DRAFT FINAL

TECHNICAL MEMORANDUM NO. 13

ADDENDUM TO FINAL PHASE I RFI/RI WORK PLAN

HUMAN HEALTH RISK ASSESSMENT MODEL DESCRIPTION FOR OPERABLE UNIT NO. 5

Rocky Flats Plant
Woman Creek Priority Drainage

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LIST OF ABBREVIATIONS AND ACRONYMS

ac	acre
AEC	U.S. Atomic Energy Commission
BCF2	Block Centered Flow 2
BOD	Biochemical Oxygen Demand
CEAM	Center for Exposure Assessment Modeling
cm	centimeters
COCs	Contaminants of Concern
CSM	Conceptual Site Model
DOE	U.S. Department of Energy
EE	Environmental Evaluation
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FDM	Fugitive Dust Model
FS	Feasibility Study
ft	feet
HHRA	Human Health Risk Assessment
HSPF9	Hydrologic Simulation Program-Fortran, Version 9
IAG	Interagency Agreement
IHSS	Individual Hazardous Substance Site
in	inches
ISC2	Industrial Source Complex Model
km	kilometers
m	meters
m/s	meters per second
mi	miles
MODFLOW	Modular Three-Dimensional Groundwater Flow Model
mph	miles per hour
MT3D	Modular Three-Dimensional Contaminant Fate and Transport Model
OU	Operable Unit
OU1	Operable Unit No. 1
OU5	Operable Unit No. 5

LIST OF ABBREVIATIONS AND ACRONYMS - Continued

PA	Protected Area
RCRA	Resource Conservation and Recovery Act
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
SID	South Interceptor Ditch
STAR	STability ARray
TM	Technical Memorandum
TM12	Technical Memorandum No. 12
TM13	Technical Memorandum No. 13
UHSU	Upper Hydrostratigraphic Unit
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

This document provides a description of the models selected to perform groundwater, surface-water, and air modeling for the Rocky Flats Plant (RFP) Operable Unit No. 5 (OU5). These models were selected to support the Human Health Risk Assessment (HHRA). The HHRA is part of the OU5 Phase I Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation (RFI/RI). The technical approach to be used in applying selected models to the site-specific conditions at OU5 will be described in detail in the Phase I RFI/RI report rather than this document.

The objectives of the modeling are as follows:

- To support the HHRA portion of the RFI/RI for OU5. This will be accomplished by simulating the transport of chemicals of concern from OU5 to potential exposure points for human receptors under present and anticipated future site conditions.
- To support the evaluation of potential remedial alternatives for the Feasibility Study (FS) at OU5.

A Conceptual Site Model (CSM) has been developed to identify and evaluate chemical source areas, chemical release mechanisms, environmental transport media, potential human intake routes, and potential human receptors related to OU5. The purpose of the CSM is to identify human exposure pathways to be quantitatively evaluated in the HHRA. Exposure pathways chosen for evaluation in the HHRA that include transport media such as groundwater, surface water, and air may require fate and transport modeling to estimate chemical exposure point concentrations. This document describes the exposure pathways to be evaluated in the HHRA that will require such modeling. It also identifies the mathematical models that will be used to estimate exposure point concentrations. The selection of models is based on preliminary data that have been collected at RFP as part of Phase I RFI/RI for OU5, use of similar models at other operable units (OUs) and hazardous waste sites, and the adequacy of the models in meeting model selection criteria as described in this document. At the time this technical memorandum was prepared, only a portion of the soil and groundwater data from the Phase I investigation was available. If additional data substantially different from those used in developing this technical memorandum become available, revisions to the modeling approach may become necessary.

The following models were selected to meet the requirements and objectives of the modeling study:

- The U.S. Geological Survey (USGS) MODFLOW numerical model has been selected for groundwater flow, and the MT3D numerical model has been selected for groundwater contaminant fate and transport in the Rocky Flats Alluvium and subcropping bedrock sandstones.

- Soil gas transport modeling will be performed with either the Jury model or the Johnson-Ettinger model. These will simulate the movement of volatile organic compounds (VOCs) from underlying soil gas as a result of volatilization from soil and Upper Hydrostratigraphic Unit (UHSU) groundwater contaminants to the OU5 surface just beneath a hypothetical onsite building.

- The Hydrologic Simulation Program-Fortran, Version 9 (HSPF9), a one-dimensional steady-state or dynamic model, has been selected for the surface-water model.

- The Fugitive Dust Model (FDM) for ambient air contaminant fate and transport of OU5 source air emissions has been selected.

- Per the U.S. Environmental Protection Agency (EPA) recommendations, the Johnson-Ettinger models for soil vapor transport into indoor building air have been selected. The model equation corresponding to an infinite contaminant source and vapor infiltration through cracks or openings in the foundation is the most useful for general application.

Data available for use as input for the modeling activities were evaluated based on a review of previous and ongoing investigations and general literature. Additional data from the Phase I RFI/RI investigation will be used in the modeling effort once those data become available.

The data presented in the model parameters data summary sections are preliminary and, in some cases, are not site-specific. The data values or ranges of values are not intended to be fixed or final. The ranges are presented to convey what is currently known of the potential variability in the parameter values that may be used in the models.

1.0 INTRODUCTION

1.1 PURPOSE

On January 22, 1992, the Interagency Agreement (IAG) (DOE, 1991) was finalized between the U.S. Department of Energy (DOE), the State of Colorado, and EPA. As part of this agreement, a baseline risk assessment must be prepared for each OU at RFP. Baseline risk assessments characterize:

- the toxicity and levels of all hazardous substances present
- the fate and transport of contaminants
- the potential for human and/or environmental exposure, and
- the risk of potential impacts or threats on human health and the environment .

In compliance with the IAG, DOE will identify actual and potential exposure points and pathways. In addition, an HHRA conceptual exposure site model has been developed in Technical Memorandum No. 12 (TM12). It is entitled *Human Health Risk Exposure Assessment Exposure Scenarios for Operable Unit No. 5* (DOE, 1993). This conceptual site model will be used as the basis for identifying exposure points and pathways for the HHRA.

Regarding modeling, the IAG requirements (DOE, 1991, Section VII.D.1.b) state that:

> "... DOE shall submit for review and approval a description of the fate and transport models that will be utilized, including a summary of the data that will be used with these models. Representative data shall be utilized, and the limitations, assumptions and uncertainties associated with the models shall be documented."

The purpose of this document, Technical Memorandum No. 13 (TM13), entitled *Human Health Risk Assessment Model Description for Operable Unit No. 5*, is to meet these IAG and DOE requirements for the HHRA model descriptions.

1.2 SCOPE

The scope of the modeling will support the following activities:

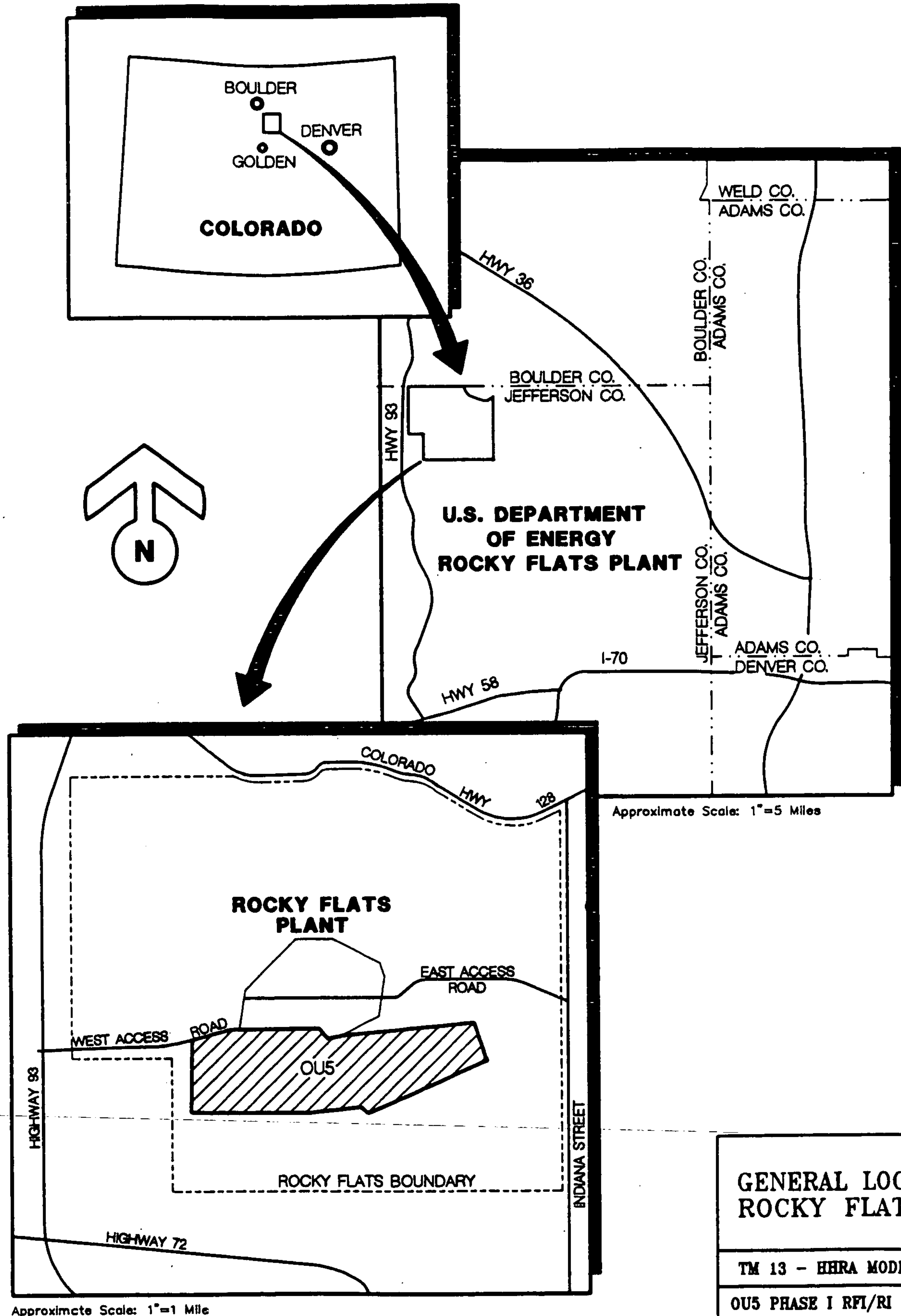
- The HHRA portion of the RFI/RI efforts at OU5. This will be accomplished by simulating the transport of chemicals of concern from OU5 to potential exposure points for human receptors. This simulation will take place under present and anticipated future site conditions as presented in TM12.
- The preliminary evaluation of potential remedial alternatives for the FS at OU5.

Quality assurance for modeling activity is covered by the sitewide quality assurance plan (EG&G, 1991a). Modeling quality assurance includes model verification, calculation verification, and technical review of modeling methods, assumptions, results, and interpretations.

1.3 SITE LOCATION

RFP is a government-owned, contractor-operated facility that is part of the nationwide nuclear weapons production complex. It is located on 6,550 acres (ac) of federally-owned land in northern Jefferson County, Colorado. RFP is located approximately 16 miles (mi) northwest of Denver (Figure 1-1). Surrounding cities include Boulder, Broomfield, Superior, Westminster, and Arvada, which are located less than 10 miles to the northwest, east, and southeast. There is a Protected Area (PA) or security area surrounded by a buffer zone of approximately 6,150 acres at RFP.

RFP was operated for the U.S. Atomic Energy Commission (AEC) from RFP's inception in 1951, until the AEC was dissolved in January 1975. At that time, responsibility for RFP was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by DOE in 1977. Dow Chemical USA, an operating unit of the Dow Chemical Company, was the prime operating contractor of the facility from 1951 until June 30, 1975, when it was succeeded by Rockwell International. On January 1, 1990, EG&G Rocky Flats, Inc. succeeded Rockwell International.



TM13_1-1DWG

GENERAL LOCATION OF ROCKY FLATS PLANT

TM 13 – HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

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FIGURE 1-1

RFP's primary mission has been to produce metal components for nuclear weapons. These components are fabricated from plutonium, uranium, and nonradioactive metals (principally, beryllium and stainless steel). Current waste handling practices involve onsite and offsite recycling of hazardous materials, onsite storage of hazardous and radioactive mixed wastes, and disposal of solid radioactive materials at another DOE facility. However, historically, the operating procedures included both onsite storage and disposal of hazardous and radioactive wastes. Some of the past onsite storage and disposal locations are potential sources of environmental contamination.

This Phase I RFI/RI modeling TM addresses OU5, which is 1 of 16 OUs at RFP. OU5 is subdivided into ten individual hazardous substances sites (IHSSs), which include the following:

- Old Landfill (IHSS 115)
- Ash Pits (IHSS 1133.1-133.4)
- Incinerator (IHSS 133.5)
- Concrete Wash Pad (IHSS 133.6)
- Detention Ponds C-1 and C-2 (IHSS 142.10 and 142.11)
- Surface Disturbance (IHSS 209)

Figure 1-2 shows the OU5 study area and the IHSSs.

A more detailed description of each IHSS and the types of associated contamination can be found in the *Historical Release Report for the Rocky Flats Plant* (DOE, 1992b).

1.4 GENERAL SITE CONDITIONS

1.4.1 Physical Setting

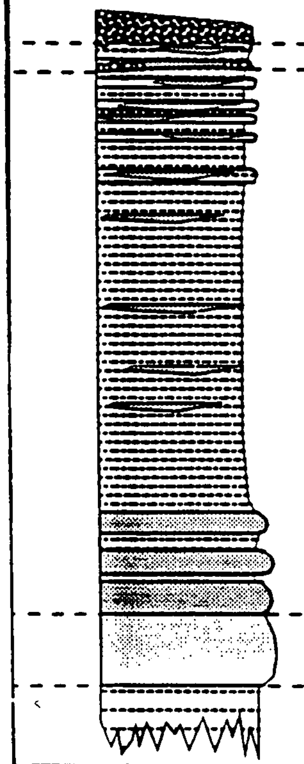
The natural environment of RFP and its vicinity is influenced primarily by its proximity to the Front Range of the Rocky Mountains. RFP is located directly east of the north-south trending Front Range. It is situated approximately 16 mi east of the Continental Divide on a broad, eastward-sloping plain of coalescing alluvial fans. The fans developed along the Front Range at an elevation of approximately 6,000 feet (ft) above mean sea level. The fans extend approximately 5 mi in an eastward direction from their origin at Coal Creek Canyon; they terminate on the east at a break in the slope as low rolling hills. The operational area at RFP is located near the eastern edge of the fans on a terrace between stream-cut valleys (North Walnut Creek and Woman Creek).

Three intermittent streams drain RFP with flow generally from west to east. These drainages are Rock Creek, Walnut Creek, and Woman Creek. Rock Creek drains the northwestern corner of RFP and flows northeast through the buffer zone to its offsite confluence with Coal Creek. North and South Walnut Creeks and an unnamed tributary drain the northern portion of the RFP PA. These three forks of Walnut Creek join in the buffer zone and flow toward the Great Western Reservoir, which is approximately 1 mi east of the confluence. This flow is currently routed around the Great Western Reservoir by the Broomfield Diversion Canal, which is operated by the City of Broomfield. Woman Creek drains the southern RFP buffer zone and flows eastward to Standley Reservoir. The OU5 study area is in the Woman Creek drainage basin.

1.4.2 Geology

The near-surface geologic materials at RFP consist of surficial, unconsolidated deposits, and shallow bedrock. The surficial deposits at OU5 consist of alluvium, colluvium, valley-fill alluvium, and artificial fill that unconformably overlay bedrock. Surficial deposits at RFP are Quaternary (Pleistocene - Holocene) in age. Near-surface bedrock consists of the Cretaceous Arapahoe and Laramie Formations. The regional dip of the bedrock is approximately 2 degrees to the east. The bedrock formations, as well as the surficial material, are shown on Figure 1-3 and are discussed below.

The Rocky Flats Alluvium is a pediment gravel deposited in a laterally-coalescing alluvial fan environment. It was deposited across a gently-sloping erosional surface cut into the underlying bedrock. The deposit consists of poorly- to moderately-sorted, poorly-stratified clays, silts, sands,

Rocky Flats Graphic Section	Thickness (feet)	Formation	Summary Description
This Study (central portion RFP) 	10-20	Rocky Flats Alluvium	**Clayey Sandy Gravels** - reddish brown to yellowish brown matrix, grayish-orange to dark gray, poorly sorted, angular to subrounded, cobbles, coarse gravels, coarse sands and gravelly clays; varying amounts of caliche
	15-25	Arapahoe Fm.	**Claystones, Silty Claystones, and Sandstone**- light to medium olive-gray with some dark olive-black claystone and silty claystone weathers yellowish orange to yellowish brown; a mappable, light to olive gray, medium- to coarse-grained, frosted sandstone to conglomeratic sandstone occurs locally at the base (Arapahoe marker bed)
	600-800 upper interval: 300-500 lower interval: 300	Laramie Formation	**Claystones, Silty Claystones, Clayey Sandstones, and Sandstones** - kaolinitic, light to medium gray claystone and silty claystone and some dark gray to black carbonaceous claystone, thin (2') coal beds and thin discontinuous, very fine to medium-grained, moderatley sorted sandstone intervals **Claystones, Sandstones, and Coals** - light to medium gray, fine- to coarse-grained, poorly to moderately sorted, silty, immature quartzitic sandstone with numerous lenticular, sub-bituminous coal beds and seams that range from 2' to 8' thick
	90-140	Fox Hills Sandstone	**Sandstones** - grayish orange to light gray, calcareous, fine-grained, subrounded, glauconitic, friable sandstone
		Pierre Shale and older units	

EG&G Rocky Flats, Inc. March 1992

LEGEND

Source: EG&G, 1992a

TM13_1-3DWG

NEAR SURFACE STRATIGRAPHIC SECTION

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | NOV. 1993 | FIGURE 1-3 gravels, and cobbles. Dissection and headward erosion by Woman Creek have cut through the alluvium into the underlying bedrock.

Colluvial materials in OU5 are derived from slope wash, slump, and creep of the Rocky Flats Alluvium and the Arapahoe and Laramie Formations. The colluvium consists of clays, sands, and gravels. It ranges in thickness from a few feet to 20 feet. Artificial fill and disturbed ground occurs in localized areas, including the landfill and the ash pits. Valley-fill alluvium occurs in the active stream channel of Woman Creek and is derived from reworked older alluvial, colluvial, and bedrock deposits. The alluvium, colluvium, and valley-fill alluvium in the OU5 area range from 0 to 35 feet thick.

The Arapahoe Formation is the uppermost bedrock formation and unconformably underlies the surficial material in the OU5 area along the higher elevations of the valley walls. The Arapahoe Formation (EG&G, 1991b) in the vicinity of RFP is the product of a fluvial depositional environment. It is composed of channel, point bar, and overbank fluvial deposits of sandstones, claystones, siltstones, and occasional lignitic coal seams and ironstones.

The Laramie Formation underlies the Arapahoe Formation. Along the middle and lower valley slopes of Woman Creek, the Laramie Formation uncomformably underlies the surficial material. The Laramie Formation, which is approximately 800 feet thick (EG&G, 1991b) in the vicinity of RFP, is informally divided into two units. The lower unit, which is approximately 250 feet thick, is composed of several sandstone layers and many coal seams. The upper unit, which is approximately 550 feet thick, is composed of deltaic claystones, siltstones, some fluvial sandstones, and an occasional coal layer.

1.4.3 Hydrogeology

The uppermost groundwater level in the OU5 area occurs in the Upper Hydrostratigraphic Unit (UHSU), which consists of the Rocky Flats Alluvium, colluvium, valley fill, artificial fill, and limited subcropping bedrock sandstones. The elevation of groundwater in the alluvium beneath

OU5 varies seasonally. Groundwater flow in the UHSU is generally downslope toward Woman Creek, locally following the paleotopography of the underlying bedrock, and occurring as isolated areas of saturation in the unconsolidated materials. The OU5 area exhibits localized flow from seeps and springs on the slopes of the Woman Creek valley.

Recharge to the UHSU within OU5 occurs primarily from infiltration of precipitation and from groundwater inflow within the UHSU from the areas west, north, and south of OU5. Based on water level measurements in wells completed in the UHSU of OU5, groundwater levels vary substantially in response to seasonal changes. Groundwater levels reach their peak in the spring and early summer when precipitation is high and evapo-transpiration is low. Groundwater levels decline during the remainder of the year with periodic rises in response to precipitation events. Many wells completed in the alluvium and colluviums along the upper slopes of the Woman Creek valley are dry during periods of low water levels.

Groundwater discharges from the UHSU at seeps and springs on the hillsides of OU5 where the bedrock claystones subcrop very near the land surface. This water then flows downslope along the ground surface, or through the shallow unconsolidated deposits to Woman Creek, or is consumed by evapo-transpiration.

1.4.4 Surface-Water Hydrology

OU5 is located within the Woman Creek Drainage basin (Figure 1-4), which generally flows from west to east. Although seasonal flows can be low, Woman Creek receives continuous flow from Antelope Springs Creek. Detention Ponds C-1 and C-2 are located within the eastern reach of the Woman Creek basin. Pond C-1 is located on the Woman Creek channel; Pond C-2 is located off the Woman Creek channel. Pond C-2 receives relatively minor local flow from its surrounding drainage basin, while receiving the majority of its flow from the South Interceptor Ditch (SID), which lies on the northern flank of the Woman Creek basin. The SID collects runoff from the southern RFP security area and diverts it to Pond C-2. The Pond C-2 water is not discharged to Woman Creek but is pumped to the Broomfield Diversion Ditch (around Great Western Reservoir) approximately semi-annually.

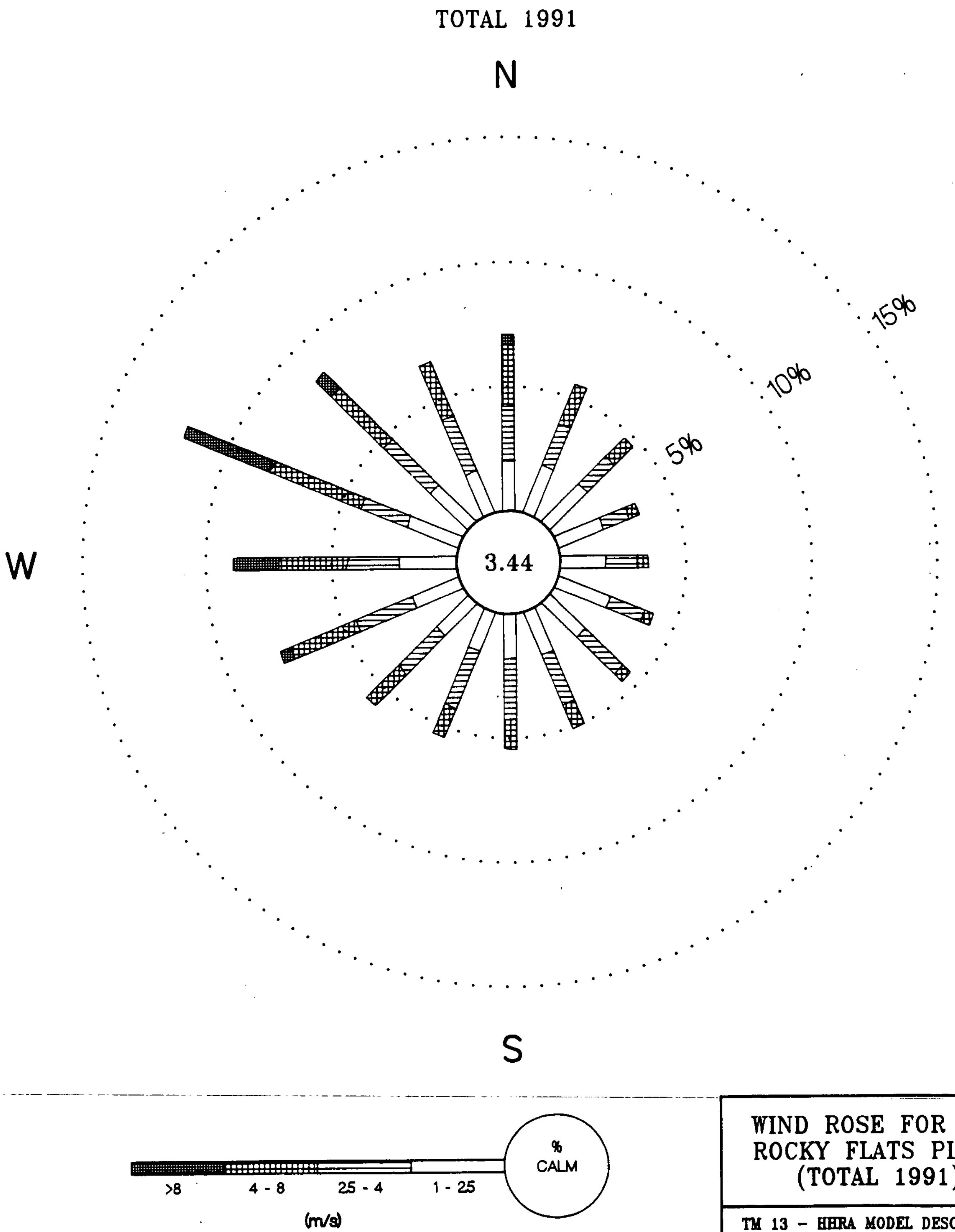
Woman Creek drains OU5 and discharges, via Mower Ditch, into Mower Reservoir and Standley Lake. During periods of high flow, Woman Creek may discharge directly to Standley Lake.

1.4.5 Climate and Meteorology

RFP is only four miles east of the Front Range of the Rocky Mountains. The ground level elevation rises along the Front Range from 1,830 meters (m) (6,000 ft) to more than 3,048 m (10,000 ft) at a distance of only 32 kilometers (km) (20 mi) to the west. Meteorology at RFP is influenced by its proximity to the Front Range.

Wind direction and speed are two meteorological variables important to the dispersion of air pollutants. A wind rose is a diagrammatic device that presents the frequency of wind directions and speeds over a selected time period. This chosen time period is frequently a year. The wind rose for RFP during 1991 is shown in Figure 1-5. Wind direction is reported as the direction from which the wind blows. The asymmetric pattern of the wind rose illustrates that predominant winds are from the west and northwest. These winds also tend to have greater speeds than winds out of the east and south (EG&G Rocky Flats, n.d.).

The average annual wind speed in 1991 was 3.9 meters per second (m/s) (8.7 miles per hour [mph]) (EG&G Rocky Flats, n.d.). High wind speeds greater than 9 m/s (20 mph) occur between 500 and 600 hours per year at RFP (DOE, 1980). During the winter and spring months, these strong winds, called chinooks and boras, are associated with continental air masses moving over the Rocky Mountains. These winds have been recorded exceeding 54 m/s (120 mph) at RFP (DOE, 1980). During the summer months, localized thunderstorms account for strong wind conditions, which are typically less intense than winter wind phenomena.



Source: EG&G Rocky Flats, n.d., Crocker pers. comm. 1993

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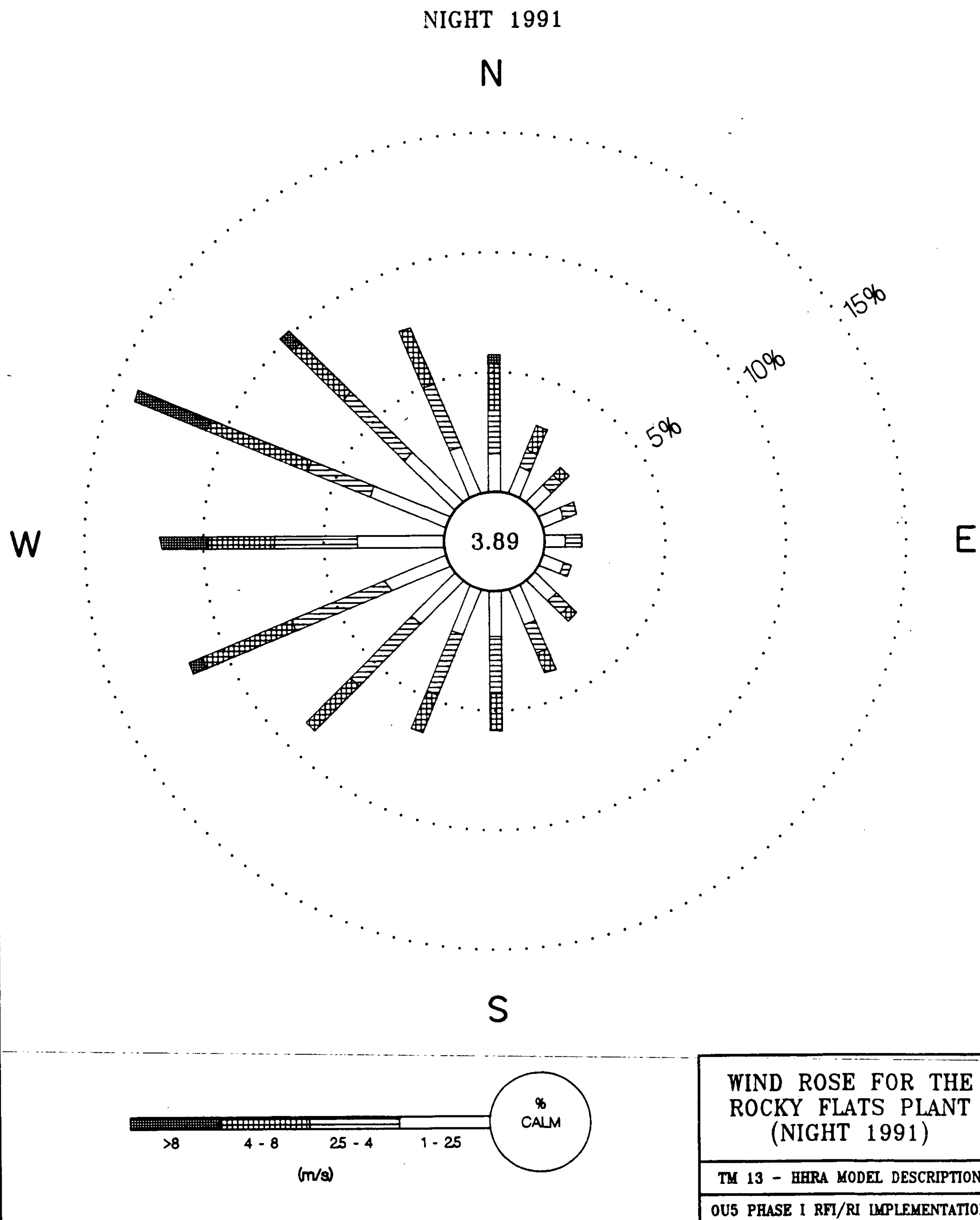
WIND ROSE FOR THE ROCKY FLATS PLANT (TOTAL 1991)		
TM 13 - HHRA MODEL DESCRIPTION		
OU5 PHASE I RFI/RI IMPLEMENTATION		
EG&G	9208151111 NOV. 1993	FIGURE 1-5

However, the more characteristic, if not so dramatic, airflow pattern at RFP is the daily cycle of mountain and valley breezes. During the night, relatively cooler air flows off the east slope of the mountains and displaces warmer air at lower elevations. The wind rose for night hours in Figure 1-6 shows this strong westerly component (EG&G Rocky Flats, n.d.). Canyons, creek drainages, and ridges tend to channel these downslope winds as they move onto the plains. Such differential airflows have implications for the dispersion of air pollutants in the vicinity of RFP (DOE, 1980). The downslope flows converge with the South Platte River Valley flow moving to the north-northeast. During the daytime hours, solar insolation heats up the air along the slopes of the mountains more quickly than the air over the plains and valleys. This warming causes breezes to move upslope out of the valleys toward the mountains. Upslope conditions tend to be less pronounced and less channelized than downslope conditions as shown in Figure 1-7 (EG&G Rocky Flats, n.d.). There are spatial and temporal distinctions in the shift from downslope to upslope conditions along the Front Range. The change typically occurs an hour or two earlier in the morning in the vicinity of RFP than at locations on the east side of the Denver Basin (DOE, 1980).

According to the Pasquill classification, atmospheric stability is most frequently neutral, Class D, at RFP. During 1991, Class D cases occurred 46.2 percent of the time. Stable conditions, Pasquill Classes E and F, occurred 42.6 percent of the time. Unstable cases, Classes A, B, and C, occurred only 11.2 percent (EG&G Rocky Flats, n.d.). Unstable atmospheric conditions enhance vertical pollutant mixing. Stable conditions oppose atmospheric turbulence and inhibit pollutant dispersion.

The depth of the atmosphere above ground level that is available for mixing of air pollutants is termed the mixing height. This meteorological feature becomes more important with increasing distance from pollutant sources. Holzworth (1972) reports that in the Denver metropolitan area, the mean annual mixing height is 268 m (879 ft) in the morning, 2,543 m (8,341 ft) in the afternoon.



Source: EG&G Rocky Flats, n.d., Crocker pers. comm. 1993

WIND ROSE FOR THE ROCKY FLATS PLANT (NIGHT 1991)

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

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FIGURE 1-6

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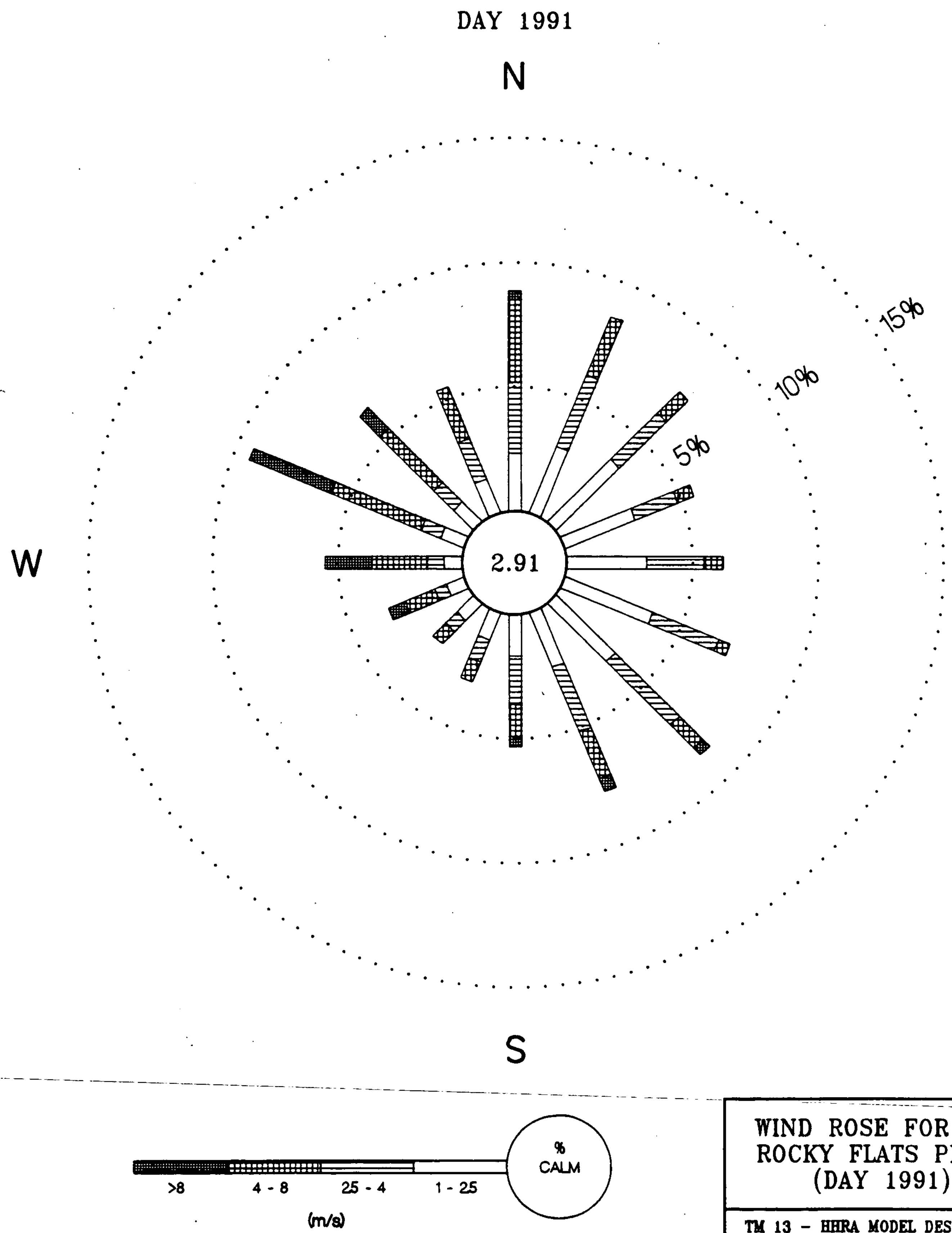


Source: EG&G Rocky Flats, n.d., Crocker pers. comm. 1993

WIND ROSE FOR THE ROCKY FLATS PLANT (DAY 1991)

TM 13 – HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G	9208151111	FIGURE 1-7
	NOV. 1993	

TM13_1-5DWG

RFP is located in a semi-arid climate. During 1991, total precipitation at RFP was 40.9 centimeters (cm) (16.1 inches [in]) (EG&G Rocky Flats, n.d.); somewhat more than the long-term annual average of 38 cm (15 in) (DOE, 1992c). Approximately 40 percent of the annual precipitation falls during the spring season, much of it as snow. Thunderstorms during the summer months provide another 30 percent of the annual precipitation (DOE, 1992c). These thunderstorm events can be intense. On August 6, 1991, for example, 2.92 cm (1.15 in) of rain fell within two hours (EG&G Rocky Flats, n.d.). The mean, maximum, and minimum temperatures in 1991 at RFP were 9.6°C (49.2°F), 33.1°C (91.6°F), -21.0°C (-5.8°F), respectively (EG&G Rocky Flats, n.d.).

The topography of the RFP site is a broad plateau sloping gently to the east. Three streams, Rock Creek, Walnut Creek, and Woman Creek, drain the plateau from west to east. Relief in the Woman Creek drainage is approximately 18 to 30 m (60 to 100 ft) south of the industrial area. The ten IHSSs that comprise OU5 are located on the slopes or in the channel of Woman Creek. There are no buildings or other fabricated structures on OU5. The OU5 sites are vegetated with grasses on the slopes and grasses, cattails, and scattered trees in the stream bed.

RFP operates a 61-m (200-ft) meteorological tower that is positioned approximately 2 km (1.2 mi) northwest of OU5. This tower provides meteorological data that are representative of the general conditions at RFP. It gives the nearest, and hence the most useful, meteorological information applicable to OU5.

2.0 GENERAL CONCEPTUAL MODEL OF OPERABLE UNIT FIVE

The general Conceptual Site Model (CSM) for OU5 has been described in detail in TM12 *Human Health Risk Assessment Exposure Scenarios for Operable Unit No. 5* (DOE, 1993). Included below is a brief overview of the CSM from that document. TM12 should be reviewed to obtain a full description of the CSM.

2.1 CONCEPTUAL SITE MODEL

The OU5 CSM evaluates the exposure potential for current and future receptor populations, both onsite and offsite. This CSM also examines exposure pathways and mechanisms of contaminant uptake for those potential receptor populations.

2.1.1 Potentially-Exposed Receptor Populations

In the OU5 CSM, potentially-exposed receptor populations that were selected for quantitative assessment in the HHRA include the following:

- Current offsite resident
- Current onsite worker
- Future onsite office worker
- Future onsite construction worker
- Future onsite ecological researcher
- Future offsite resident, and
- Future onsite resident

2.1.2 Exposure Points

Exposure points in the CSM are selected so that reasonable maximum exposures will be quantitatively evaluated. An exposure point is a specific location where human receptors can come in contact with OU5 site-related chemicals. The exposure points are presented in Table 2-1 and shown in Figure 2-1.

Table 2-1

Exposure Points by Receptor and Location

Timeframe	Receptor	Location
Current	Residential	Nearest residence to RFP is located at the southeast corner of the RFP property boundary
	Occupational	Onsite within the OU5 study area
Future	Occupational	Onsite within the OU5 study area
	Hypothetical Ecological Researcher	Onsite within the OU5 study area
	Hypothetical Residential	Offsite residence at the point where Woman Creek intersects the eastern RFP property boundary
		Onsite residences within the OU5 study area

Source: DOE, 1993

2.1.3 Human Uptake Mechanisms

A human uptake mechanism is the route by which a chemical can be internally absorbed by the receptor. There are four basic human uptake mechanisms:

- Dermal absorption
- Inhalation

- Ingestion, and
- External irradiation, if radionuclides are present

Exposure pathways by which these mechanisms may occur include inhalation of VOCs and airborne particulates, soil ingestion, surface-water and groundwater ingestion, and dermal contact with soil or surface water. These uptake mechanisms are described further in TM12 (DOE, 1993).

The CSM, presented on Figure 2-2, is a schematic representation of the contaminant source areas, contaminant release mechanisms, environmental transport media, potential human intake routes, and potential human receptors. The purposes of the CSM are to:

- Provide a framework for problem definition
- Identify exposure pathways that may result in human health risks
- Aid in identifying data gaps, and
- Aid in identifying effective cleanup measures, if necessary, that are targeted at significant contaminant sources and exposure pathways

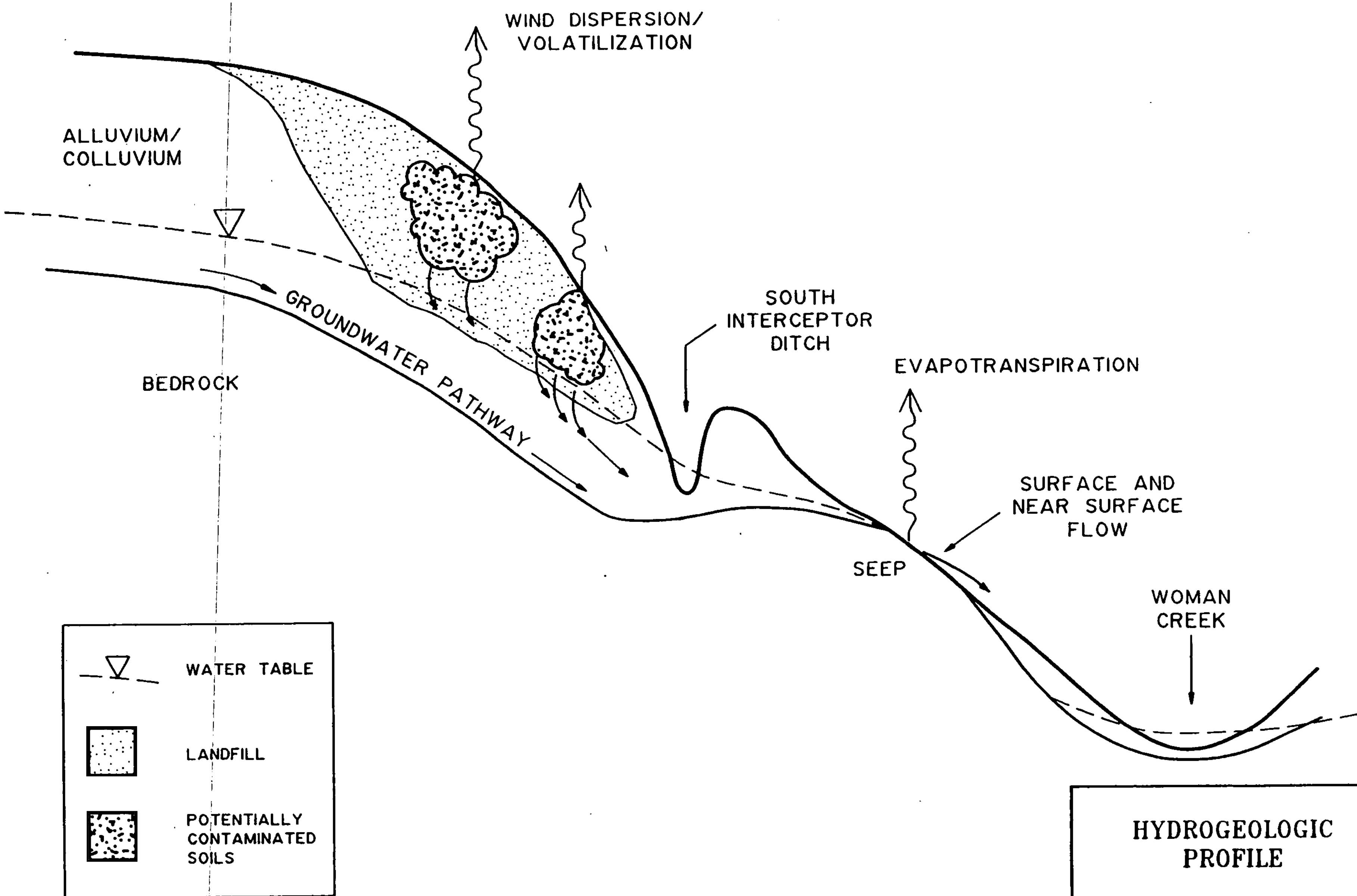
Contaminant release mechanisms, environmental transport media, and potential human intake routes to the contaminated site soil were identified for each potentially-exposed receptor and are discussed in TM12 (DOE, 1993).

In the CSM, potentially-complete and significant exposure pathways are designated by an "S." Potentially-complete and relatively-insignificant exposure pathways are designated by an "I." Both potentially-complete significant and relatively-insignificant exposure pathways will be quantitatively addressed in the risk assessment. Quantitatively addressing potentially-complete and relatively-insignificant exposure pathways will provide for risk estimates that do not underestimate actual risks. Negligible or incomplete exposure pathways are designated by an "N" and are not addressed in the HHRA. In the CSM, potentially-complete dermal exposure pathways are designated as insignificant. These pathways will only be assessed quantitatively if results from the Phase I site investigation demonstrate the presence of organic chemicals or metals of concern, as discussed in TM12.

2.2 GROUNDWATER

The hydrogeologic profile of the OU5 groundwater flow and contaminant transport system, including saturated and unsaturated zones, illustrates the potential migration of contaminants from a source (e.g., the landfill area). This potential migration runs through the unsaturated zone and the UHSU to the creek or to seeps along the hillsides adjacent to Woman Creek (Figure 2-3). The profile also depicts the potential contamination of groundwater and soils with VOCs. Once the contaminants reach the seeps, they evaporate or migrate downslope in surface flow or near-surface groundwater flow in the unconsolidated material to the creek. They may then be transported via surface water processes. Surface water processes are discussed in Sections 2.3 and 3.4. VOC contaminants in the unsaturated zone could be mobilized by desorption, dissolution, or vaporization from contaminated soil. Once mobilized, contaminants would migrate to the surface and escape into the atmosphere by volatilization. The contaminants could also migrate into groundwater.

The hydrogeologic profile (Figure 2-3) does not include all of the contaminant sources that may occur at the site, such as metals and particulate radioactive contamination in soils. Under the hydrogeochemical conditions of OU5, metals and radionuclides are not expected to be very mobile. Therefore, migration of metals and radionuclides through the groundwater pathway (considered to be negligible) is not illustrated. Nevertheless, the selected transport model has the capability to incorporate radioactive decay and sorption of radionuclides and the movement of radionuclides and metals will be addressed.



HYDROGEOLOGIC PROFILE

TM 13 - HHRA MODEL DESCRIPTION

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FIGURE 2-3

HYDRODWG

The groundwater exposure pathway within the CSM is highlighted in Figure 2-4. It interfaces with both the surface water and air transport exposure pathways.

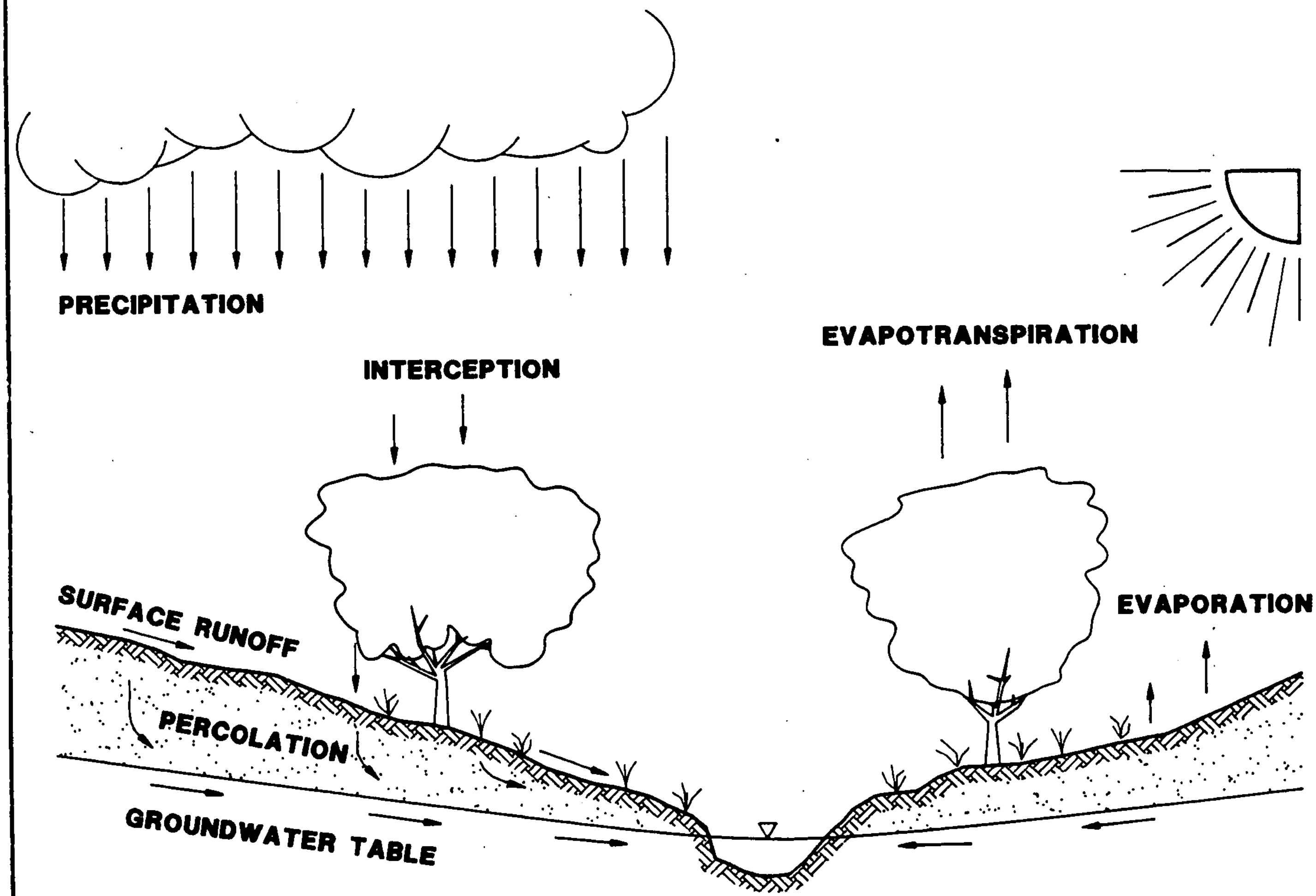
2.3 SURFACE WATER

The surface water model will contribute to the overall HHRA effort by means of several exposure pathways. The profile of surface water pathways (Figure 2-5) illustrates the numerous potential mechanisms for human exposure. Storm water runoff may transport contaminated soils to surface waters through erosion with subsequent transport to downstream receptors. Potential intake of chemicals in surface water via oral or dermal exposure will be evaluated in the HHRA. Potential health risks associated with chemicals in suspended sediments will also be evaluated.

Surface waters and suspended sediments may be impacted from the discharge of contaminated groundwater via seeps and springs. Once groundwater-borne contamination reaches surface waters, the potential exposure pathways are identical to those described above for contaminated storm water, i.e., ingestion and/or dermal contact of surface waters. Figure 2-6 illustrates the surface water exposure for these pathways within the CSM.

2.4 AIR

The air emissions and dispersion models selected to assess air contaminant concentrations at sensitive receptors will estimate exposure point concentrations for the exposure pathways associated with air transport (Figure 2-7). VOCs may be transported through the vadose zone from underlying soils or groundwater and may intrude into a hypothetical building located within OU5 (volatilization into indoor air and subsequent inhalation by a future onsite office worker or resident). Chemicals in surface soils may be transported via fugitive particulate emissions from OU5 to onsite (inhalation of particulates by the future onsite outdoor worker and ecological researcher) and offsite exposure points (inhalation of particulates by the current and future residents). Fugitive dust emissions from OU5 may also result in the deposition of chemicals in



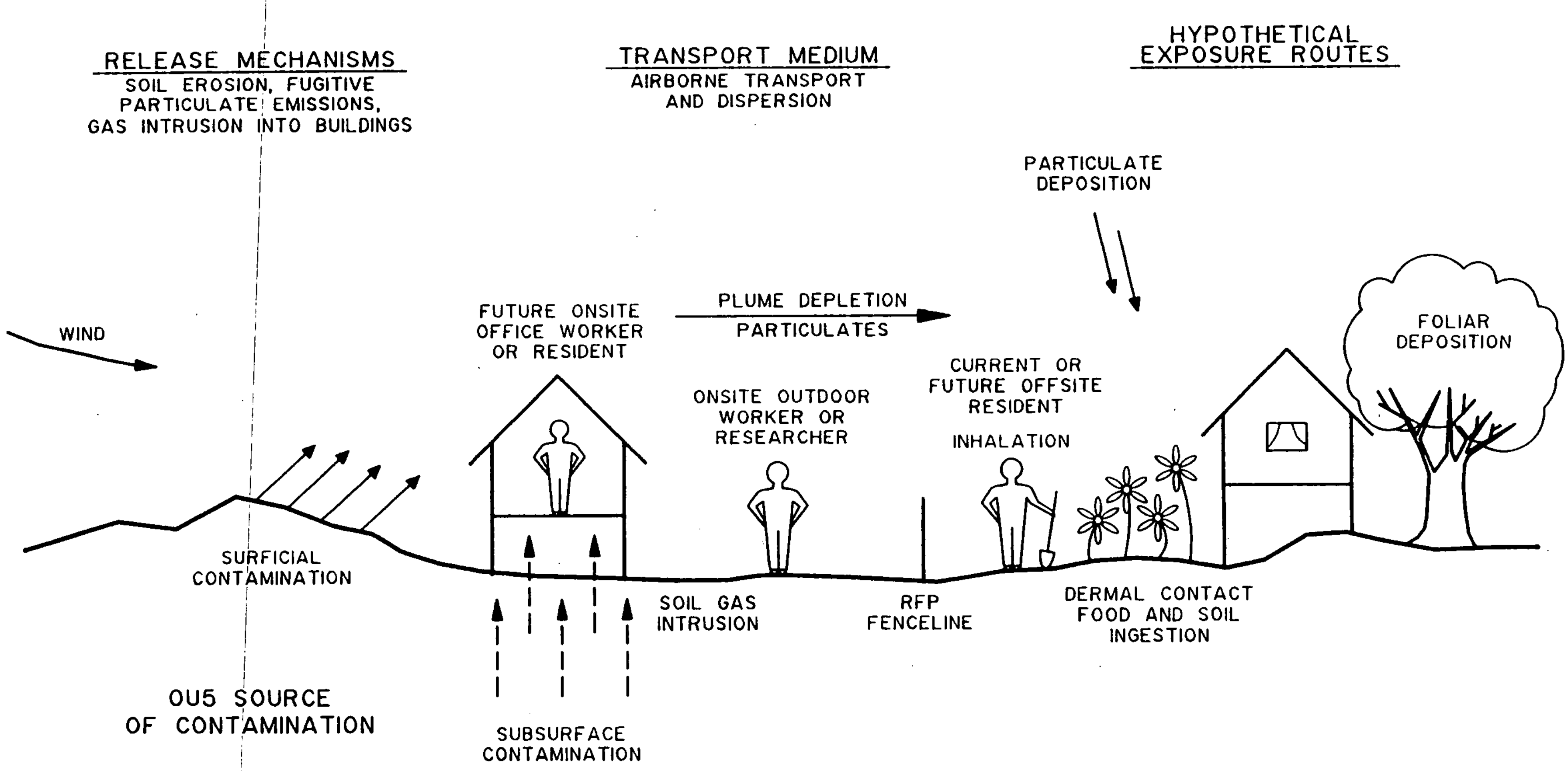
SURFACE
WATER PROFILE

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | FIGURE 2-5
NOV. 1993

TM13_2-5DWG



AIR TRANSPORT PROFILE

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | FIGURE 2-7
NOV. 1993

TM13_2-7.DWG

airborne particulates on surface soils and plants. Potential chemical intake and corresponding risks associated with these media will also be evaluated. The airborne exposure pathways within the CSM are shown on Figure 2-8.

3.0 MODEL DESCRIPTION

This section specifies the models to be used in characterizing and predicting exposure point concentrations at specific receptor locations for the OU5 HHRA. The considerations for model selection are also discussed below.

The term "model" refers to computer codes or a set of equations that can be used to mathematically represent site conditions and simulate media behavior (e.g., groundwater flow) and contaminant fate and transport in the model domain. The models will incorporate site-specific data to allow simulation of site-specific conditions and media behavior. The combination of a computer code and the necessary site-specific data will be referred to as a "site-specific model."

3.1 GENERAL CONSIDERATIONS FOR MODEL SELECTION

According to Bond and Hwang (1988) and van der Heijde and Park (1986), the following issues should be considered when selecting groundwater models for simulating conditions at a site: (1) the objectives of the project, (2) the physical and chemical conditions of the site, and (3) the requirements for implementing the models. Although the discussions presented by Bond and Hwang, and van der Heijde and Park were directed at groundwater models, it is reasonable to apply the same considerations to surface-water and air models.

The OU5 modeling objectives (issue no. 1) are to simulate the transport of contaminants of concern for risk assessment purposes and to support the evaluation of remedial alternatives for the FS. The physical and chemical conditions of the site (issue no. 2) have been and are continuing to be characterized as part of the ongoing RFI/RI process. Models selected should be capable of incorporating key onsite transport processes. Models should also be capable of accurately representing the site characteristics, including the variability of media properties as defined by the RFI/RI. Requirements for implementing the models (issue no. 3) include:

- the availability of the model

- the degree and nature of documentation

- the extent of peer review of the model, and

- the nature of model verification and testing (model verification is the process of verifying that the model results are numerically correct and involves an independent check of the calculations performed by the model)

Based on the issues described above, a set of criteria was developed for selecting the models to be used at OU5. The general criteria are that:

1) The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.

2) The selected models should be able to satisfy the objectives of the study.

3) The selected models should be verified using published equations and solutions.

4) The selected models should be complete and well-documented and preferably available to the public.

5) The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.

These five criteria were used as the basis for selecting the groundwater, surface-water, and air models to be used to simulate conditions within the OU5 study area. The following sections discuss the selected models relative to their ability to satisfy the identified selection criteria.

All mathematical models have limitations and uncertainties associated with assumptions inherent in the models. This is true for the models selected for use on OU5. However, it is believed that the selected models presented herein are the most appropriate models available for use on OU5 and that the associated limitations and uncertainties are inherent in the state of modeling methodology as applied to problems containing similar prototype complexities and field data limitations.

3.2 GROUNDWATER FLOW MODEL FOR SATURATED CONDITIONS

3.2.1 Description

Groundwater flow modeling will be performed for use as input to the groundwater contaminant fate and transport model in support of the OU5 HHRA. Available hydrologic and geologic information will be integrated to aid in understanding and quantifying the groundwater flow system within the UHSU. Data collected during OU5 field activities indicate at least three units comprise the unconsolidated material, Rocky Flats alluvium, colluvium, and valley-fill alluvium, each with distinct hydrogeologic properties. The complexity of the groundwater flow system, the heterogeneity of the geologic materials within the UHSU along potential flowpaths from the IHSSs to Woman Creek, the diverse boundary conditions within the OU5 area and the need to support the OU5 HHRA, necessitate the use of a two-dimensional numerical groundwater flow model. The numerical flow model that will be used is the USGS modular three-dimensional finite-difference groundwater flow model (MODFLOW) (McDonald and Harbaugh, 1988). Specifically, the groundwater flow model will simulate saturated steady-state, two-dimensional groundwater flow in the UHSU in the OU5 area. It will also provide hydraulic head distributions over the model domain. Areas of patchy saturation will be simulated using the Block Centered Flow 2 (BCF2) (McDonald, et al., 1992), a MODFLOW package which allows the wetting and drying of cells. The hydraulic head distribution from the MODFLOW output will serve as input to the contaminant fate and transport model to estimate concentrations of chemicals of concern at exposure points for potential human receptors.

Included in the modeling process are calibration, sensitivity analysis, and uncertainty analysis. A validation of the calibrated model will not be conducted since there is insufficient data available to form a second data set.

Calibration is a process whereby input parameters are adjusted until the model-produced heads or head trends approximate field heads or head trends. Calibration criteria are established prior to modeling in order to evaluate the calibration. In the OU5 area, heads vary considerably within short distances reflecting the topographic relief. A calibration criteria compatible with these field conditions is one described by Cooley (1977) which takes into account the wide range in heads in the model region. Cooley's method uses the error variance as follows:

$$S_e/\Delta h$$

where Δh is the difference between the highest and lowest heads, S_e^2 is the error variance from $S_e^2 = \Sigma_n(E_i)^2/(N-1)$, and E_i is observed minus computed head at observation point i and N is the number of points. The value of $S_e/\Delta h$ should be minimized.

The sensitivity of the input parameters will be addressed within the uncertainty analysis as described in Section 3.3.1.

The limitations inherent in the MODFLOW program include those related to discretization and to parameter uncertainty. The steady-state application of MODFLOW introduces the additional limitation of approximating a time-variant system with a steady one.

MODFLOW was selected for its compatibility with the sitewide model and its cost effectiveness (pre-processors, post-processors, and GIS available). MODFLOW is widely used and accepted in the scientific community. MODFLOW also satisfies the five selection criteria presented above. A discussion of how MODFLOW meets each of these criteria follows.

Selection Criterion No. 1 - **The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

MODFLOW is capable of incorporating key processes and representing the conditions known to occur at the site. These include:

- saturated porous media flow,
- the spatial distribution of the geologic units,

- the spatial distribution of hydraulic parameters for the geologic materials present at the site (i.e., hydraulic conductivity),

- the spatial distribution of groundwater levels in the UHSU, and

- the influence of hydraulic inputs and outputs to the system (such as recharge from precipitation), and hydraulic boundary conditions (i.e., groundwater inflow, and outflow to seeps).

One of MODFLOW's strongest attributes is its ability to integrate complex hydraulic and hydrogeologic data into a comprehensive model that can be used to aid in understanding and quantifying the groundwater flow system. MODFLOW's ability to simultaneously deal with complex hydrogeologic conditions, complex hydraulic boundaries, and multiple hydraulic inputs and outputs to the system makes it valuable for characterizing the site groundwater flow system. The output from MODFLOW can be used as input to other computer programs to yield groundwater flow directions and velocities, and to transport models to simulate contaminant fate and transport.

Selection Criterion No. 2 - **The selected models should be able to satisfy the objectives of the study.**

MODFLOW is capable of satisfying the objectives listed in Section 1.1. Although MODFLOW is a groundwater flow model and does not simulate contaminant fate and transport, the output from the site-specific MODFLOW flow model can be used as input for the contaminant fate and transport model to predict exposure point concentrations for risk assessment.

Selection Criteria 3 and 4 - **The selected models should be verified using published equations and solutions. The selected models should be complete and well-documented and preferably available to the public.**

MODFLOW has been successfully applied to many complex flow problems and is a widely-used and well-documented finite-difference groundwater flow model supported by USGS and accepted by EPA. MODFLOW is documented in a comprehensive manual prepared by USGS (McDonald and Harbaugh, 1988). The manual documents the model theory and program structure, provides instructions for model use, and presents a listing and narrative of the model code. Verification of MODFLOW has been performed by USGS and independent users using published analytical solutions to the partial-differential equation for groundwater flow through porous media (Anderson and Woessner, 1992). MODFLOW is a public domain code that is readily available. A copy of the MODFLOW source code is provided with the purchase of MODFLOW.

Selection Criterion 5 - **The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

MODFLOW can be practically and cost-effectively applied to the OU5 site and is designed for pre-processors and post-processors which facilitate the use of the model and its cost-effectiveness.

3.2.2 Model Parameters Data Summary

A summary of the data available to conduct groundwater flow modeling is provided in Table 3-1. Most data required for groundwater flow modeling are from OU1 and OU5 investigations. OU1 overlaps the OU5 boundary to the north, and the geologic materials and stratigraphy of these OU1 and OU5 are similar. Some of the data collected during OU5 field activities are not currently available but will be used during modeling efforts.

Three pumping tests and one slug test were conducted during OU5 field activities. This data, along with aquifer tests conducted during sitewide studies (EG&G, 1991c) and OU1 field activities in the OU5 area (EG&G, 1992b) will yield values for hydraulic conductivities and specific yield for the three geologic units within the UHSU.

The OU5 data are based on Phase I preliminary field investigations and, as such, are subject to change. Some of the parameters listed in Table 3-1 will not be assessed during Phase I activities. These parameters have been assigned values from OU1 data or from the literature.

Table 3-1

Data Summary for Groundwater Modeling

Parameter	Units	Range of Values	Source
Properties of Colluvium/Alluvium			
Hydraulic Conductivity	cm/sec	NYA	OU5 Phase I Preliminary Field Data and other site-specific data from other field activities
Storage Term	--	NYA	OU5 Phase I Preliminary Field Data and other site-specific data from other field activities
Bulk Density	g/cm^3	1.65 - 1.97	OU1 data from Fedors and Warner (1992)
Properties of Bedrock (Sandstone)			
Hydraulic Conductivity	cm/sec	$2x10^{-4}$ to $2x10^{-6}$	OU1 data from Fedors and Warner (1992)
Effective Porosity	%	2 - 27 1 - 12	Fetter (1980), EG&G (1992c)
Bulk Density	g/cm^3	1.93	OU1 data from Fedors and Warner (1992)
Dispersivity (longitudinal)	ft	39-200	Walton, 1985

NYA = Not yet available

3.3 GROUNDWATER CONTAMINANT FATE AND TRANSPORT MODEL FOR SATURATED CONDITIONS

3.3.1 Introduction

Groundwater contaminant fate and transport modeling will be performed to simulate the movement of dissolved contaminants in groundwater in the saturated zone beneath OU5. This modeling will also estimate future dissolved contaminant concentrations in groundwater at identified discharge points. This will allow the evaluation of contaminant transport to potential human receptors in the OU5 HHRA. As needed, this modeling can also be useful in evaluating discharge of contaminants by seeps into surface waters (Lewis, 1993).

Since little data are available for the vadose zone, it is anticipated a one-dimensional analytical solute transport model will be appropriate for simulating contaminant movement through the vadose zone to provide input to the groundwater model. ODAST, a computer program for a one-dimensional analytical solution will be used to evaluate contaminant transport from the unsaturated contaminated landfill to the groundwater table (Jarandel, et al., 1984). This solution considers convection, dispersion, decay, and adsorption in porous media.

It is believed that a numerical model should be used to simulate contaminant fate and transport in the UHSU at OU5, because of the spatial and temporal complexity of the groundwater flow system within the UHSU as discussed in Section 3.2. The model that has been selected is the modular three-dimensional contaminant fate and transport model MT3D (Zheng, 1990). MT3D is similar in structure to MODFLOW and can incorporate MODFLOW output directly, including information generated using BCF2. MT3D simulates the processes of advection, dispersion, sink/source mixing, and chemical reactions, including equilibrium-controlled linear or nonlinear sorption and first-order irreversible decay or biodegradation.

Available data on fate and transport parameters (e.g., dispersivity), source areas, and the nature and extent of groundwater contamination will be integrated with the MODFLOW groundwater flow data to simulate the fate and transport of dissolved phase contaminants with MT3D. Specifically, the site-specific MT3D will be used to simulate existing groundwater contamination conditions and to estimate future contaminant concentrations at groundwater discharge points.

Calibration will take place similar to that described for groundwater flow in Section 3.2.1 with adjustments of parameters within expected ranges of the contaminant concentrations until the model output approximates field concentrations. A calibration criteria will not be established until the data have been reviewed. A validation of the calibration will not be performed since a second set of data is not available.

The sensitivity analysis and the uncertainty analysis will be conducted within the same procedure. The distribution coefficient (k_d) for each COC, the dispersivities (longitudinal and transverse), and porosity will be varied to produce a best case scenario (minimum concentration) and a worst case scenario (maximum concentration), each using the appropriate uncertainty run from the flow modeling. For instance, heads derived from the high hydraulic conductivity uncertainty flow model run would be paired with the parameters expected to yield the worst case scenario (maximum concentrations) and vice versa. Two uncertainty runs of the solute transport model will be performed for each COC.

MT3D was selected from a number of available contaminant fate and transport models because it satisfies the selection criteria presented in Section 3.1 above and because it is compatible with MODFLOW. A discussion of how MT3D meets each of these criteria follows in the order in which the selection criteria are presented in Section 3.1.

Selection Criterion No. 1 - **The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

MT3D is capable of incorporating key contaminant fate and transport processes known to occur at RFP. Those key processes include complex advection, dispersion, retardation, and decay processes. MT3D is also capable of representing the complex conditions that occur at RFP. These conditions include the potential spatial (horizontal and vertical) distribution of fate and transport parameters (such as retardation and dispersion coefficients), the influence of boundary conditions, the spatial and temporal variations of chemical contaminant concentrations in the UHSU, and the spatial distribution and temporal behavior of multiple sources.

Selection Criterion No.2 - **The selected models should be able to satisfy the objectives of the study.**

MT3D is capable of satisfying the applicable objectives listed in Section 1.1. Output from the site-specific MODFLOW groundwater flow model in the form of a groundwater flow field will serve as input to MT3D. MT3D will then be used to simulate the movement of dissolved chemical contaminants in groundwater through the UHSU and to estimate future concentrations of chemical contaminants at identified groundwater discharge points. Those results will then be used to provide input to the surface-water model used to estimate concentrations of chemicals of concern at exposure points for potential human receptors in support of the OU5 HHRA.

MT3D is able to simulate the key contaminant fate and transport processes, and incorporate the heterogeneity of the transport parameters, the complex boundary, and the source conditions into a comprehensive fate and transport model. This makes it well suited for use at RFP.

Selection Criteria No. 3 and 4 - **The selected models should be verified using published equations and solutions. The selected models should be complete and well-documented and preferably available to the public.**

MT3D is a widely-used and well-documented finite difference contaminant fate and transport model. MT3D is documented in a comprehensive manual that describes the model theory and program structure, provides instructions for use, and addresses verification and application of the model. Verification of MT3D using test problems for which analytical solutions are available has been performed by the developers and is documented in a section of the MT3D manual. MT3D is distributed by S.S. Papadopulos & Associates with the model source code and is readily available.

Selection Criterion No. 5 - **The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

MT3D can be practically and cost-effectively applied to the OU5 site. MT3D is designed in a structure similar to MODFLOW and is therefore easy to set up and use. Using MT3D in conjunction with MODFLOW is advantageous because MT3D has been designed to directly take MODFLOW hydraulic head output data. This eliminates the need for intermediate data manipulation steps.

3.3.2 Model Parameters Data Summary

The parameters which will be used for groundwater transport modeling are summarized in Table 3-1. All parameters directly related to the solute transport model will be derived from the literature, including dispersivities, porosities, distribution coefficients, and half-lives. Values for distribution coefficients and half-lives will not be reviewed until the COCs have been determined. Data for contaminant concentrations from laboratory analysis of field samples are not presented as they are not yet available.

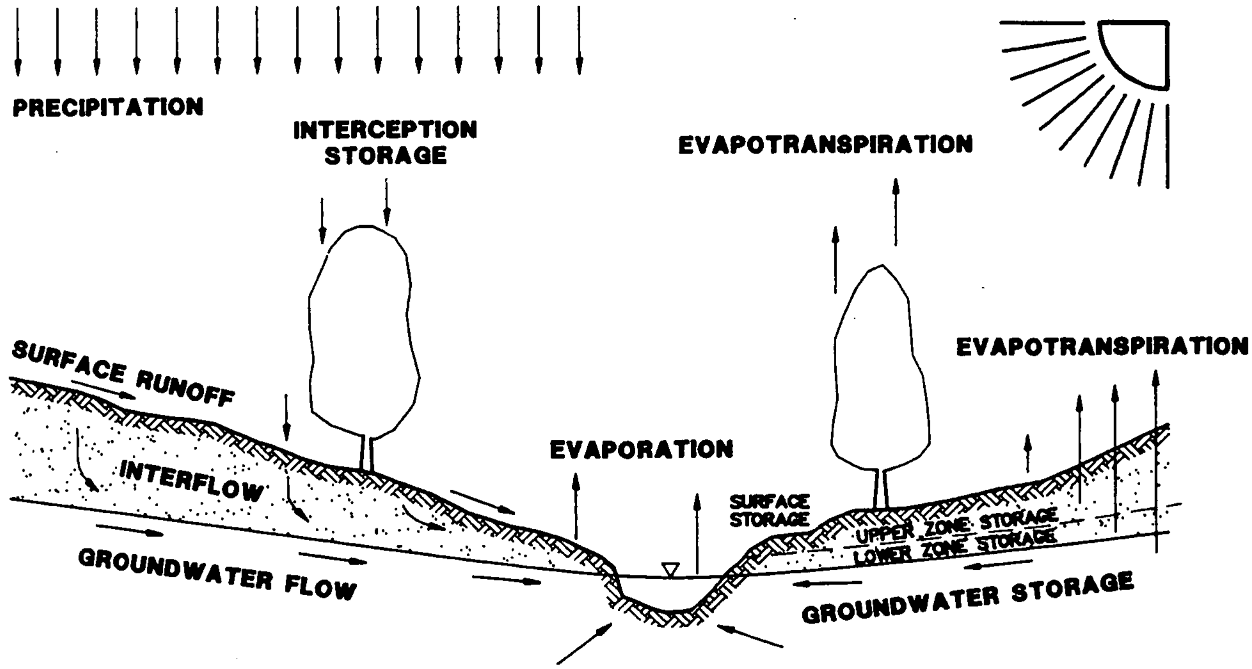
3.4 SURFACE-WATER MODEL

3.4.1 Description

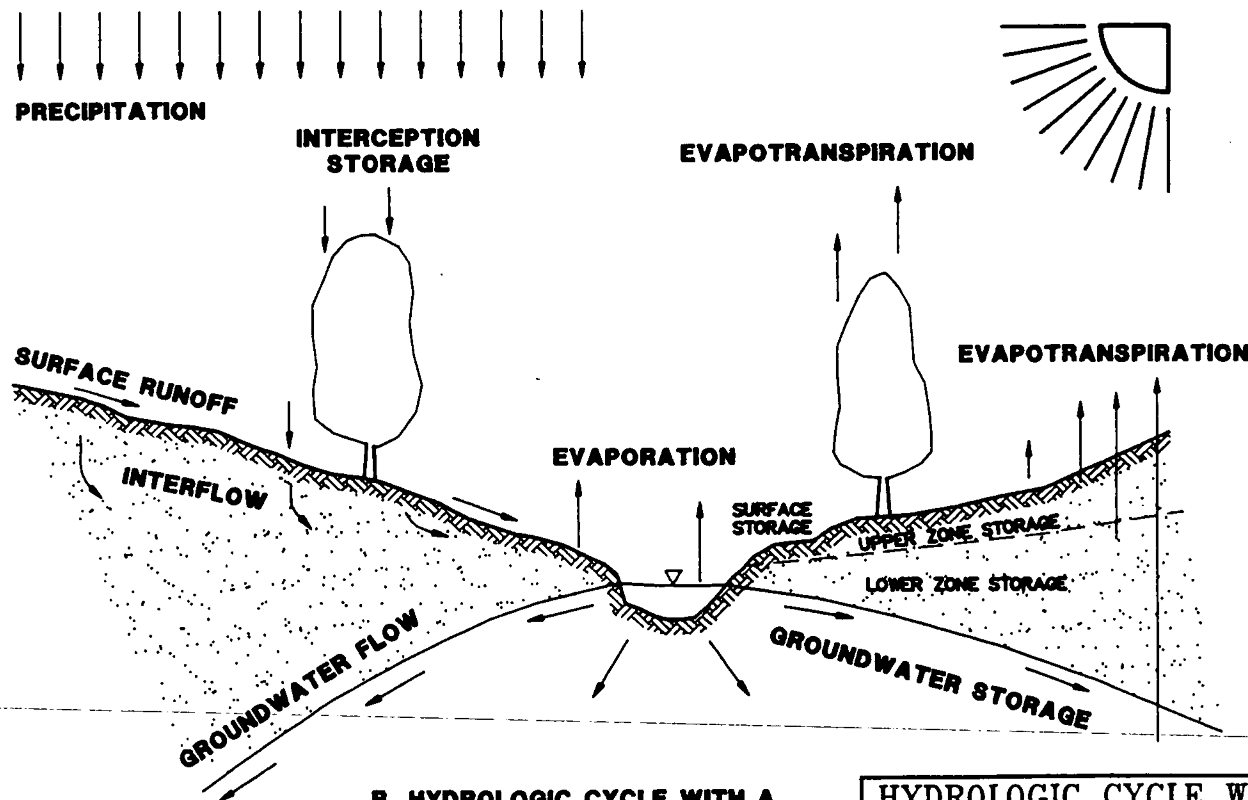
To characterize the general surface-water hydrologic system of OU5, a surface-water flow and transport model will be applied. The Hydrologic Simulation Program - Fortran, Version 9 (HSPF9) (Johanson, et al., 1984), a one-dimensional steady-state or dynamic model, has been selected for the surface-water model. This model includes the Woman Creek segments located at RFP. The model uses both basin runoff and stream-reach/pond modules to simulate the total Woman Creek surface-water system. Historical data and data collected during surface-water and sediment sampling, including background sampling, will be used, to help characterize hydrologic aspects of Woman Creek, the SID, and the C-Series ponds. They will also be used to calibrate the model.

HSPF9 is a comprehensive package for simulation of watershed hydrology and water quality. Figure 3-1 shows the hydrologic cycle components that are simulated using the HSPF9 model. HSPF9 is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with instream hydraulic and sediment-chemical interactions (Ambrose and Barnwell, 1989).

HSPF9 can simulate branching, one-dimensional stream/reservoir systems, including groundwater simulation and pond simulation. The model is capable of simulating water and sediment budgets, water temperature, dissolved oxygen, biochemical oxygen demand (BOD), organic-nitrogen, ammonia-nitrogen, nitrate-nitrogen, organic-phosphorus, dissolved-phosphorus, pesticides, pH, CO_2, total inorganic carbon, alkalinity, plankton populations, arbitrary non-conservative constituents using a first-order decay function, and conservative constituents. However, the modeling application will focus only on selected water-quality and sediment-related variables of concern at OU5. As indicated in TM1 (ASI, 1993), HSPF9 will be used to model six scenarios consisting of water temperature, dissolved oxygen, nitrate, one non-conservative, and one



A. HYDROLOGIC CYCLE WITH A GAINING STREAM REACH



B. HYDROLOGIC CYCLE WITH A LOSING STREAM REACH

Source: Modified From Johanson and others (1984).

HYDROLOGIC CYCLE WITH GAINING AND LOSING STREAM REACHES		
TM 13 - HHRA MODEL DESCRIPTION		
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EG&G	9208151111 / NOV. 1993	FIGURE 3-1

TM13_3-1DWG

conservative tracer for a low-flow and high-flow period in a typical dry, average, and wet year. The non-conservative tracer will be a radionuclide using a first-order decay assumption.

HSPF9 inputs will be sequential time-series records of hourly meteorological data, including precipitation, air and dew point temperatures, solar radiation, wind speed, and potential evapotranspiration.

The time series are obtained from the RFP meteorological tower as 15-minute readings and aggregated to a 1-hour interval by summing or averaging the 15-minute readings. The evapotranspiration time series is developed from the other series mentioned using the 15-minute values as input.

A 1-hour input (simulation) time step was chosen so that the effects of temporally short, but relatively intense meteorological events will not be obscure, as may occur if the meteorological conditions were considered on a mean daily basis. Output can be obtained at any aggregation of the simulation interval. Daily summaries will be used, as 1-hour to 1-hour comparisons of simulated versus observed values require extremely detailed boundary condition development and determination of localized variations that are beyond the scope of this project. Further, though it would be possible to attempt flow calibration at this time scale, there are no water quality data available at this time resolution for use in such a model calibration. Given that the water quality data are point readings, daily summaries of simulation are the preferred method.

The simulation timeframe to be used is July 1, 1989 to June 30, 1993. This timeframe was selected as it encompasses the period where flow and water quality data is available in sufficient quantity and quality for use in model calibration. The four years meteorological data averages are considered typical for this region and include an event with a greater than 10-year recurrence interval. Simulating specific recurrence intervals are not in the scope of this project.

Seepage is to be added to the model as sequential time series. The seepage time series is a "boundary condition" that may be modified during the calibration process. Initial estimates of seepage will be obtained from a sitewide groundwater flow model that is currently under development and modified during model calibration if necessary. Baseflow data is a boundary time series that is available from pond operation records and flow recording instrumentation.

A more thorough description of input parameters and site-specific data available for the model are found in Section 3.4.3.

HSPF9 outputs will be daily mean discharge and contaminant concentrations as a function of distance along Woman Creek. Both dissolved and particulate (i.e., contaminants associated with suspended solids) will be modeled. Standard deviations of these mean discharges and constituent concentrations will also be estimated as part of the uncertainty analysis.

The purpose of the surface-water flow and transport model application will be to assess the water quality of Woman Creek over its various segments for a range of flow conditions. It will also assess the potential surface-water contaminant pathways. Flow in Woman Creek can be attributed to groundwater, storm runoff, and bank-storage outflow from both rainfall and snowmelt, and inflows from irrigation diversions through the Smart 2 and Kinnear Ditches (Figure 1-4). Each of these flow sources will be included in the flow and transport model.

The major processes affecting surface-water/sediment pollutant concentrations in OU5 are:

- Precipitation and runoff
- Soil erosion and associated pollutants
- Stream and pond hydraulics, and
- Pollutant-specific fate mechanisms

The following sections describe how these major processes are handled by the HSPF9 model.

Precipitation and Runoff

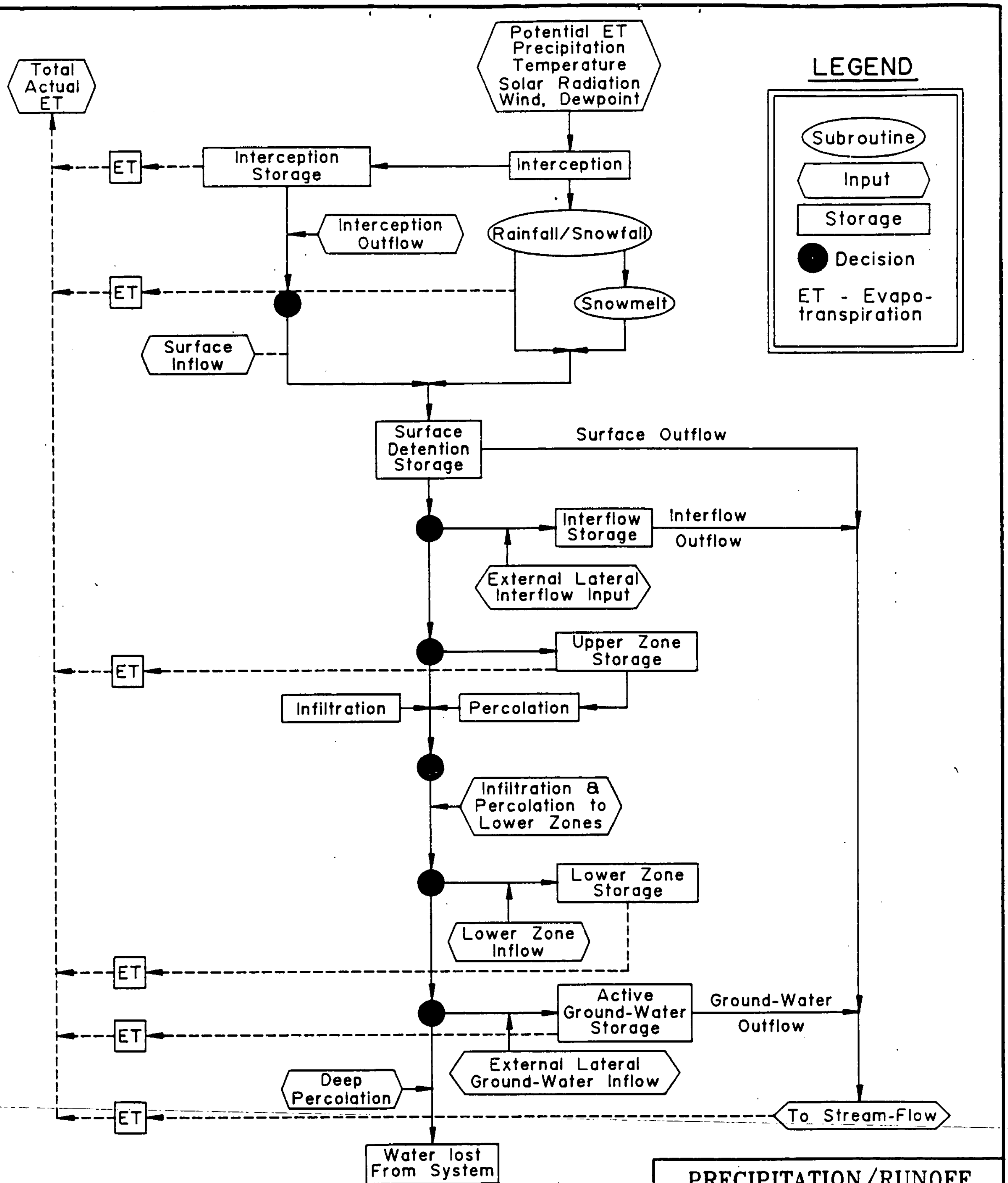
Hydrologic simulation in HSPF9 is performed using a moisture-accounting technique first developed in the Stanford Watershed Model (Crawford and Linsley, 1966). This technique computes the movement of water into, between, and out of a set of conceptual storages using a fixed time step. Figure 3-2 is a schematic diagram of the precipitation and runoff processes that are depicted in the HSPF9 simulation model. Rainfall and snowfall are subject to interception. If interception storage is full, water infiltrates the subsurface, if not limited by the upper-zone storage capacity. Water that does not infiltrate the upper zone exits the system as surface outflow or interflow outflow (Figure 3-2). Water that infiltrates the upper-zone storage and subsurface is then possibly further routed to and/or through the upper-, lower-, and groundwater storages, based upon those storages' current capacities. If all these capacities are exceeded, water leaves the system as groundwater outflow according to HSPF9. Evapo-transpiration is calculated for all of the above storages before capacity exceedance is calculated (Figure 3-2). The effects of the impervious area will be modeled as necessary.

Soil Erosion

Soil erosion in HSPF9 is simulated as illustrated in Figure 3-3. Erosion can occur either due to particle detachment from rainfall impact and subsequent wash off, or as a result of rill and gully scour.

Stream and Pond Hydraulics

Flow routing is modeled using the catchment-stream network technique, which is divided into reaches and flow-routing calculations that proceed from upstream to downstream reaches. The stream network can be of any complexity, including flows which are split and later recombined downstream. Impoundments (ponds, lakes, reservoirs) also are included, although HSPF9



Source: Johanson and others (1984).

PRECIPITATION/RUNOFF PROCESSES USED IN HSPF9

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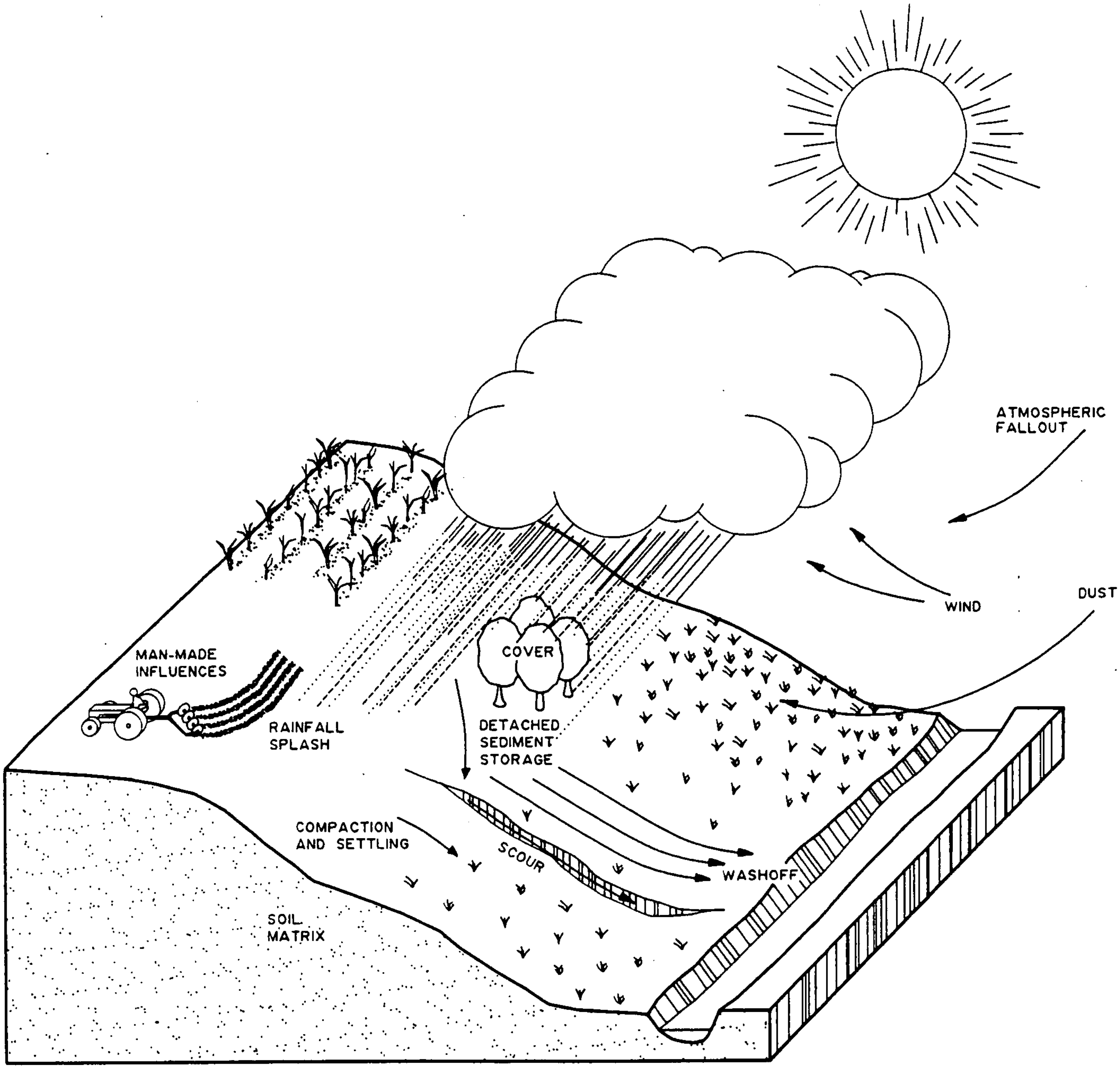


Source: Johanson and others (1984).

SOIL-EROSION PROCESSES USED IN HSPF9

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | NOV. 1993 | FIGURE 3-3

TM13_3-3DWG

assumes such impoundments to be completely mixed; that is, stratification is not modeled. The RFP reservoirs, and Ponds C-1 and C-2 have been determined to be fully mixed based on their depths and turnover ratios (ASI, 1992).

Pollutant-Specific Fate Mechanisms

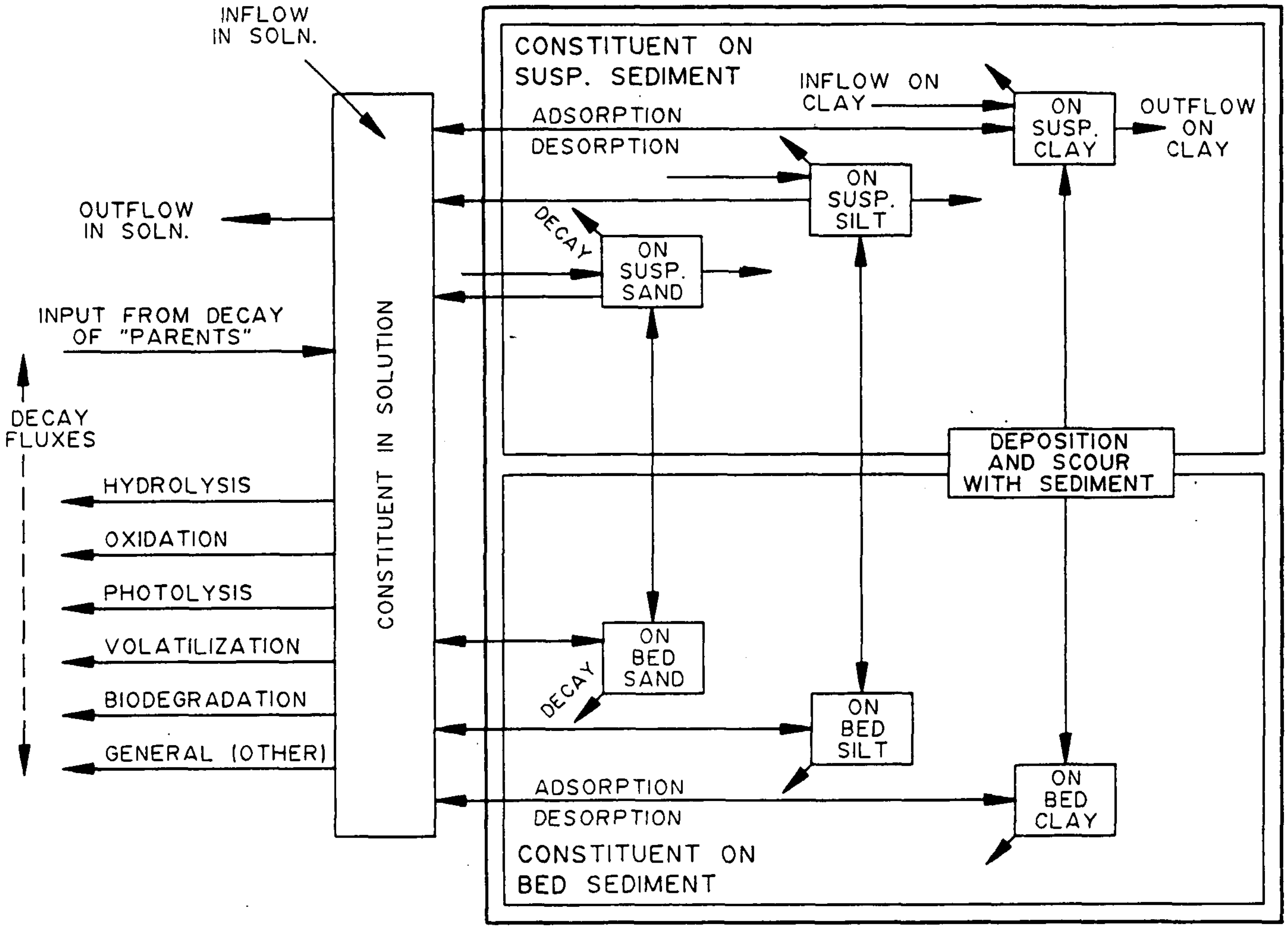
Several important mechanisms affect the chemicals of concern including partitioning between dissolved/particulate phases, interactions between chemicals in the water column and the sediment bed, and any of a number of chemical-specific, physical/chemical/biological processes (e.g., volatilization, biodegradation). HSPF9 can simulate these mechanisms for the quality constituents to be modeled, as illustrated in Figure 3-4.

3.4.2 Model-Selection Criteria Evaluation

The HSPF9 model described above was selected, because it is believed to adequately satisfy the following five selection criteria. A discussion of how this model fulfills the needs of each criterion is given below.

Selection Criterion 1 - **The selected model should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

Key processes associated with surface-water aspects of OU5 include, as described before, precipitation and runoff, soil erosion and associated pollutant movement, stream and pond hydraulics, and pollutant-specific fate mechanisms. HSPF9 has extensive capabilities to incorporate these processes, and it is the only physical-process/water-quality model known to integrate these processes within a single computer code.



Source: Johanson and others (1984).

POLLUTANT-FATE MECHANISMS MODELED BY HSPF9

TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | NOV. 1993 | FIGURE 3-4

TM13_3-4DWG

Selection Criterion 2 - **The selected model should be able to satisfy the objectives of the study.**

The HSPF9 model meets the modeling objectives discussed in Section 1.1. To support the risk-assessment objectives, the model can simulate the transport of chemicals of concern from sources (storm-water runoff, groundwater discharge) to downstream exposure points. This modelprovides the capability to estimate risks posed by individual sources, i.e., the risks associated with either storm-water runoff only or groundwater discharge (base flow) only.

Selection Criteria 3 and 4 - **The selected model should be verified using published equations and solutions. The selected model should be complete and well-documented and preferably available to the public.**

Verification is the process that demonstrates whether the computer program correctly performs its stated mathematical capabilities (Brooks and Coplan, 1988). Code verification involves comparing numerical code results with analytical solutions (Cole, et al., 1988). HSPF9 modules have been verified using empirical formulas and analytical solutions for the various processes being simulated (Crawford and Linsley, 1966; Ambrose and Barnwell, 1989).

Validation, on the other hand, is the process of assuring that the model is a correct representation of the processes and system at the OU5 site. Therefore, validation is an extension of calibration and is, thus, carried out by comparison of calculations with observations and experimental measurements (Cole, et al., 1988). HSPF9 has been validated using both field data and physical model experiments and has been reviewed by independent experts (Ambrose and Barnwell, 1989). It is available to the public and is distributed and maintained by the EPA Center for Exposure Assessment Modeling (CEAM) in Athens, Georgia.

Selection Criterion 5 - **The selected model should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

Although HSPF9 is a comprehensive, physical-process model, its modular construction allows it to be tailored to site-specific conditions and objectives. It can be configured to be as detailed or as general as the modeling application dictates by activation of more or less detail in the individual modules. This flexibility ensures its "cost-effectiveness." HSPF9 is a purely deterministic model; no stochastic or uncertainty analysis capabilities exist. Uncertainty analysis will be performed outside of the HSPF9 environment by analysis of data-input statistics and model-prediction errors.

3.4.3 Model Parameters Data Summary

This section provides a summary of the various types of data required as inputs into the HSPF9 model. When applicable, site-specific data collected during the Phase I RFI/RI investigations or earlier studies will be used. All required meteorological data are available from the RFP Meteorological Station located in the west buffer zone. A detailed available summary of OU5 site-specific input and calibration data, as well as available validation data, for the HSPF9 model application can be found in ASI (1992), which currently is being updated to include 1993 field data collected at OU5. If certain site-specific data or model parameter inputs are not available, it is anticipated that published literature values will be used. Table 3-2 presents a listing of the model parameters, units, and range of values to be used in the HSPF9 model. Model calibration will involve varying these parameters to produce the best correlation with observed data. The agreement between simulated and recorded hydrologic values required for an adequate calibration of the HSPF9 model is highly dependent upon the specific watershed, available data, data quality, and the specific problem being analyzed. Donigian, et al., (1984) give the following general guidelines for characterizing a calibration for the HSPF9 model:

Difference Between Simulated and Recorded Values (Percent)

	Calibration Results		
	Very Good	Good	Fair
Hydrology/Hydraulics	<10	10-15	15-25
Sediment	<15	15-25	25-35
Water Quality	<20	20-30	30-40

Table 3-2
Surface-Water Model Parameter Values

Parameter	Units	Range of Values[1)]
Precipitation/Runoff		
Nominal soil moisture storage (LZSN, UZSN)	inches	0.01 - 100
Infiltration capacity index (INFILT)	in/hr	0.0001 - 100
Groundwater recession rate (AGWRC)	per day	0.001 - 1.0
Interception storage capacity (CEPSC)	inches	0 - 10
Trade-off between interflow and surface runoff (INTFW)	none	min of 0 (no max)
Interflow recession parameter (IRC)	per day	0 - 1.0
Lower-zone ET parameter for density of deep-rooted vegetation (LZETP)	none	0 - 1
Fraction of the land segment which is shaded from solar radiation (SHADE)	none	0 - 1
Interception storage capacity of an impervious surface (RETSC)	inches	0 - 10
Soil erosion		
Initial storage of detached sediment (DETSB)	tons/acre	min of 0 (no max)
Fraction of detached sediment which reattached each day (AFFIX)	per day	0 - 1
Flux to/from atmosphere from/to detached storage (NVSI)	lbs/acre-day	none
Coefficient for detached sediment washoff (KSER)	none	0 - 1
Coefficient for soil scour (KGER)	none	0 - 1
Hydrodynamics		
Median diameter of bed sediment (DB50)	inches	0.0001 - 100
Channel characteristics as functions of the water surface elevation:		
depth	feet	none
surface area	sq. feet	none
volume	cubic feet	none
Contaminant Fate		
Ratio of volatilization rate to oxygen reaeration rate (CFGAS)	none	min of 0 (no max)
Partitioning coefficient between dissolved and suspended states (KDJ)	liters/mg	min of $1x10^{-10}$ (no max)
First-order biodegradation rate constant (KBIO)	per day	0 - 1

1) Parameter ranges were obtained from the HSPF9 User's Manual, Version 8.0 (Johanson, et al., 1984).

3.5 SOIL GAS TRANSPORT MODEL

3.5.1 Introduction

Soil gas transport modeling will be performed to simulate the movement of VOCs from underlying soil gas as a result of volatilization from soil and UHSU groundwater contaminants to the OU5 surface beneath a hypothetical onsite building. An air transport and dispersion model, discussed in Section 3.7, will then be used to estimate airborne VOC concentrations within the building. This activity will support and provide input to an HHRA.

At the time this report was prepared, most of the data from the Phase I investigation were unavailable; however, preliminary field data generally indicated that the contamination is located in the unsaturated zone. If further analysis of data confirms this, estimates of volatilization will be provided by the utilization of the Jury, Spencer, and Farmer (1983) analytical solution. In the event that analysis of the data suggests contamination in the saturated zone, a different soil gas transport model, the Johnson-Ettinger analytical solution (1991), will be used. The selection of these models was based on the considerations discussed in Section 3.1.

The soil gas model developed by Jury, Spencer, and Farmer (1983) and referenced hereafter as the Jury model is a one-dimensional, analytical solution of the advection-dispersion equation. The Jury model is applicable to areas of the unsaturated zone that are uniformly contaminated.

The Jury model incorporates adsorption, decay, and transport in the soil gas phase and in water in the unsaturated zone. The Jury model's equation for contaminant mass-flux at the top of a contaminated zone is:

(Equation 1)

$$J_s(0,t) = \frac{1}{2} C_0 e^{-ut} \left[V \left\{ erfc\left(\frac{Vt}{\sqrt{4Dt}} - erfc \frac{(L + Vt)}{\sqrt{4Dt}} \right) \right\} + (2H + V)\, e^{(H(H+V)t/D)} \left\{ e^{(HL/D)}\, erfc\left(\frac{(L + (2H + V)t)}{\sqrt{4Dt}} \right) - erfc\left(\frac{(2H + V)t}{\sqrt{4Dt}} \right) \right\} \right]$$

where

J_s	=	contaminant mass flow per soil area per time ($M/L^2/T$) at the top of the contaminated zone and some time, t
C_0	=	initial, uniformly-distributed contaminant concentration at time 0 (M/L^3)
u	=	biodegradation rate (1/T)
t	=	time (T)
V	=	retarded advective velocity of a contaminant in liquid soil water (L/T)
D	=	retarded diffusion coefficient of a contaminant in soil vapor and liquid soil water (L^2/T)
L	=	vertical length over which contaminated soil exists (L)
H	=	retarded transport coefficient across a stagnant air layer at the top of the contaminated zone of a specified thickness (L/T)
erfc	=	complementary error function

Assumptions and limitations inherent in the Jury model include the following:

- An assumption of a homogeneous, porous media is used. Short transport distances in the unsaturated zone beneath OU5 are likely and changes in the properties of subsurface soils probably do not vary significantly over short distances. Therefore, the impact of heterogeneity on soil gas transport is not likely to be significant.

- An assumption of a linear equilibrium sorption is used and adsorption and desorption are assumed to be linear, rapid, and reversible. This assumption can be used to provide conservative estimates of the impact of adsorption (for the purposes of risk assessment).

- An assumption of linear equilibrium liquid-gas partitioning is used. The Jury model assumes that Henry's law applies to partitioning (volatilization) between the liquid and gas phases. Henry's law applies to situations in which contaminant concentrations in water are relatively small. This is the case at OU5 according to preliminary Phase I field data. Henry's law does not apply to concentrated solutions or to volatilization from a pure phase of contaminant.

- Volatilization at the soil surface is controlled by a stagnant-air boundary layer. The model does not apply to situations in which there is air flow immediately above the soil surface. Air flow must allow a stagnation layer to exist above the soil surface (interior of a structure).

- The distribution of contaminants is uniform in unsaturated soil with a constant thickness. The model does not apply to discontinuous or heterogeneously-contaminated zones. However, this assumption can be used to provide conservative estimates. The Jury model is only applicable to the unsaturated zone.

- Advection is by a steady water flux. The model assumes that evapo-transpiration and groundwater recharge are constant. In reality, evapo-transpiration and recharge vary according to season but will tend toward a constant average.

- The depth of uniform soil below the depth of incorporation is infinite. The model assumes that gas and liquid flow are uniform and vertically-oriented. This implies an infinite source and that edge effects are minimal. This assumption is conservative since the concentration of the contaminant source does not change with time.

The Jury model does not apply to the volatilization of organic compounds from contaminated water in the saturated zone. For such cases, the model of Johnson and Ettinger (1991) can be used. It employs the following equation:

(Equation 2)

$$E = \frac{A\,(C_v - C_{soil})\,D}{L_{soil}}$$

where

E	=	contaminant transport rate (M/T) through some cross-sectional area, A
A	=	cross-sectional area (L^2)
C_v	=	contaminant concentration in soil gas due to volatilization from contaminated groundwater (M/L^3)
C_{soil}	=	contaminant concentration in soil near the point at which E is to be estimated (M/L^3)
D	=	retarded diffusion coefficient of a contaminant in soil vapor (L^2/T)
L_{soil}	=	vertical distance between contaminated groundwater and the point at which E is to be estimated (L)

This equation is a one-dimensional expression of Fick's first law.

In the above equation, C_v is related to the concentration of a contaminant in groundwater through Henry's law:

(Equation 3)

$$C_v = C_w K_h$$

where

C_w	=	contaminant concentration in groundwater (M/L^3)
K_h	=	Henry's law constant

Equation 2 describes the diffusion of contaminants from the source to a location near the base of a structure (basement floor or floor slab).

The assumptions and limitations inherent in the Johnson-Ettinger model include the following:

- The transport of gas in the unsaturated zone is by diffusion. The model does not account for advection of contaminants in the unsaturated zone. Pressure differentials associated with air (or gas) in the unsaturated zone are typically zero because air pressures are usually equivalent to ambient atmospheric pressures. Therefore, there is no driving force for advective gas transport in the unsaturated zone.

- The source of contaminant gas is uniform and infinite. The Johnson-Ettinger model assumes that the source of contaminant gas is large enough to provide an "infinite source."

- The media is homogeneous and porous. Transport distances in the unsaturated zone beneath OU5 are likely short, and changes in the properties of subsurface soils probably do not vary significantly over short distances. Therefore, the impact of heterogeneity on soil gas transport is not likely to be significant. In addition, this assumption can be used to provide conservative estimates.

- Linear equilibrium sorption is assumed where adsorption and desorption are assumed to be linear, rapid, and reversible. For the purposes of risk assessment, this is a conservative assumption.

- Linear equilibrium liquid-gas partitioning is assumed. The Johnson-Ettinger model assumes that Henry's law applies to partitioning (volatilization) between the liquid and gas phases. Henry's law applies to situations in which contaminant concentrations in water are relatively small. This is the case at OU5 according to preliminary Phase I field data. Henry's law does not apply to concentrated solutions or to volatilization from a pure phase of contaminant.

- The distribution of contaminants in groundwater is uniform. The model does not apply to discontinuous or heterogeneously-contaminated zones.

These two soil gas transport models will be used to simulate the migration of contaminants from the subsurface to the soil surface potential onsite structures. These structures are associated with the potential-future onsite commercial/industrial receptor.

The Johnson-Ettinger and Jury models were selected because they are believed to best satisfy the selection criteria defined in Section 3.1.

Selection Criterion 1 - **The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

The Johnson-Ettinger and Jury models are capable of representing key contaminant processes in estimating soil gas transport. The models simulate soil gas transport to the surface as a result of underlying soil and groundwater contamination and diffusion from areas of soil and groundwater contamination. The key processes in the Jury model include adsorption, decay, diffusion, and advection of soil contaminants.

Examination of onsite data suggests that volatilization as a result of soil gas transport will primarily originate from near-ground surface soil contamination areas.

Selection Criterion 2 - **The selected models should be able to satisfy the objectives of the study.**

The Johnson-Ettinger and Jury models estimate surface volatilization from underlying soil gas with consideration of physical and chemical mechanisms. The resulting emission estimates can then be applied to the estimate of exposure point concentrations.

Selection Criteria 3 and 4 - **The selected models should be verified using published equations and solutions. The selected models should be complete and well-documented and preferably available to the public.**

The Johnson-Ettinger and Jury models for soil gas transport are widely used and well-documented in EPA literature for use in baseline scenarios. They are available for public use through publication.

Selection Criterion 5 - **The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

These soil gas transport models thoroughly document the proper use of easily-obtainable input parameters. These models can be placed easily into a spreadsheet format to handle multiple VOCs. Since these models are available to the public, there are no procurement or licensing costs for their use.

3.5.2 Data Summary for Soil Gas Modeling

A summary of data available to conduct the soil gas modeling is provided in Table 3-3. Most data required for soil gas modeling have been collected at OU5, OU1, and other literature. At this writing, very little data are available from the OU5 Phase I field investigation. None of the parameters listed in Table 3-3 should be regarded as site-specific at this time. Contaminants of concern (VOCs) have not yet been established for OU5; therefore, specific contaminant properties are not presented. Site-specific parameters for each COC will be developed after the COC list is finalized.

Table 3-3

Data Summary for Soil Gas Modeling

Parameter	Units	Range[a]	Source
Properties of Colluvium/Alluvium			
Porosity	%	26 - 38	OU1 Data Fedors and Warner (1992)
Bulk Density	kg/m^3	1.65 - 1.97	OU1 Data Fedors and Warner (1992)
Fraction of Organic Carbon	%	NYA	OU5 Phase I Preliminary Lab Data
Hydraulic Conductivity	cm/sec	NYA	OU5 Phase I Preliminary Lab Data
Environmental Properties			
Relative Humidity	%	36 - 50	Koffer (1989)
Evapo-transpiration Rate	m/day	$5.59x10^{-3}$ - $6.7x10^{-4}$	Koffer (1989)

a Range of observed values, typically from Phase I, II, and III reports
NYA Not yet available

3.6 AIR TRANSPORT AND DISPERSION MODEL

Air dispersion models are utilized in the air pathway analysis. These models estimate pollutant concentrations at receptor locations of interest where actual ambient contaminant monitoring data are unavailable presently or, of course, in the future. A selected model can provide specific point exposure concentrations of either gaseous and/or particulate matter emissions using emission rate data based on field measurements or emission model predictions. These specific point exposure concentration values support and provide input to the risk calculations of the HHRA.

3.6.1 Model Description

The model selected for the OU5 HHRA is the Fugitive Dust Model (FDM), version 93070 (Winges, 1991). Development of the FDM has been sponsored by EPA, Region 10, to address the concentration and deposition of particulate matter from fugitive dust sources. The model is generally based on the Gaussian plume equation, but the model has been adapted to incorporate an improved gradient-transfer deposition algorithm. Gravitational settling and deposition velocity are calculated by the FDM for each of a series of particle-size classes defined by the user. Concentration and deposition are computed at each user-specified location. Up to 200 sources and 500 receptors can be processed. The FDM will also treat gaseous emissions.

The FDM accepts three types of meteorological data: pre-processed, long-term STability ARray (STAR) format; pre-processed, long-term hourly RAMMET format; and user-defined, short-term format. The model allows output for 1-, 3-, 8-, and 24-hour averages and a long-term average over the entire meteorological base provided.

The sources may be points, lines, or areas. The line and area source algorithms are based on the CALINE3 Model developed by the California Department of Transportation. Area sources can be rectangular, up to an aspect ratio of 1 to 5 (ratio of width to length), and can be arbitrarily oriented in any compass direction.

The FDM has been validated by four field evaluation studies (Winges, 1991; Dames and Moore, 1990) and is available from EPA. As discussed below, the FDM satisfies each of the five selection criteria outlined in Section 3.1.

Assumptions and limitations inherent in the FDM include those common to all air dispersion models based on the Gaussian plume equation:

- The source emission rate is assumed to be constant.
- Diffusion in the direction of transport is assumed to be small compared with advection by wind speed in that direction.
- The material diffused is assumed to be a stable gas or aerosol that remains suspended in the air over long periods.
- All pollutants are assumed to exhibit perfect reflection from the ground and from an upper inversion surface.
- A mean wind speed is assumed to be representative of the diffusing layer chosen.
- The mean wind direction specifies the x-axis.
- Wind speed is assumed to be constant and the component in the x-direction is much greater than the y- or z-components.
- The plume constituents are assumed to be distributed normally in both the cross-wind and vertical directions.
- Averaging times represent periods of about 10 minutes.
- Downwind concentration values are limited to receptors within 50 km of the source (Turner, 1970).

With the FDM deposition routine, these assumptions and limitations apply:

- Eddy diffusivities are assumed to be functions only of downwind distance.
- Eddy diffusivity is assumed to be constant for all space and time.
- Concentration and deposition values have been numerically integrated for a large number of cases involving different meteorological conditions, different particle sizes, and different release heights. A numerical solution was developed to correct the concentration values so that approximate mass conservation is obtained for all cases. In general, for particles smaller than 10 microns, the corrections are very small for all cases examined. However, for larger particles at long distances, the corrections are significant. Correction factors are built into the FDM and the use of correction factors is entirely transparent to the user (Winges, 1991).

Selection Criterion 1 - **The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

The germane processes and conditions that have been identified at the OU5 site can be grouped according to source, site, and receptor.

Key source processes and conditions are:

- The ambient air contaminant of concern at OU5 is fugitive particulate emissions. Outdoor exposure to volatilized gases less dense than air is considered a negligible or incomplete exposure pathway. The identified sources of the fugitive particulate emissions are the contaminated surface land areas, paved and unpaved, vegetated and unvegetated, that are exposed to wind erosion. The potential sources of gaseous emissions are chemicals disposed in the subsurface. The selected model(s) must be capable of handling particulate and neutrally-buoyant gaseous emissions. The selected model(s) must calculate both concentrations and depositions.

- Emission rates from OU5 sources can be either continuous or event-related. The selected model(s) must be capable of calculating both continuous and variable, even instantaneous, emission rates.

- OU5 has ten IHSSs so the selected model(s) must be capable of treating multiple sources.

- Particulate emissions of different sizes will settle and deposit at varying rates. The selected model(s) must be capable of handling user-supplied settling and deposition rates for various particulate size ranges or be capable of internally calculating them.

- Sources of emissions within OU5 are at ground level, not elevated. The selected model(s) will not require special elevated-source features.

- The sources of emissions within OU5 and the IHSSs are area sources. Selected model(s) must be capable of reliably handling area sources.

The FDM is specifically designed to calculate concentrations and depositional impacts from fugitive dust sources (Winges, 1991). The FDM will accommodate gaseous emissions with appropriate adjustment of input data parameters (Wilson, pers. comm., 1993). The FDM is based on the Gaussian plume formulation for computing concentration values, but the model has been specifically adapted to incorporate an improved gradient-transfer deposition algorithm. Because the FDM uses only continuous emission rates, separate runs for episodic meteorological events are necessary. This model can process as many as 121 sources and will accommodate up to 20 particle-size classes. The code will calculate settling and deposition velocities for each class unless the user supplies specific values for these characteristics.

The FDM has the capability of handling area sources that are rectangular and arbitrarily oriented; that is, the area sources do not have be square and oriented north-south. The FDM can model receptors that are actually within the source area, and it is reliable for treating receptors close to the source. A convergence option based on the CALINE3 line source algorithm for nearby receptors provides this capability. The code has actually been lifted from the CALINE3 Model and incorporated in the FDM. The drawback of the convergence option is the considerable computer time required for these calculations; therefore, the convergence option should be exercised only for modeling nearby receptors. The FDM treats ground-level sources and sources for which an emission height is pre-calculated and supplied by the user.

Key site processes and conditions are:

- Meteorological data actually collected year-round on a continuous basis at RFP will be the most useful data for reliably modeling. The selected model(s) should be capable of accepting these data.
- Both short-term (1-hour to 1-day) and long-term (1-year) exposures are of interest in this study. The selected model(s) should be capable of calculating both short-term and long-term exposure values.
- Because there are no buildings within OU5, aerodynamic downwash is not a concern with this study.
- Because emissions are passive (diffusion or wind-generated), plume rise due to exhaust velocity or heat buoyancy is not a concern with this study.

- Because the contaminants of concern are not chemically reactive in the atmosphere or have a long half-life, chemical transformation and radioactive decay are not concerns with this study.

- Although OU5 is located in a topographical drainage feature, all potential receptors are situated at elevations lower than the contaminant source. Therefore, a "simple" terrain model rather than a "complex" model will be used.

The FDM accepts long-term meteorology data in STAR format and also in pre-processed form. For episodic events, such as high-wind conditions that can possibly generate fugitive dust, separate runs with specified wind speed and direction, stability class, mixing height, and ambient temperature are supplied by the user.

The FDM codes do not contain algorithms for building downwash, buoyant gases, or plume rise. Likewise, the FDM cannot accommodate a decay or transformation coefficients; however, such capabilities are not required for the OU5 HHRA.

Key receptor processes and conditions are:

- All receptors are located at ground level; none are situated on elevated terrain; none are at heights above local ground level. Therefore, the selected model(s) will not require capabilities for receptor heights on elevated terrain, which would then require a complex-terrain model. Some receptors may be situated above-grade (so-called "flagpole" receptors).

- The selected model(s) must be capable of handling multiple receptors.

- Exposure scenarios concerning oral and dermal exposures to contaminated soils and plants have been assessed as insignificant and will be quantitatively evaluated. The selected model(s) must be capable of calculating atmospheric deposition of contaminated soil on downwind receptor locations.

- Cumulative effects from multiple sources must be calculated for each selected receptor.

The FDM is a simple-terrain model designed to model receptors that are located at equal and lower elevations than the source. However, the FDM will accept above-ground receptors, along with ground-level receptors. This model will handle up to 500 receptors. The FDM calculates deposition values of particulate matter as well as concentration values of gaseous and aerosol emissions. FDM calculates the cumulative impacts of all defined sources at the selected receptors.

Selection Criterion 2 - **The selected models should be able to satisfy the objectives of the study.**

The FDM is capable of satisfying the objectives listed in Section 1.1. The basic purpose of the modeling is to estimate exposure point concentrations of COCs that are released and/or transported from the IHSSs to present and potential future receptors, onsite and offsite. These receptors have been identified in TM12 (DOE, 1993).

The FDM will calculate short-term (1-hour to 24-hour) and long-term (1-year) concentrations and depositions at the selected receptor points. These resulting exposure point concentrations and depositions can be utilized directly in the risk calculations of the OU5 HHRA.

Selection Criterion 3 - **The selected models should be verified using published analytical equations and solutions.**

The FDM is based on the well-known analytical Gaussian plume formulation that constitutes the basis of almost all atmospheric dispersion models approved by EPA for regulatory use, including the Industrial Source Complex models (Turner, 1970; EPA, 1986). The FDM incorporates an improved gradient-transfer deposition algorithm based on the analytical equations of Ermak (1977) for computing concentration and deposition values of fugitive particulate matter at user-selected receptors. The line source and area source algorithms in the FDM are those in the CALINE3 Model. The CALINE series is also based on the analytical Gaussian equation and is a "preferred" regulatory model of EPA (EPA, 1986).

Four field validation studies have indicated an improved accuracy of the FDM over the current available version of the most frequently cited regulatory model, the Industrial Source Complex model (ISC2) (Winges, 1991; Dames and Moore, 1990). The FDM algorithms for modeling area sources of fugitive dust emissions have consistently demonstrated a superior predictive capability, especially for receptors near the source.

The FDM method of calculating deposition and plume depletion accounts for this improved accuracy over the ISC2 model. Deposition flux within the FDM is based on the fact that deposition velocities of particles smaller than 30 microns vary with the size of the particles. The FDM computes separately the gravitational settling and deposition velocities for each designated particle size class. The FDM method of smoothly integrating area-source terms with the CALINE3 algorithms adds to the predictive superiority over ISC2 (Wilson, pers. comm., 1993).

Selection Criterion 4 - **The selected models should be complete and well-documented and preferably available to the public.**

The FDM is available from EPA and is reinforced by a guidance document. Since EPA sponsored the development of the FDM, technical support through EPA is accessible. The basic FORTRAN code of the FDM is available for examination by the user. At least two commercial versions of the FDM are available with improved presentational aspects or expanded capabilities of the basic algorithms.

Selection Criterion 5 - **The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

Input files containing information on sources, receptors, meteorology, and various model switches and options can be quickly prepared. Run-times depend on computer attributes but are expected to be reasonably short. Because the convergent algorithm for the FDM area source will considerably slow down execution time, this option will be utilized only for receptors near the source.

Uncertainty analysis in air quality modeling is an emerging consideration and practice (Fox, 1984). EPA has not incorporated standard methodologies for uncertainty analyses into its guidance documents or policies for air quality modeling (Tikvart, pers. comm., 1993). Principles of uncertainty analyses will be applied to the FDM exercise to quantify as much as possible, in terms of a range of output values and an accuracy assessment, the appropriate significance of the modeling results. Priority will be placed on assessing the uncertainties associated with source input parameters and then on meteorological input parameters.

3.6.2 Model Data Parameters Summary

A summary of the input data currently available for the FDM is presented in Table 3-4. Information concerning the contaminants of concern will be based on the analysis of data obtained through the RFI/RI field work.

Table 3-4

Fugitive Dust Model Input Data Requirements

Parameters	Units	Range of Values	Source
Source Parameters			
Location of sources (x,y,z coordinates)	meters for x,y,z coordinates	x,y coordinates according to Universal Transverse Mercator system; z coordinate: 0 m	USGS maps (Louisville Quadrangle), 7.5 min. topographic)
Area source rotation angle (theta)	degrees for rotation angle	theta according to maps	USGS maps (Louisville Quadrangle), 7.5 min. topographic) Midwest Research Institute 1993 field study of OU3 (Cowherd, pers. comm., 1993)
Pollutant emission rate	g/sec for point sources; g/m^2-sec for area sources	0-i (To be determined by the OU5 Phase I RFI/RI)	OU5 Phase I RFI/RI and results of soil gas transport model discussed in Section 3.5
Pollutant concentration in the soil	pCI/g for radionuclides; ug/g for organics	0-j (To be determined by the OU5 Phase I RFI/RI)	OU5 Phase I RFI/RI
Classes of particle size diameters	microns	2 classes: <10 (respirable) and 10-80 (transportable)	OU5 Phase I RFI/RI
Particle size distribution	dimensionless	2 values, each >0 and <1; sum is unity	OU5 Phase I RFI/RI
Meteorological Parameters			
STAR format: joint frequency distribution of atmospheric stability class (A, B, C, D, E, F), wind speed (1-<3, 3-<6, 6-<10, 10-<16, 16-<21, >21), and wind direction (16 sectors)	dimensionless	576 values, each >0 and <1; sum of all values is unity	EG&G Rocky Flats (n.d.) *Rocky Flats Plant Site Environmental Report for 1991* Appendix C; 1992 STAR data

Table 3-4 - Continued

Fugitive Dust Model Input Data Requirements

Parameters	Units	Range of Values	Source
Anemometer height	meters	60	EG&G Rocky Flats (n.d.) *Rocky Flats Plant Site Environmental Report for 1991*; EG&G RF staff meteorologist
Episodic ambient temperature	°K	291	EG&G Rocky Flats (n.d.) *Rocky Flats Plant Site Environmental Report for 1991*; EG&G RF staff meteorologist
Episodic wind speed	m/sec	37.4	EG&G Rocky Flats (n.d.) *Rocky Flats Plant Site Environmental Report for 1991*; EG&G RF staff meteorologist
Episodic wind direction	degrees	270	EG&G Rocky Flats (n.d.) *Rocky Flats Plant Site Environmental Report for 1991*; EG&G RF staff meteorologist
Episodic mixing height	meters	236 - 2,437	Holzworth, 1972
Site Parameters			
Surface roughness height	cm	10^{-2} - 10^{-3}	Winges, 1991; onsite observations
Particulate matter density	g/m^3	1.0 - 3.0	Winges, 1991
Receptor Parameters			
Location of receptors (x,y,z coordinates)	meters	x,y coordinates according to Universal Transverse Mercator system; z coordinate: 1.5 m	USGS maps (Louisville Quadrangle, 7.5 min. topographic)

Source: Winges, 1991

3.7 INDOOR AIR TRANSPORT MODELS

Soil gases that originate directly from the vadose zone of the soils surrounding the building foundation or that diffuse from contaminated groundwater in the vicinity can intrude through the foundation floors and walls. The exposure scenarios of the intrusion of soil gases through the below-grade foundation floor and walls of a future onsite office building or onsite residence have been identified as a significant pathway for the OU5 IHSSs (DOE, 1993). EPA provides technical guidance for assessing potential indoor air impacts for contaminated sites (EPA, 1992).

3.7.1 Description of Model

For modeling indoor air concentration values of chemical vapors due to soil gas entry, the Johnson-Ettinger models are recommended (EPA, 1992; Johnson and Ettinger, 1991). The model equation corresponding to an infinite contaminant source and vapor infiltration through cracks/openings in the foundation is the most useful for general application. The model assumes that neither the distance between source and building nor the contaminant concentration change over time.

The Johnson-Ettinger equation calculates a ratio (α) of the concentration inside the building to the soil gas concentration at the source:

(Equation 4)

$$\alpha = [D_T^{eff} A_B / Q_{bldg} L_T] * \exp(Q_{soil} L_{crack} / D^{crack} A_{crack}) / \{\exp(Q_{soil} L_{crack} / D^{crack} A_{crack}) + [D_T^{eff} A_B / Q_{bldg} L_T] + [D_T^{eff} A_B / Q_{soil} L_T][\exp(Q_{soil} L_{crack} / D^{crack} A_{crack}) - 1]\}$$

where

α = $C_{building}/C_{source}$, vapor concentration in building/vapor concentration at source (i.e., soil)

D_T^{eff} = overall effective diffusion coefficient (cm^2/sec)

A_B	=	cross-sectional area through which contaminants may pass (approximated by area of floor and below-grade walls (cm^2)
Q_{bldg}	=	building ventilation rate (cm^3/sec)
L_T	=	distance from contaminant source to building foundation (cm)
Q_{soil}	=	volumetric flow rate of soil gas into the building (cm^3/sec)
L_{crack}	=	thickness of foundation (cm)
D^{crack}	=	effective vapor pressure diffusion coefficient through the crack (cm^2/sec)
A_{crack}	=	area of cracks/openings through which vapors can pass (cm^2)

If the source lies directly beneath the foundation, as it would in the exposure scenario of contaminated soil adjacent to the foundation, then α approaches the value Q_{soil}/Q_{bldg}. This is the expected result for convection-dominated transport of a vapor stream with a concentration C_{source}.

The soil gas flow rate, Q_{soil}, is likely to be dependent of the basement crack area, A_{crack}, soil type and stratigraphy, building under pressurization, and basement geometry. For simplicity, Q_{soil} is estimated by:

(Equation 5)

$$Q_{soil} = 2\pi \Delta P k_v X_{crack}/\mu \ln(2Z_{crack}/r_{crack}) \qquad r_{crack}/Z_{crack} << 1$$

(Equation 5 is an analytical solution for flow to a cylinder of length X_{crack} and radius r_{crack} located at a depth Z_{crack} below the surface. This is an idealized model for soil gas flow to cracks located at floor/wall seams.)

where

ΔP	=	building pressure difference relative to ambient pressure (g/cm-sec^2)
k_v	=	soil permeability to vapor flow (cm^2)
X_{crack}	=	total floor/wall seam perimeter distance (cm)
μ	=	vapor viscosity (g/cm-sec)
Z_{crack}	=	depth of crack below ground surface (cm)

and

$$r_{crack} = \eta A_B/X_{crack}$$

where

$$\eta = A_{crack}/A_B\text{, so that } 0 <= \eta <= 1$$

For a contaminant source adjacent to the building (L_T = 0), α is proportional to the soil permeability to vapor flow, k_v, at $k_v > 10^{-8}$ cm^2 (permeable soils). The effect of crack size on contaminant intrusion rates will be relatively insignificant in the limit of convective-dominated transport.

A number of studies referenced in the technical guidance have indicated that the mean concentration of radon in basements is about twice the mean value for above-ground living spaces. The conclusion of these studies can be extended to volatile and semi-volatile organic gases. The ratio of indoor air contaminant concentration in a basement to that in an associated living space is 2 to 1.

Assumptions and limitations inherent in the Johnson-Ettinger equation corresponding to the general application, in which the contaminant source is infinite with respect to the modeling time of interest and vapor infiltration is through cracks or openings in the foundation, include the following:

- The distance from the source to the building is assumed not to change with time and is assumed not to change in composition over the time of interest for the calculation.
- The contaminant source is assumed to lie directly beneath the foundation.
- The modeling equation applies to structures with crawl spaces and slab floor construction with solid (e.g., poured concrete) below-grade walls. Other Johnson-Ettinger modeling equations correspond to cases in which soil gas transport into buildings is substantially higher through relatively permeable (e.g., concrete block construction below grade) than through foundation cracks and openings or to cases in which a contaminant is located near the building and decreases over time (EPA, 1992).

Selection Criterion 1 - **The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.**

The Johnson-Ettinger models provide a good representation of both contaminant transport and the effects of building characteristics on soil gas entry into a building. In conjunction with appropriate calculations of the contaminant source gas phase concentrations and measurements, equations, or estimates of building air exchange rates, the models are evaluated as the best available, in the absence of detailed numerical simulations (Diehl and Westbrook, 1993).

Selection Criterion 2 - **The selected models should be able to satisfy the objectives of the study.**

The basic purpose of the modeling exercise is to estimate exposure point concentrations of contaminants of concern that are released from the IHSSs to potential future onsite receptors. The Johnson-Ettinger equation will estimate gaseous contaminant concentration values for future indoor air quality scenarios. These resulting exposure point concentrations can be incorporated directly into the risk calculations of the OU5 HHRA.

Selection Criterion 3 - **The selected models should be verified using published equations and solutions.**

The Johnson-Ettinger models are those recommended by EPA for modeling indoor air concentrations due to vapor transport from contaminated soils into buildings (EPA, 1992). The Johnson-Ettinger equations are based on the work of a number of researchers attempting to model the transport of radon into buildings. Johnson and Ettinger (1991) have adapted this work and extended it to the case of chemical vapors.

"Currently, there are few experimental studies that are sufficiently detailed to compare model predictions. However, the range of behavior, dependence on relevant parameters, and limiting bounds of the model are in qualitative agreement with published case histories. At this point, more detailed field studies and numerical simulations are needed to help validate this [Johnson-Ettinger] model." (Johnson and Ettinger, 1991) EPA's technical guidance document (EPA, 1992) clearly advises that inadequate field data currently exist to validate modeling connecting soil gas flux rate to indoor air concentrations. A range of an indoor air concentration values for a selected contaminants of concern can be calculated from the ranges of values for typical commercial and residential buildings in Jefferson County.

Selection Criterion 4 - **The selected models should be complete and well-documented and preferably available to the public.**

The Johnson-Ettinger equation is presented fully in the original citation (Johnson and Ettinger, 1991), as well as the technical guidance document (EPA, 1992).

Selection Criterion 5 - **The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.**

The Johnson-Ettinger models are practical and cost-effective because they can be solved with hand calculations.

Resolution of uncertainty cannot be addressed fully within the scope of this assessment. The future exposure scenarios for onsite office and residential structures are hypothetical. Calibration of any indoor air pollution models with actual onsite measurements will not be feasible.

Execution of the models will be based on values for parameter for building, chemical, and soil properties. These are advised by the technical guidance document and other public-domain literature, such as the EPA technical guidance study series and the Superfund manuals and chemical, physical, and engineering handbooks.

3.7.2 Model Parameters Data Summary

A summary of the input data required for the indoor air screening models is presented in Table 3-5. Information about the contaminants of concern will be based on the analysis of data obtained through the RFI/RI field work.

Table 3-5

Indoor Air Transport Model Input Data Requirements

Parameters	Units	Range of Values	Source
Johnson-Ettinger Equations			
A_B = area of building basement floor and walls below grade	cm^2 (m^2)	Commercial: 562 (483-639)m^2 Residential: 158 m^2 (Based on size of typical buildings in Jefferson County)	Jefferson County Building Department, Nihiser, pers. comm., (1993)
V = volume of building	m^3	Commercial: 1,359 (1,133-1,586) Residential: 510 (453-566) (Based on size of typical buildings in Jefferson County)	Jefferson County Building Department, Nihiser, pers. comm., (1993)
ACH = number of building air changes per hour	dimensionless	0.5 (0.5-1.5); Commercial: 0.04 Residential: 0.08	EPA (1992); Jefferson County Building Department, Nihiser, pers. comm., (1993)
Q_{bldg} = building ventilation rate (V*ACH)	cm^3/sec or m^3/hr	Commercial: 680 (45-2,379) m^3/hr Residential: 255 (36-850) m^3/hr (Based on size of typical buildings in Jefferson County)	EPA (1992); Jefferson County Building Department, Nihiser, pers. comm., (1993)
X_{crack} = total floor/wall seam perimeter distance	cm	Commercial : 7,730 (7,057-8,350) Residential: 3,448 (Based on size of typical buildings in Jefferson County)	Jefferson County Building Department, Nihiser, pers. comm., (1993)
Z_{crack} = depth of crack below surface	cm	244	Jefferson County Building Department, Nihiser, pers. comm., (1993)
r_{crack} = width of crack	cm	1.9	Jefferson County Building Department, Nihiser, pers. comm., (1993)
ΔP = building pressure difference relative to ambient pressure	Pascals or g/cm-sec^2	1-10 Pa	EPA (1992)

Table 3-5 - Continued

Indoor Air Transport Models Input Data Requirements

Parameters	Units	Range of Values	Source
k_v = soil permeability to vapor flow	darcy ($10^{-8}cm^2$)	0.01-100 (To be determined by the OU5 Phase I RFI/RI)	OU5 Phase I RFI/RI; Johnson and Ettinger, (1991)
μ = vapor viscosity	g/cm-sec	0-j (To be determined from published literature)	Reference literature
C_{source} = contaminant concentration in soil	g/cm^3	0-k (To be determined by the OU5 Phase I RFI/RI)	OU5 Phase I RFI/RI

Sources: EPA, 1992; Johnson and Ettinger, 1991; Nihiser, pers. comm., 1993.

4.0 SUMMARY

In order to model the fate and transport of contaminants at OU5 to specific exposure point locations for the HHRA, several models have been evaluated for application to groundwater, surface water, and air modeling. Model selection was based on the following five criteria:

1) The selected models should be able to incorporate key processes and accurately represent conditions known to occur at the site.

2) The selected models should be able to satisfy the objectives of the study.

3) The selected models should be verified using published equations and solutions.

4) The selected models should be complete and well-documented and preferably available to the public.

5) The selected models should be practical and cost-effective in terms of actual application as well as resolution of uncertainty.

The following models were selected to meet the requirements of the modeling study:

- The USGS MODFLOW numerical model with BCF2 module for groundwater flow
- The MT3D numerical model for groundwater contaminant fate and transport in the Rocky Flats Alluvium and the underlying sandstone
- HSPF9 for surface-water and fate and transport modeling
- The Jury and Johnson-Ettinger models for soil gas fate and transport
- FDM for offsite ambient air contaminant fate and transport of OU5 source air emissions, and
- EPA guidelines with the Johnson-Ettinger model for indoor air transport modeling (EPA, 1992)

Data currently available for use as input for the modeling activities were evaluated. Additional data from the Phase I RFI/RI investigation may also be used in the modeling effort once those data become available. Since the final analytical data from OU5 were not available at the time of preparation of this document, the models selected are believed to be appropriate and adequate for the HHRA. These selections were based on the best available data, previous modeling efforts as described in various TMs from other OUs, and information from the technical literature.

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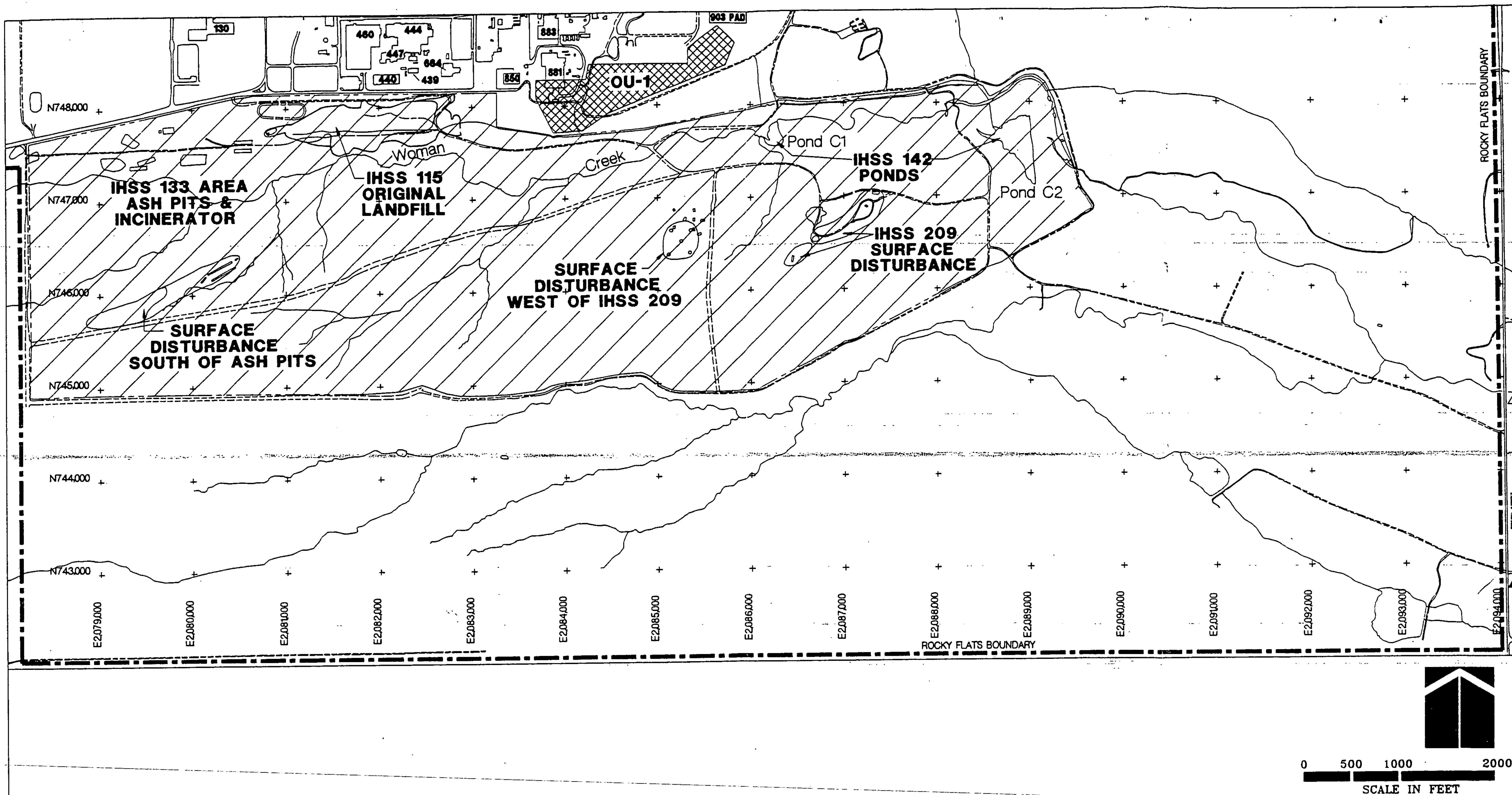


LEGEND

EXPOSURE STUDY AREA APPROXIMATELY 720 ACRES

OU5 STUDY AREA BOUNDARY

ROCKY FLATS BOUNDARY

OU5
STUDY LOCATION

TM 13 – HHRA MODEL DISCRIPTIONS

OU5 PHASE I RFI/RI IMPLEMENTATION

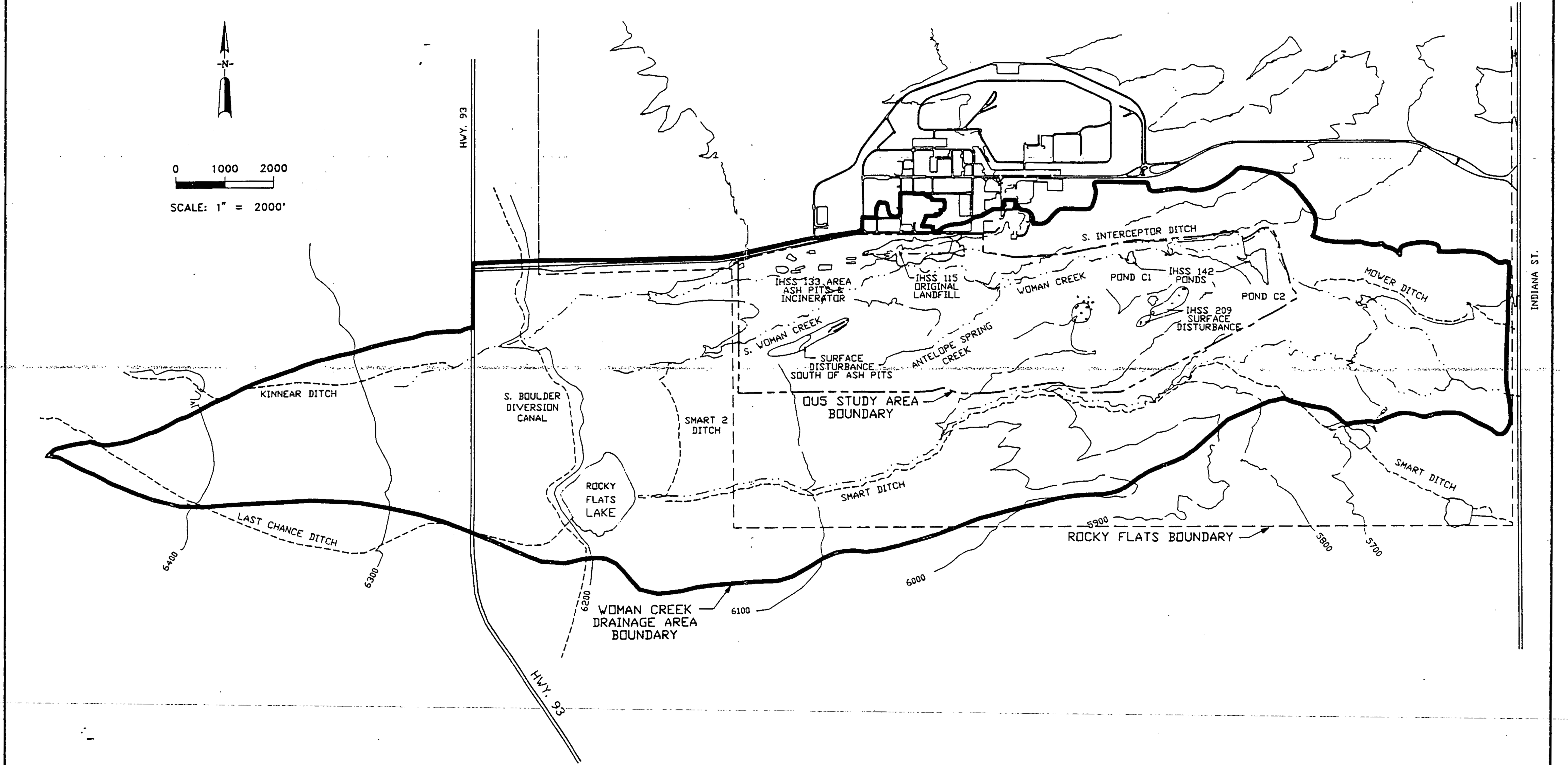
EG&G

9208151111

NOV. 1993

FIGURE 1-2

TM13_1-2.DWG



WOMAN CREEK DRAINAGES

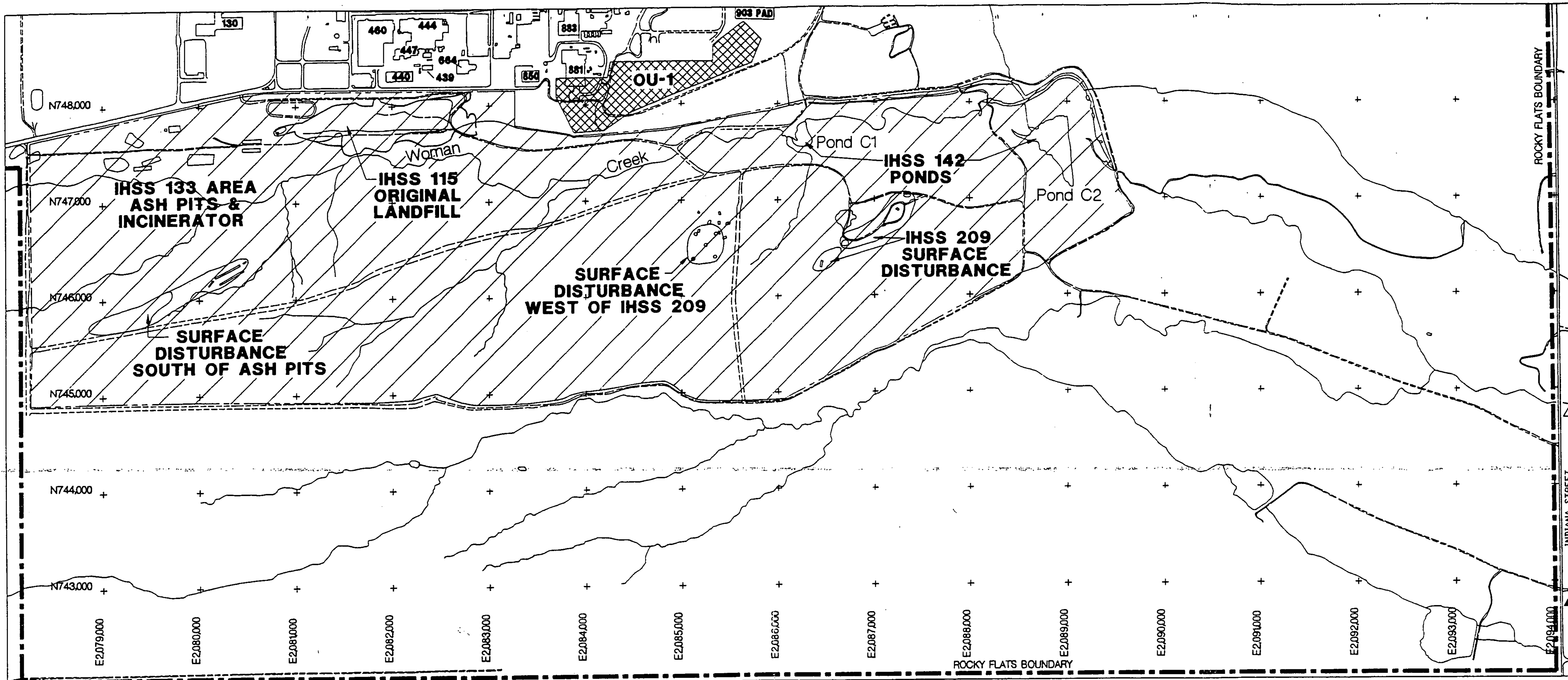
TM 13 - HHRA MODEL DESCRIPTION

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G 9208151111 NOV. 1993

FIGURE 1-4

TM13_1-4DWG



LEGEND

△ APPROXIMATE EXPOSURE POINT FUTURE OFF-SITE RESIDENT

▲ EXPOSURE POINT CURRENT RESIDENT

EXPOSURE STUDY AREA APPROXIMATELY 720 ACRES

OU5 STUDY AREA BOUNDARY

ROCKY FLATS BOUNDARY

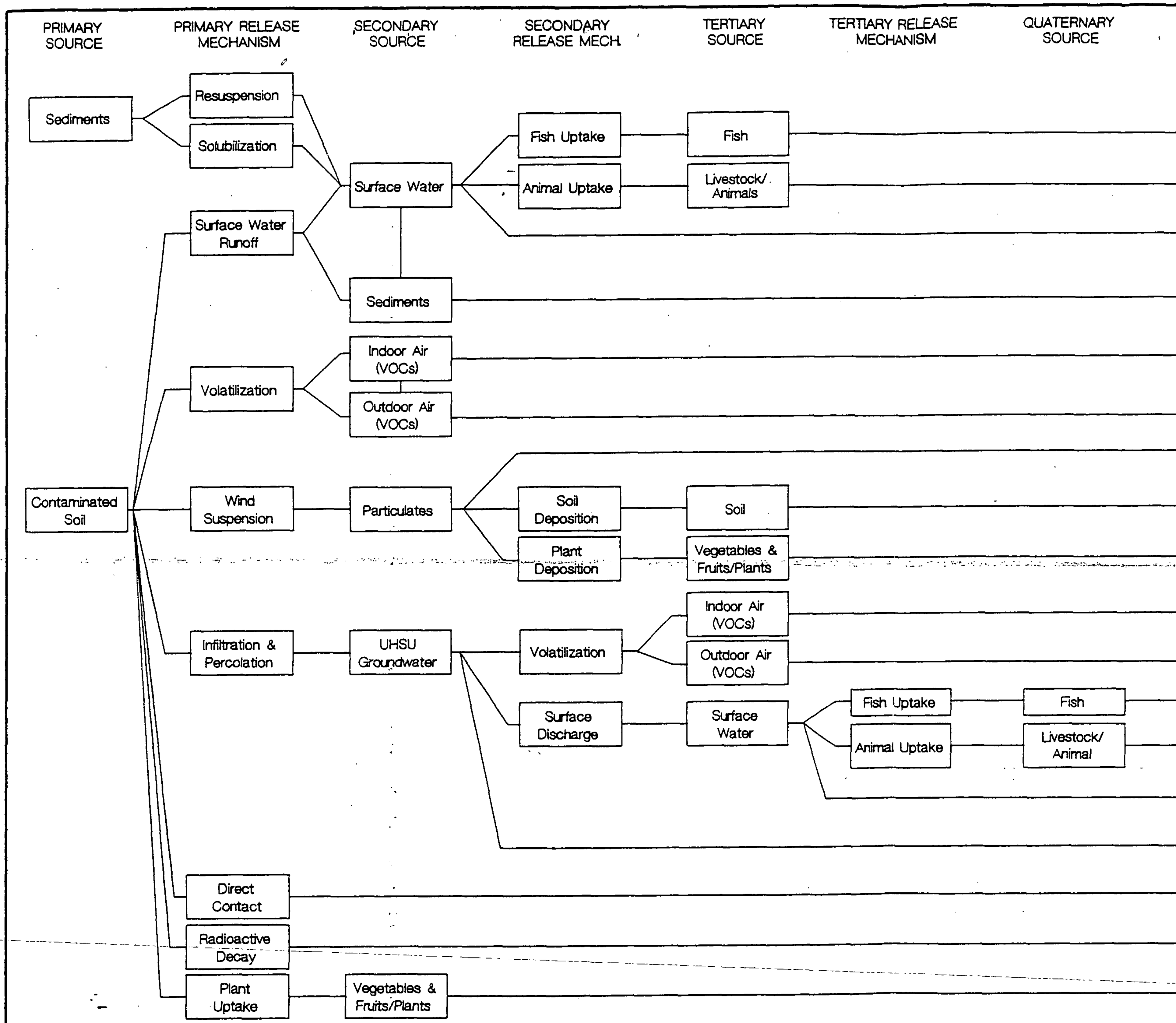
RISK ASSESSMENT STUDY AREA POTENTIAL RECEPTOR LOCATIONS

TM 13 - HHRA MODEL DISCRIPTIONS

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | NOV. 1993 | FIGURE 2-1

TM13_2-1DWG



EXPOSURE ROUTE	Current Off-site Resident	Current On-site Worker	Future On-site Office Worker	Future On-site Construct. Worker	Future On-site Ecological Researcher	Future On-site Resident	Future Off-site Resident
Oral	N	N	N	N	N	N	N
Oral	N	N	N	N	N	N	N
Oral	N	N	N	N	S	S	S
Dermal	N	N	N	N	I	I	I
Oral	N	N	N	N	S	S	S
Dermal	N	N	N	N	I	I	I
Inhalation	N	N	S	N	N	S	N
Inhalation	N	N	N	N	N	N	N
Inhalation	I	I	I	I	I	I	I
Oral	I	N	N	N	N	N	I
Dermal	I	N	N	N	N	N	I
Oral	I	N	N	N	N	I	I
Inhalation	N	N	S	N	N	S	N
Inhalation	N	N	N	N	N	N	N
Oral	N	N	N	N	N	N	N
Oral	N	N	N	N	N	N	N
Oral	N	N	N	N	S	S	S
Dermal	N	N	N	N	I	I	I
Oral	N	N	N	N	N	N	N
Oral	N	S	I	S	S	S	N
Dermal	N	I	I	I	I	I	N
External Radiation	N	I	I	I	I	I	N
Oral	N	N	N	N	N	I	N

(Column group heading: POTENTIALLY EXPOSED HUMAN RECEPTOR)

S = Significant Potential Exposure Pathway
I = Insignificant Potential Exposure Pathway
N = Negligible or Incomplete Exposure Pathway
UHSU = Upper hydrostratigraphic unit

Notes: Potentially complete dermal pathways will be quantitively assessed only if investigation demonstrates presence of organic contaminants of concern.

Significant and insignificant potential exposure pathways will be quantitatively evaluated.

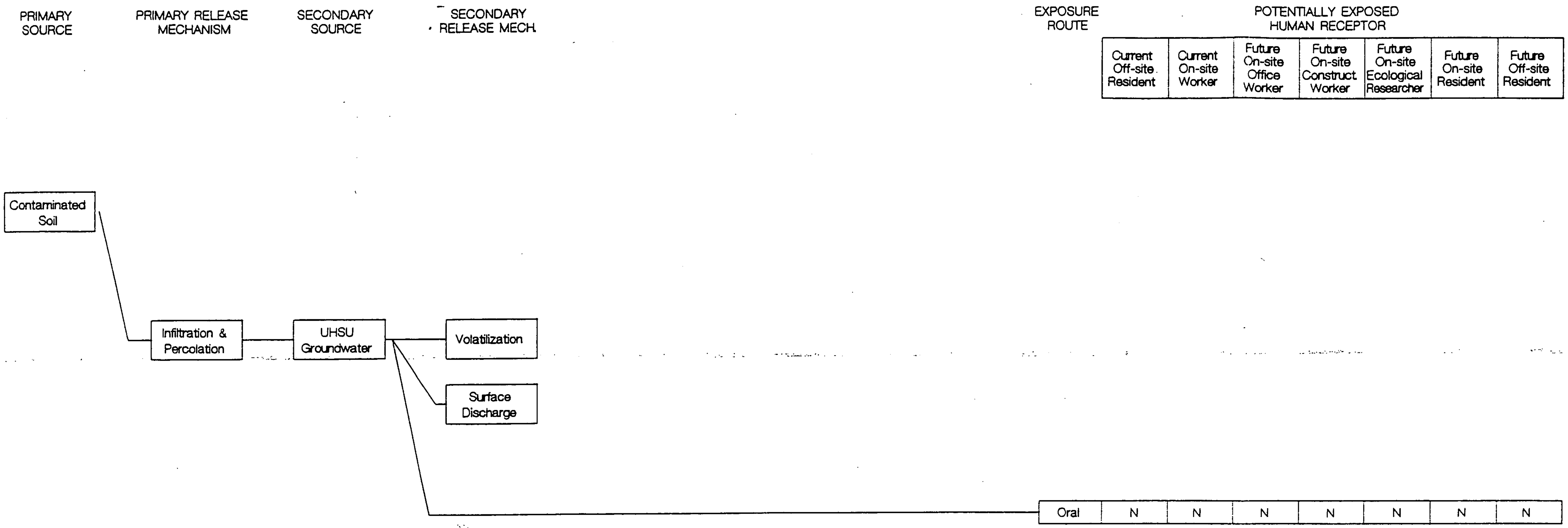
CONCEPTUAL SITE MODEL

TM 13 – HHRA MODEL DESCRIPTIONS

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G | 9208151111 | NOV. 1993 | FIGURE 2-2

TM13_2-2DWG



S = Significant Potential Exposure Pathway
I = Insignificant Potential Exposure Pathway
N = Negligible or Incomplete Exposure Pathway
UHSU = Upper hydrostratigraphic unit

Notes: Potentially complete dermal pathways will be quantitively assessed only if investigation demonstrates presence of organic contaminants of concern.

Significant and insignificant potential exposure pathways will be quantitatively evaluated.

GROUNDWATER EXPOSURE PATHWAYS IN THE CONCEPTUAL SITE MODEL

TM 13 – HHRA MODEL DESCRIPTIONS

OU5 PHASE I RFI/RI IMPLEMENTATION

EG&G

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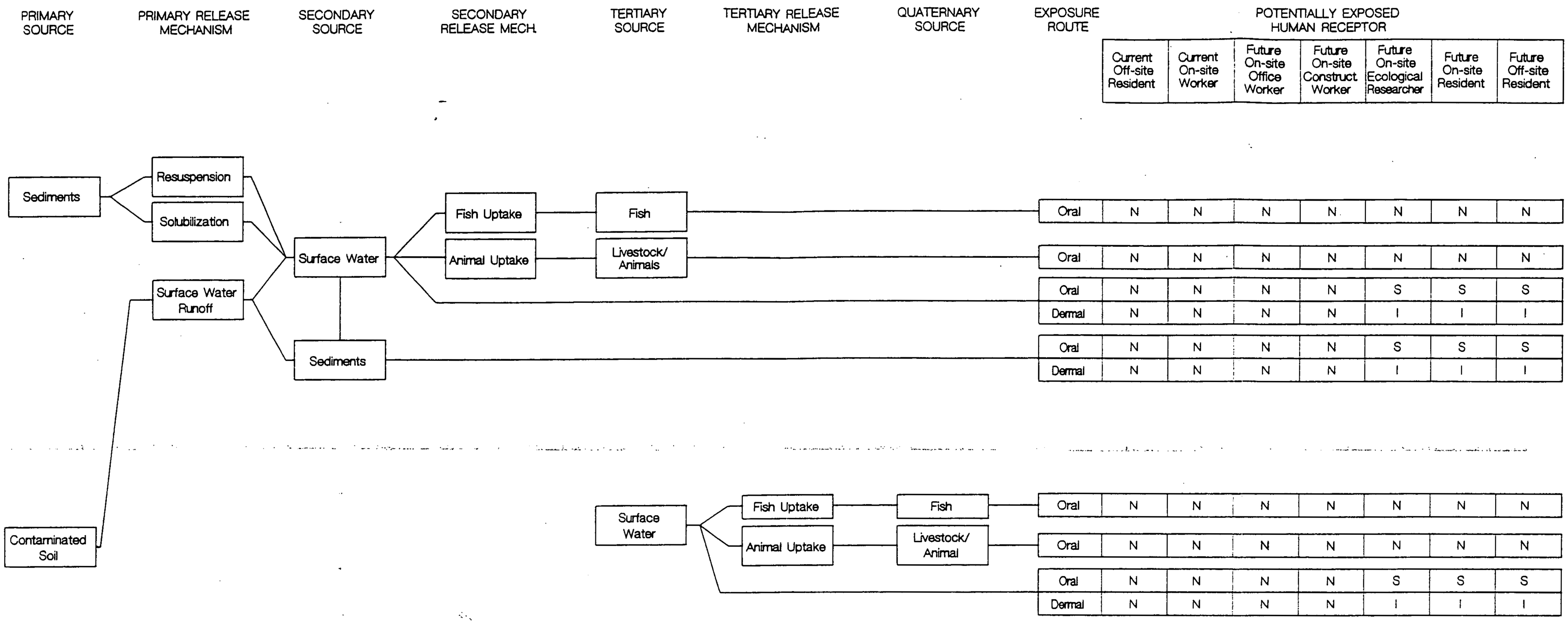
NOV. 1993

FIGURE 2-4

TM13_2-4.DWG



S = Significant Potential Exposure Pathway
I = Insignificant Potential Exposure Pathway
N = Negligible or Incomplete Exposure Pathway
UHSU = Upper hydrostratigraphic unit

Notes: Potentially complete dermal pathways will be quantitively assessed only if investigation demonstrates presence of organic contaminants of concern.

Significant and insignificant potential exposure pathways will be quantitatively evaluated.

TM13_2-6DWG

SURFACE WATER EXPOSURE PATHWAYS IN THE CONCEPTUAL SITE MODEL

TM 13 - HHRA MODEL DESCRIPTIONS

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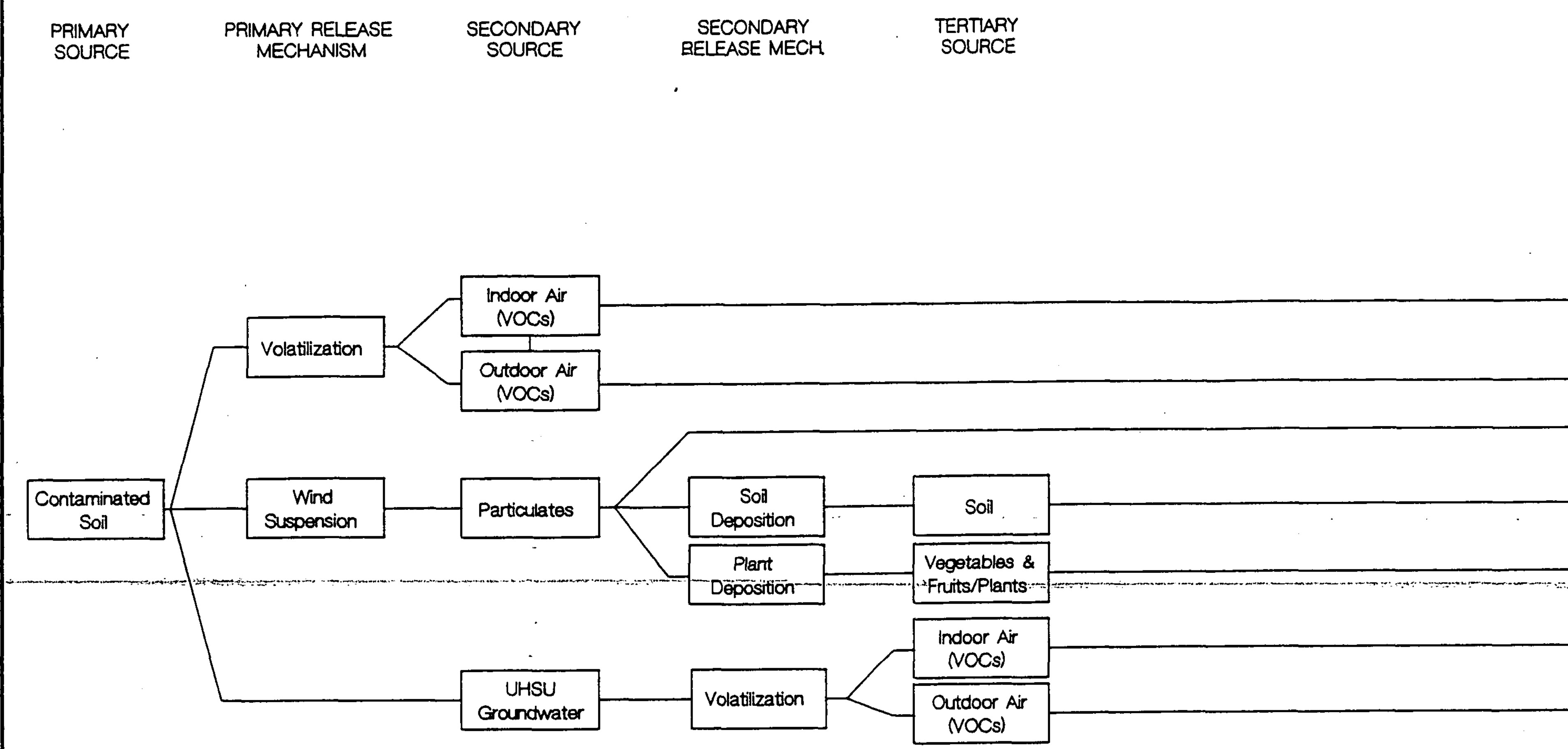
FIGURE 2-6



EXPOSURE ROUTE	Current Off-site Resident	Current On-site Worker	Future On-site Office Worker	Future On-site Construct Worker	Future On-site Ecological Researcher	Future On-site Resident	Future Off-site Resident
Inhalation	N	N	S	N	N	S	N
Inhalation	N	N	N	N	N	N	N
Inhalation	I	I	I	I	I	I	I
Oral	I	N	N	N	N	N	I
Dermal	I	N	N	N	N	N	I
Oral	I	N	N	N	N	I	I
Inhalation	N	N	S	N	N	S	N
Inhalation	N	N	N	N	N	N	N

(Column group heading: POTENTIALLY EXPOSED HUMAN RECEPTOR)

S = Significant Potential Exposure Pathway
I = Insignificant Potential Exposure Pathway
N = Negligible or Incomplete Exposure Pathway
UHSU = Upper hydrostratigraphic unit

Notes: Potentially complete dermal pathways will be quantitively assessed only if investigation demonstrates presence of organic contaminants of concern.

Significant and insignificant potential exposure pathways will be quantitatively evaluated.

TM13_2-8DWG

AIRBORNE EXPOSURE PATHWAYS IN THE CONCEPTUAL SITE MODEL

TM 13 - HHRA MODEL DESCRIPTIONS

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