyt Groups Affected
M Met ls
R Radionuclides

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AREA OF CONCERN 1
(NORTH SPRAY FIELD)
MIGRATION PATHWAYS OF
CHEMICALS OF CONCERN

FIGURE 5 3-1 JUNE 1995

0U6RI271 1=1

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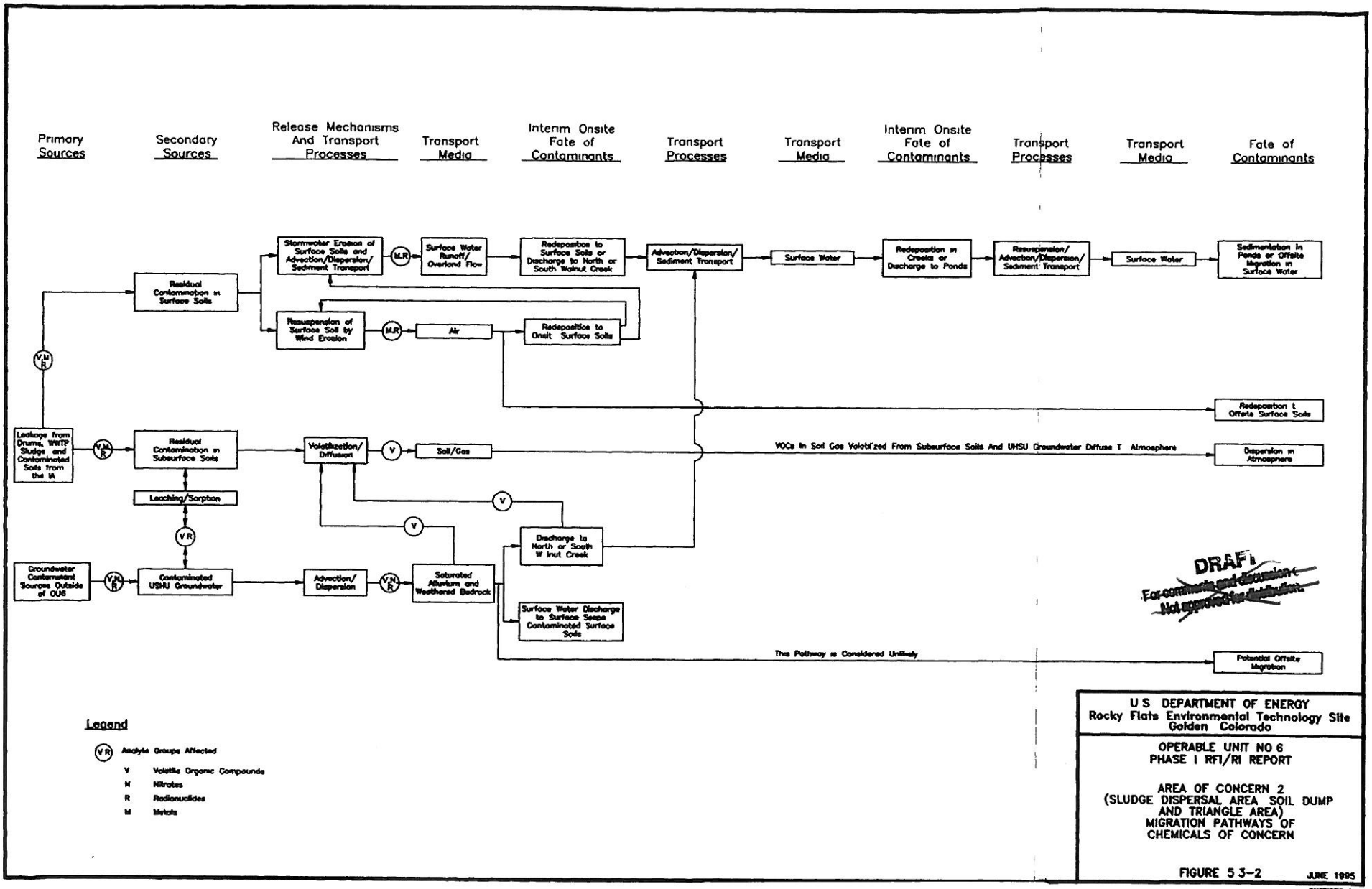

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AREA OF CONCERN 2
(SLUDGE DISPERSAL AREA SOIL DUMP AND TRIANGLE AREA)
MIGRATION PATHWAYS OF CHEMICALS OF CONCERN

FIGURE 5 3-2 JUNE 1995

006R272 1-1

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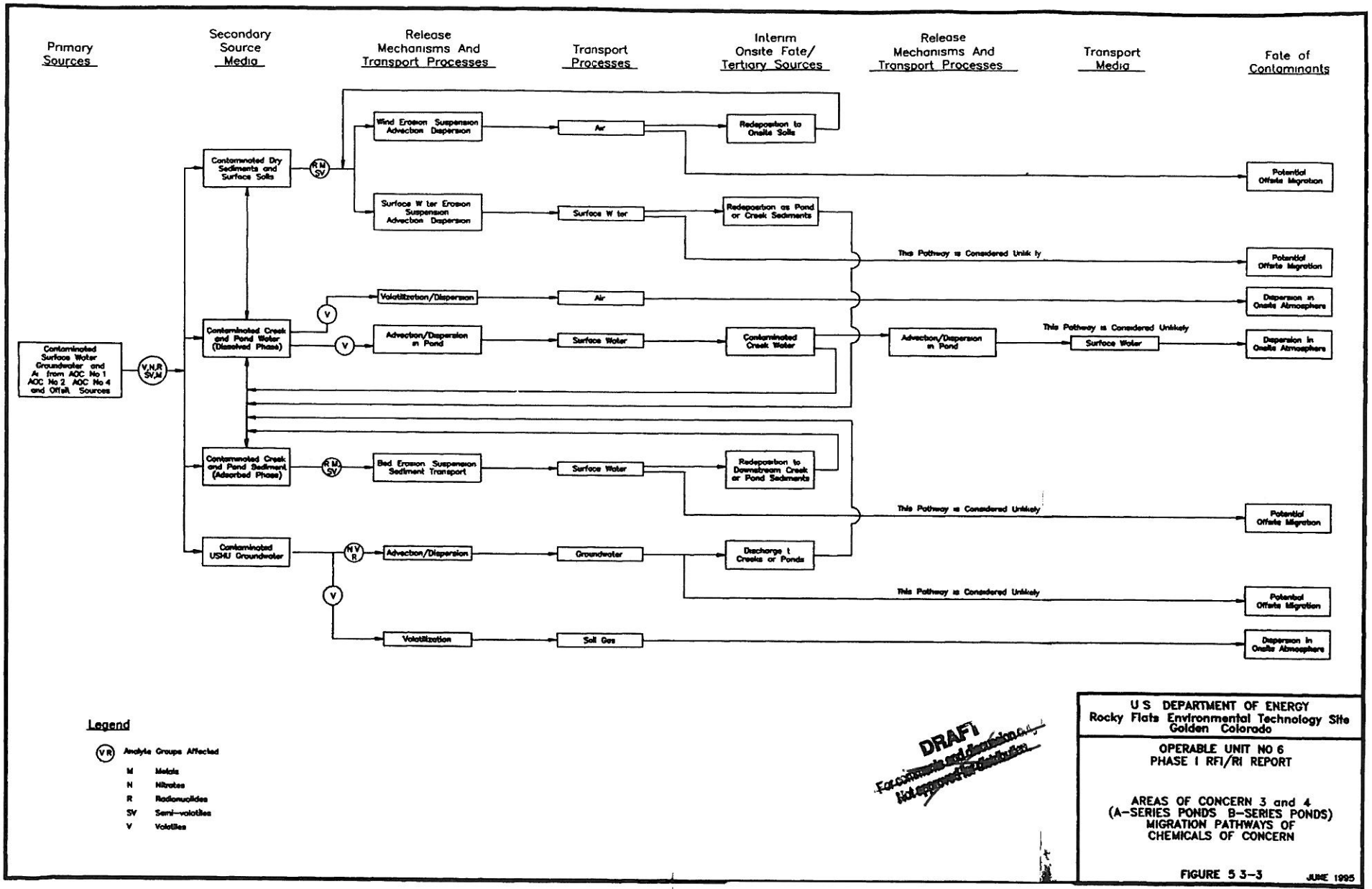

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AREAS OF CONCERN 3 and 4
(A-SERIES PONDS B-SERIES PONDS)
MIGRATION PATHWAYS OF
CHEMICALS OF CONCERN

FIGURE 5 3-3 JUNE 1995

OU6R273 1=1

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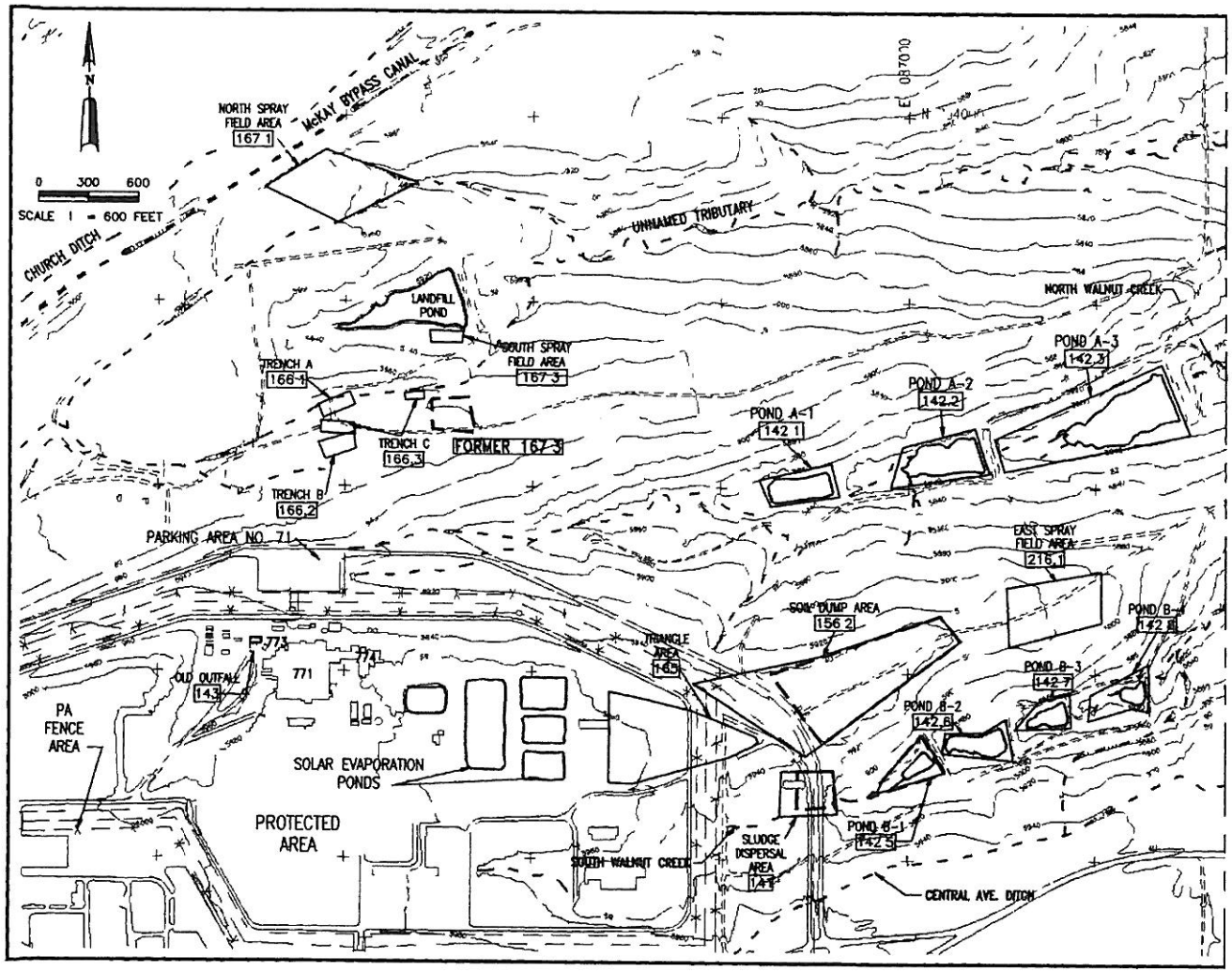

SOURCE: DOE 1992a

EXPLANATION

- INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS) IN OPERABLE UNIT 6 (OU6)
- 142.3 — IHSS REFERENCE NUMBER
- 167.3 — OU6 HISTORICAL IHSS BOUNDARY (DOE 1987)
- PROTECTED AREA (PA) FENCE
- DIRT ROAD
- INTERMITTENT STREAM

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LOCATION AND IDENTIFICATION OF OU6 IHSSs AND DIVERSION STRUCTURES ALONG NORTH & SOUTH WALNUT CREEKS (PAGE 1 OF 2)

FIGURE 6 1-1 REV APRIL 1995

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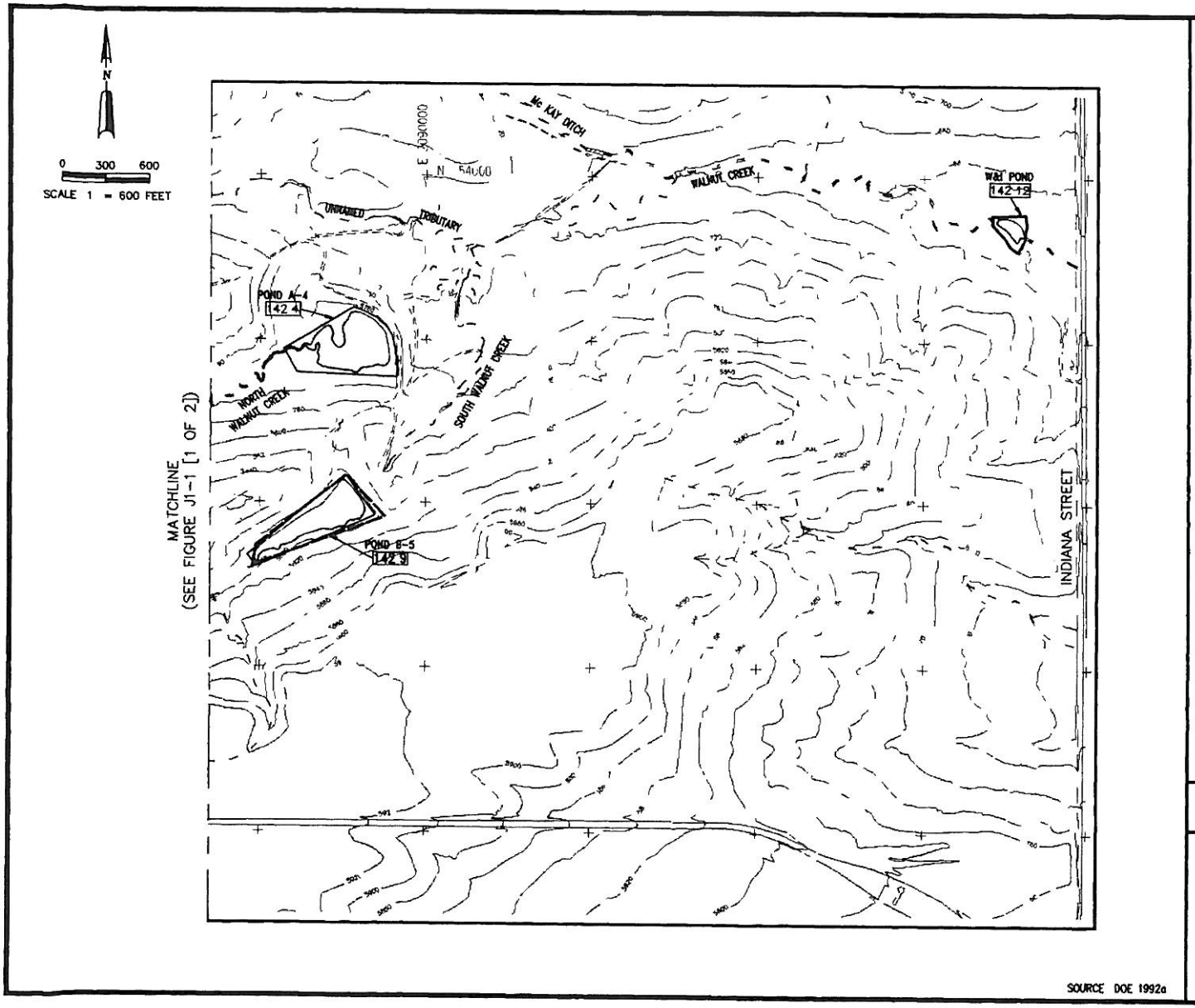

SOURCE DOE 1992a

EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS) IN OPERABLE UNIT 6 (OU6)

142.12 IHSS REFERENCE NUMBER

142.9 OU6 HISTORICAL IHSS BOUNDARY (DOE 1987)

DIRT ROAD

INTERMITTENT STREAM

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LOCATION AND IDENTIFICATION OF OU6 IHSSs AND DIVERSION STRUCTURES ALONG NORTH & SOUTH WALNUT CREEKS (PAGE 2 OF 2)

FIGURE 6 1-1 REV APRIL 1995

8/11/95 OUHRE324 1 600

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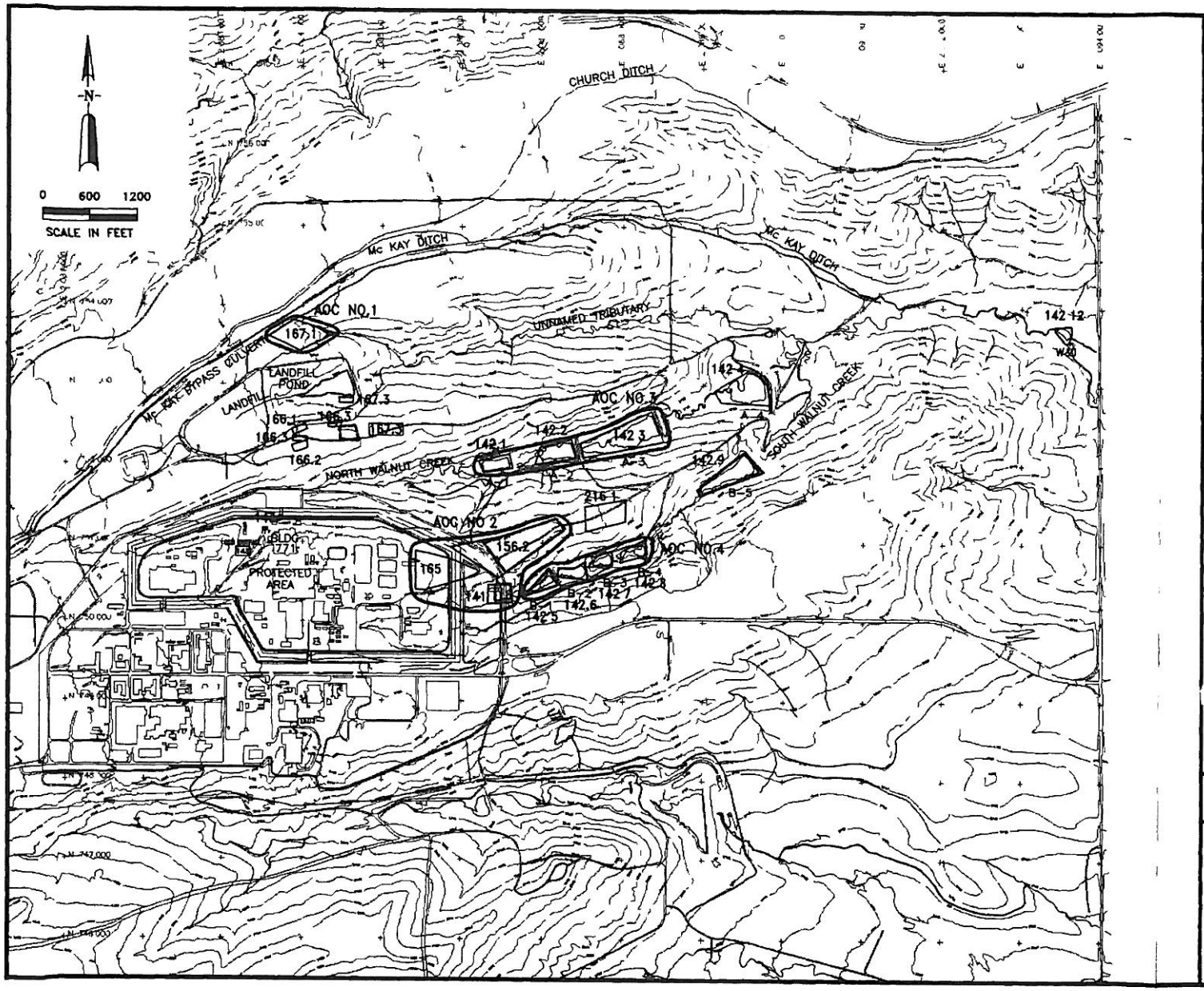

EXPLANATION

PONDS/LAKES

142 12 OU6 IHSS

PROTECTED AREA BOUNDARY

167.3 OU6 HISTORICAL IHSS BOUNDARY FOR IHSSs 141 142 5 142 9 143 AND 156 2

141	SLUDGE DISPERSAL AREA
142	PONDS
143	OLD OUTFALL
156 2	SOIL DUMP AREA
165	TRIANGLE AREA
166 1–166 3	TRENCHES A B C
167 1	SPRAY FIELD
216 1	EAST SPRAY FIELDS

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AREAS OF CONCERN
WITHIN OPERABLE UNIT NO 6

FIGURE 6 2–1 JUNE 1995

8/11/95 DIMENSION 1 1200

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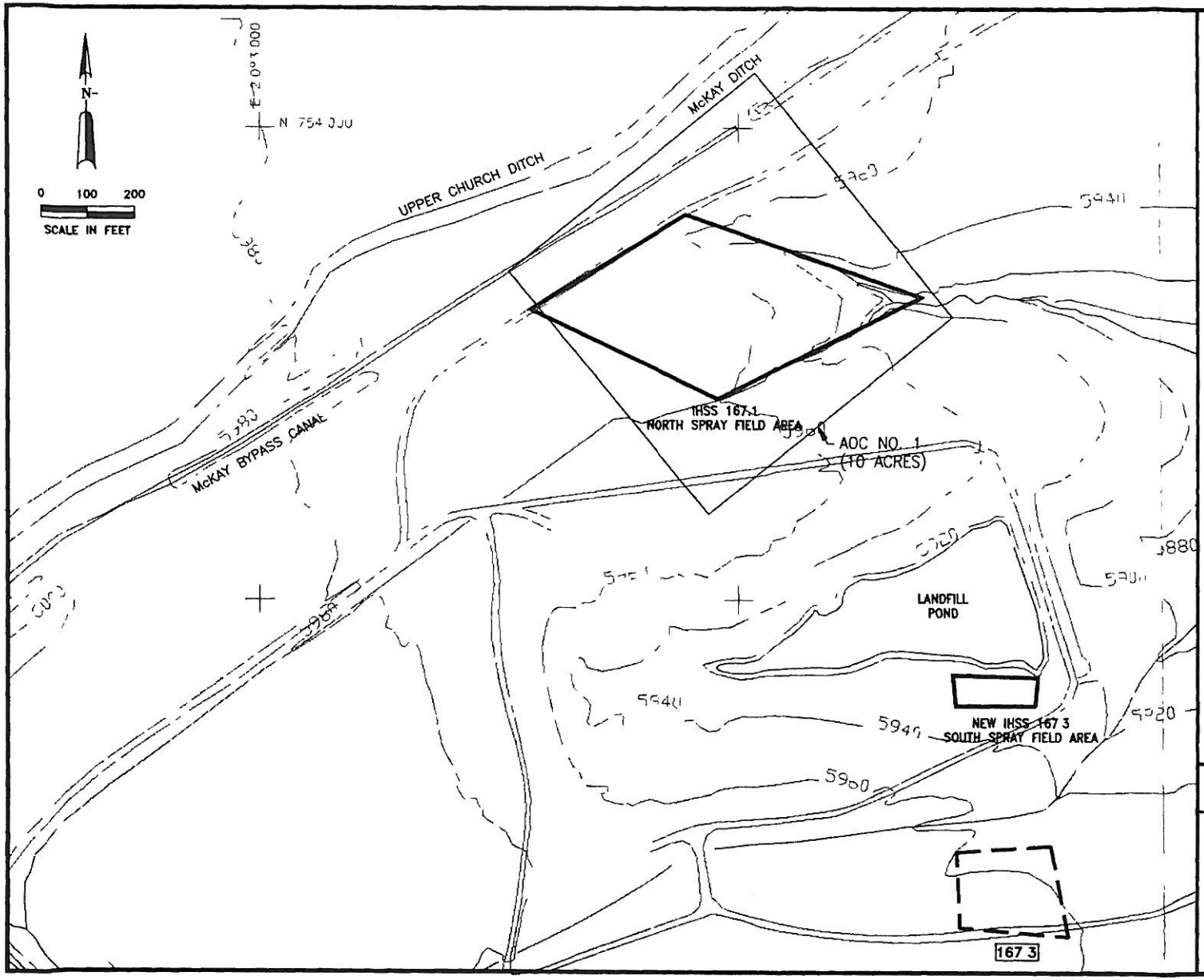

EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITES

HISTORICAL IHSS BOUNDARIES DOE 1987

167 3

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AREA OF CONCERN NO 1

FIGURE 6 4-1 JUNE 1995

1327 1=200

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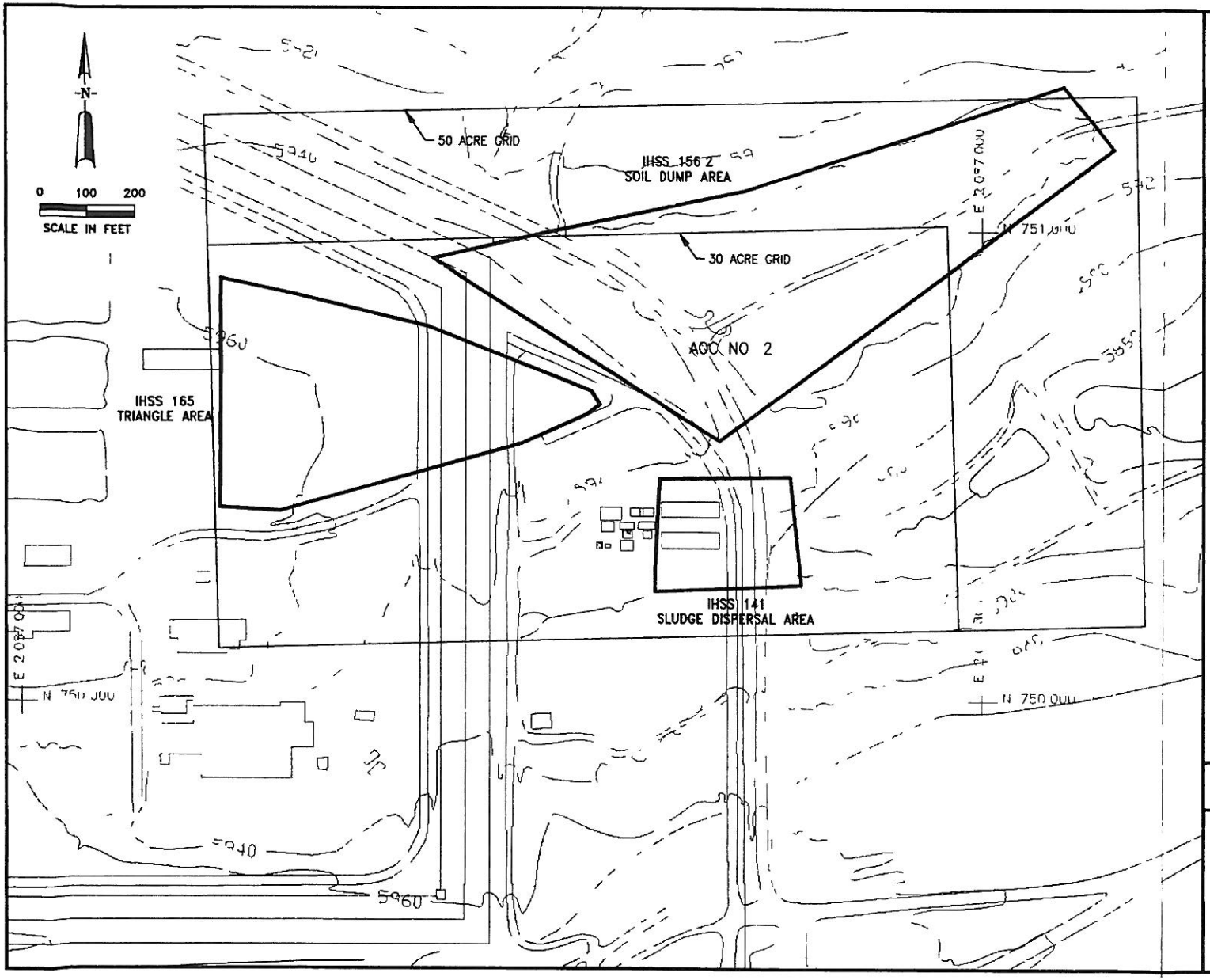

EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITES

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AREA OF CONCERN NO 2
AND 30 ACRE
MAXIMUM EXPOSURE AREA

FIGURE 6 4-2 JUNE 1995

OU6RI301 1=200

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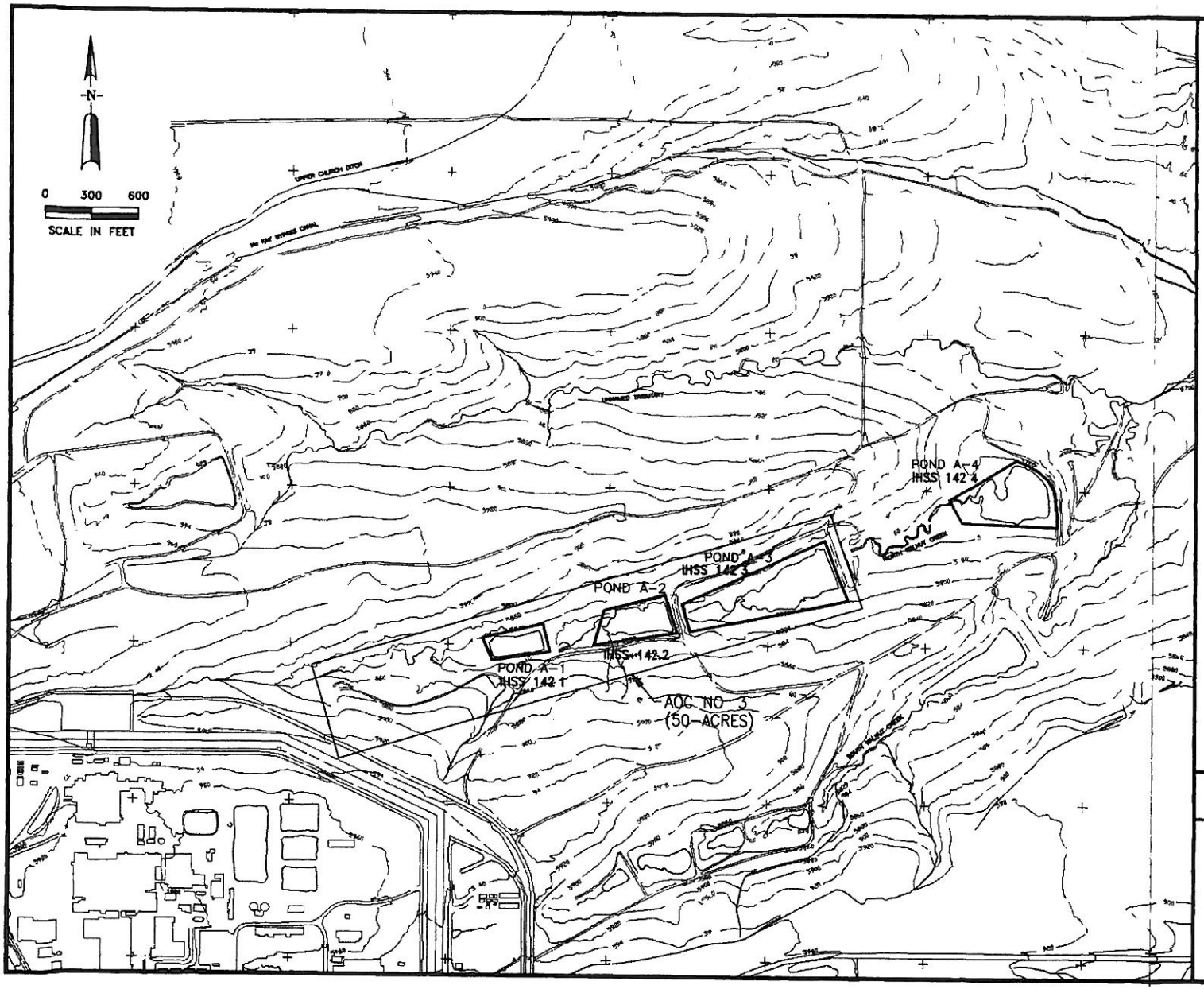

EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITES

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AREA OF CONCERN NO 3

FIGURE 6 4-3 JUNE 1995

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AREA OF CONCERN NO 4

FIGURE 6 4-4 JUNE 1995

1=400

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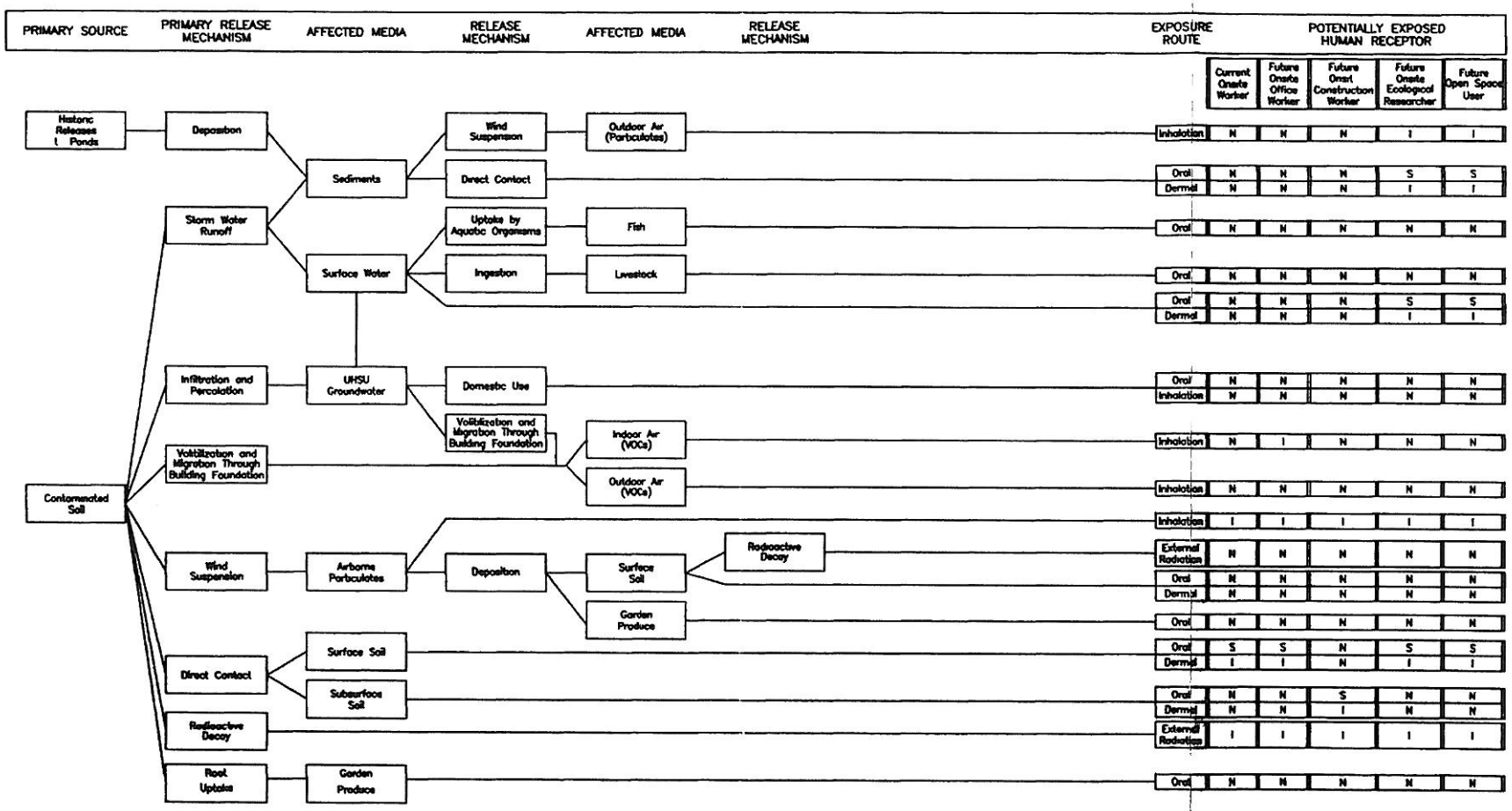

LEGEND

S Potentially Complete Exposure Pathway (Evaluated May Be Significant)
I Potentially Complete Exposure Pathway (Evaluated Probably Insignificant)
N Not Evaluated (Either Incomplete Or Potentially Complete But Not Assessed)
UHSU Upper Hydrostratigraphic Unit

Note Pathways that were potentially complete but not assessed did not warrant quantitative evaluation because they would not contribute measurably to the estimate of overall risk (see text)

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CONCEPTUAL SITE MODEL
FOR HUMAN EXPOSURE PATHWAYS

FIGURE 6 4-5 APRIL 1995

OU6R325 t=1

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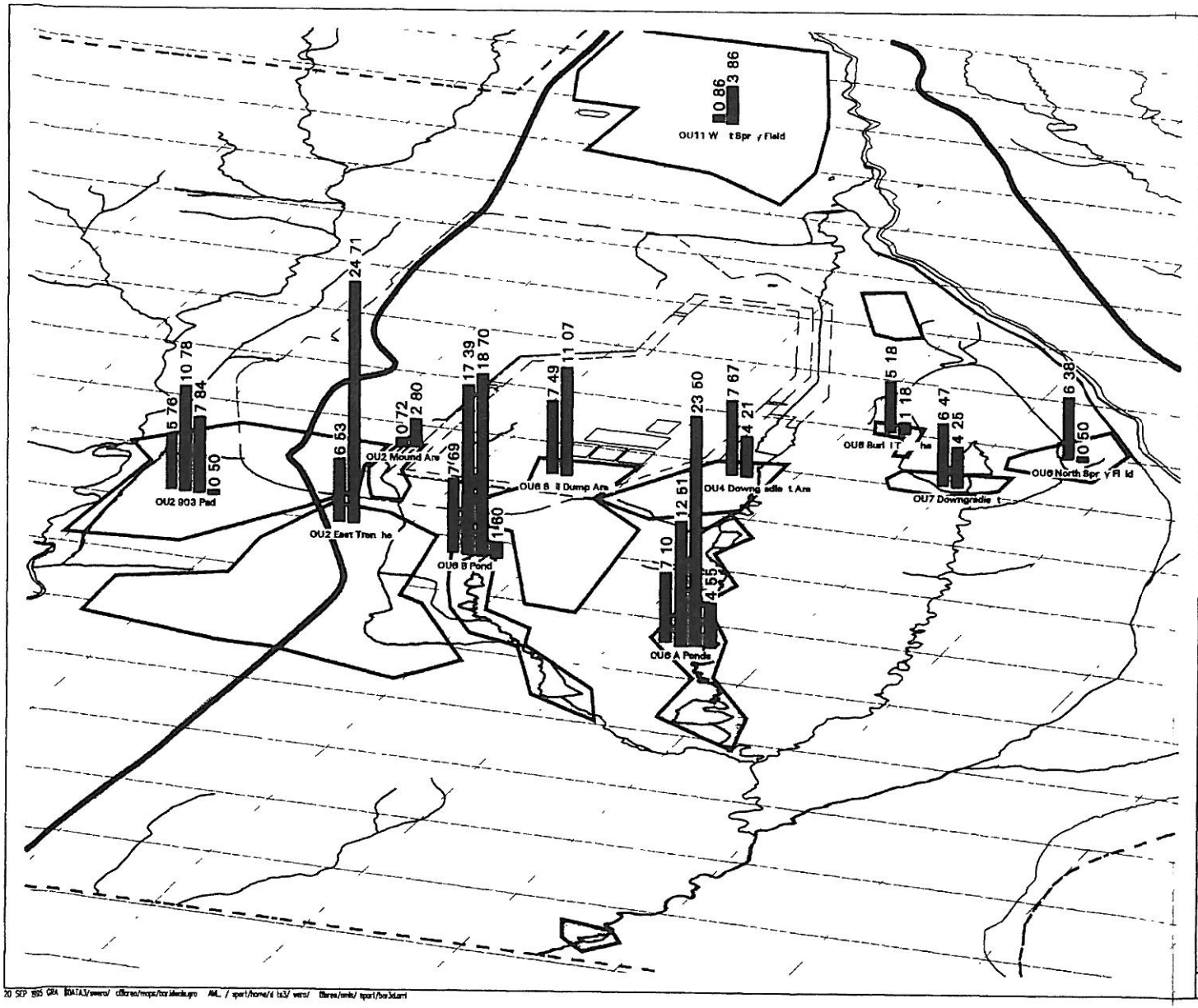

EXPLANATION

- Watershed Boundary
- Rock Creek Watershed
- Walnut Creek Watershed
- Woman Creek Watershed
- Canals and Ditches
- Security Fences
- Rocky Flats Buffer Zone
- Lakes and Ponds
- Source Areas

- Preble s Meadow Jumping Mouse
- American Kestrel
- Great Blue Heron
- Mallard

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ERAs for Walnut Creek and Woman Creek Watersheds at RFETS

Hazard Indices for Walnut Creek Watershed

September 1995 | Figure 7 2 2

20 SEP 1995 ORA DATA3/swers/ cflores/maps/tcrisk4ecs.gro AML / spar1/home/4 ta3/ wers/ tflores/amls/ spar1/bra3d.aml

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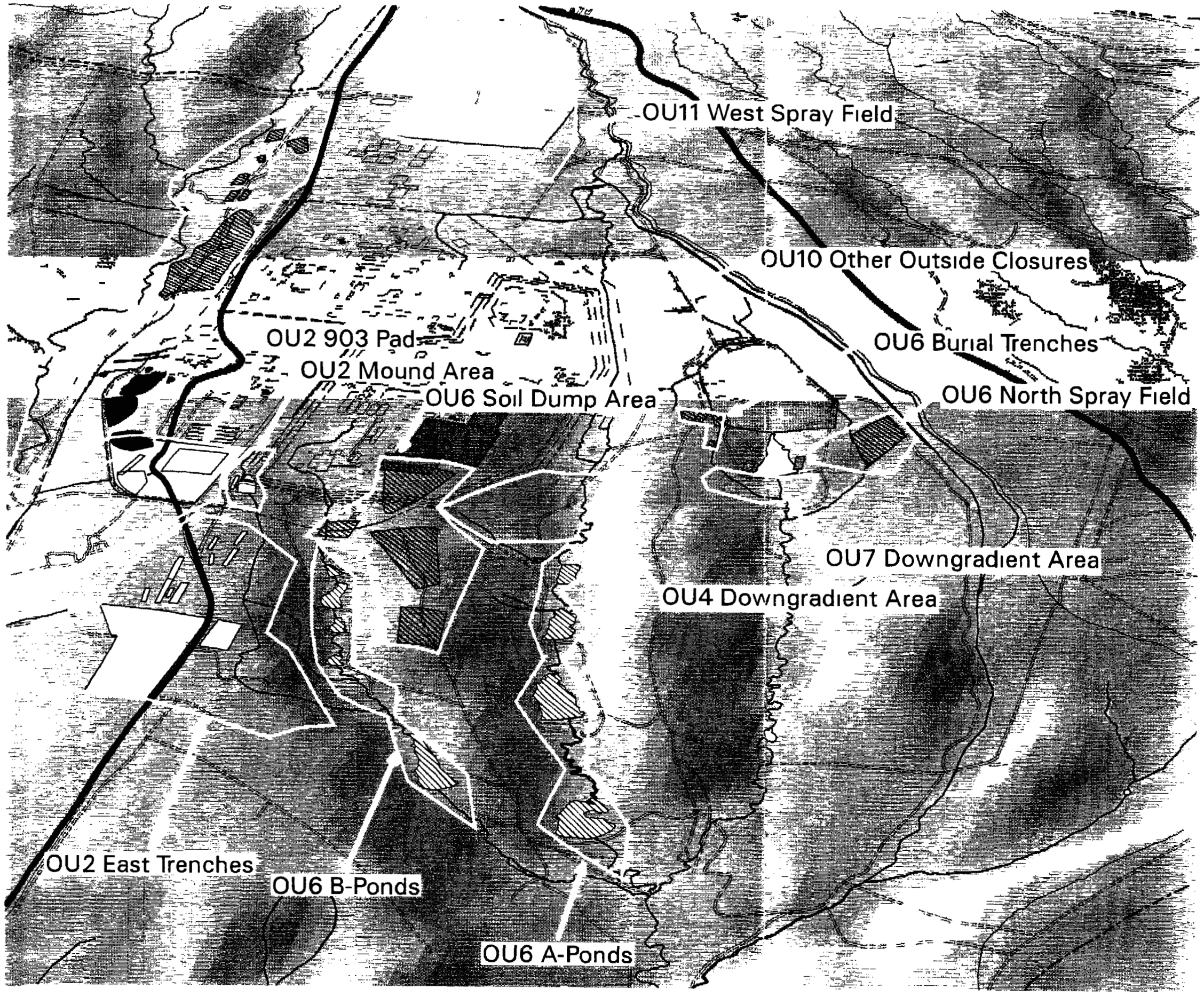

EXPLANATION

- Watershed Boundary
- Rock Creek Watershed
- Walnut Creek Watershed
- Woman Creek Watershed
- Central Avenue
- Dirt Roads
- Canals and Ditches
- Security Fences
- Rocky Flats Buffer Zone
- Lakes and Ponds
- Buildings
- Operable Unit 1 881 Hillside
- Operable Unit 2 903 Pad Mound and East Trenches
- Operable Unit 4 Solar Ponds
- Operable Unit 5 Woman Creek
- Operable Unit 6 Walnut Creek
- Operable Unit 7 Present Landfill
- Operable Unit 10 Other Outside Closures
- Operable Unit 11 West Spray Field
- ERA Source Areas

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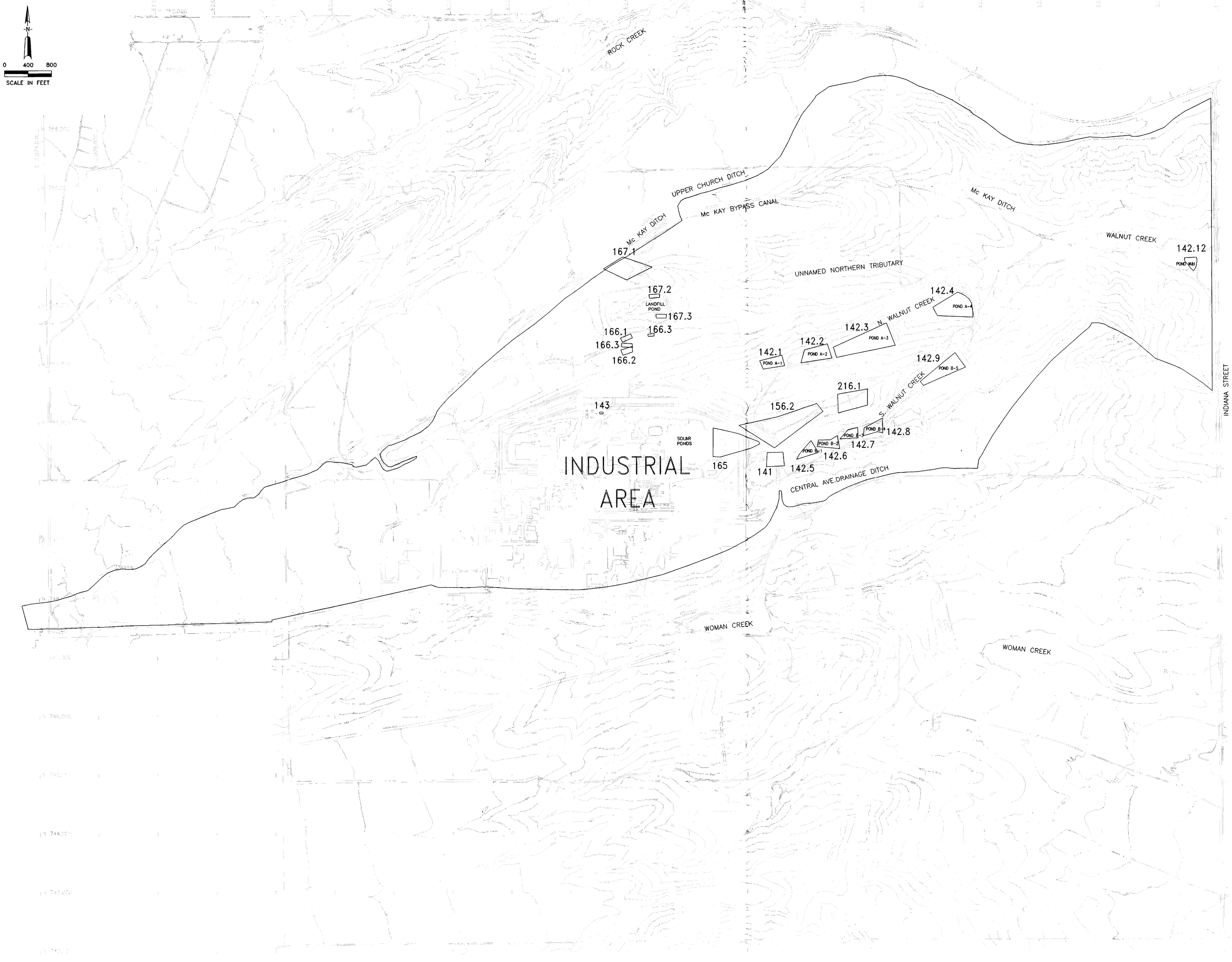
ERAs for Walnut Creek and Woman Creek
W t sh d at RFETS

ERA Source Areas
in
Walnut Creek Watershed

September 1995

F gure 7 2 1



EXPLANATION

IHSS BOUNDARIES

216.1 IHSS NUMBER

WALNUT CREEK DRAINAGE (OU-6 MODEL AREA)

PONDS/LAKES

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WALNUT CREEK DRAINAGE
AREA AND OU-6 IHSSs

PLATE 5.5-1 APRIL 1995

OU6RI259 1=600