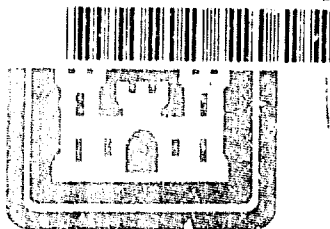


AD-A253 750



SATHAMA
TECH INFO CTR

(2)
Circulation Copy

3940 1

US Army Corps of Engineers

Toxic and Hazardous
Materials Agency

DTIC
ELECTE
JUL 28 1992
S A D

FINAL

RISK ASSESSMENT FOR THE EXPLOSIVE WASHOUT LAGOONS (SITE 4), UMATILLA DEPOT ACTIVITY HERMISTON, OREGON

Contract No. DAAA15-88-D-0008
Delivery Order No. 3

Prepared for:

U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
Aberdeen Proving Ground, Maryland 21010

Prepared by:

DAMES & MOORE
A Professional Limited Partnership
7101 Wisconsin Avenue
Bethesda, Maryland 20814

DISTRIBUTION UNLIMITED.
APPROVED FOR PUBLIC RELEASE.

~~REQUEST FOR THIS DOCUMENT MUST BE REFERRED TO:~~
COMMANDER
U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5401

MARCH 1992

Printed on Recycled Paper

92-19999



THAMMA 487145 Jul 90

92 7 24 010

**THE VIEWS, OPINIONS, AND/OR FINDINGS CONTAINED IN THIS REPORT
ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS
AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR
DECISION, UNLESS SO DESIGNATED BY OTHER DOCUMENTATION.**

**THE USE OF TRADE NAMES IN THIS REPORT DOES NOT CONSTITUTE
AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH
COMMERCIAL PRODUCTS. THIS REPORT MAY NOT BE CITED FOR
PURPOSES OF ADVERTISEMENT.**

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704 0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1992		3. REPORT TYPE AND DATES COVERED Final (March 1991 - March 1992)	
4. TITLE AND SUBTITLE Risk Assessment for the Explosive Washout Lagoons (Site 4), Umatilla Depot Activity, Hermiston, Oregon				5. FUNDING NUMBERS C DAAA15-88-D-0008 TA 3	
6. AUTHOR(S) A. Leinbach, A.M. Enright, W. Eaton, and S. Lemont					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dames & Moore 7101 Wisconsin Avenue, Suite 700 Bethesda, Maryland 20814				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Toxic and Hazardous Materials Agency Aberdeen Proving Ground, Maryland 21010				10. SPONSORING/MONITORING AGENCY REPORT NUMBER CETHA-BC/CR-92014 ✓ ✓	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Distribution Unlimited. Approved for Public Release.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This document is the Risk Assessment (RA) for the Explosive Washout Lagoons (Site 4) at Umatilla Army Depot Activity (UMDA). The purpose of this RA is to address the potential future health risks posed by explosives-contaminated soil and groundwater associated with Site 4 in the absence of remediation, and to identify safe residual explosives concentrations (remedial action criteria) in soil if remediation is determined to be a requirement. This RA is not intended to address the remediation of contaminated groundwater; contaminated groundwater is addressed only to the extent that contaminants in Site 4 soil are affecting groundwater quality. The potential remediation of contaminated groundwater will be addressed in the installation-wide Baseline RA for UMDA. Based on the available data, explosives contamination appears to be widespread in soil near the lagoons and in groundwater at distances of over 650 yards from the lagoons. Three future land use scenarios—residential, light industrial, and military—and four potential future exposure pathways—soil ingestion, dust inhalation, dermal contact with soil, and groundwater ingestion—were evaluated in the RA to estimate potential future carcinogenic risks and noncarcinogenic hazards. The results of RA indicate that remediation may be a requirement for soil at Site 4; therefore, remedial action criteria for soil were developed.					
14. SUBJECT TERMS Risk Assessment				15. NUMBER OF PAGES	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT	

CONTENTS

1.0	INTRODUCTION	1-1
1.1	PURPOSE	1-1
1.2	RISK ASSESSMENT PROCESS	1-1
1.2.1	Data Collection and Contamination Assessment	1-4
1.2.2	Exposure Assessment	1-5
1.2.3	Toxicity Assessment	1-5
1.2.4	Risk Characterization and Development of Remedial Action Objectives	1-6
2.0	SITE DESCRIPTION, HISTORY OF OPERATION, AND PREVIOUS INVESTIGATIONS	2-1
2.1	SITE DESCRIPTION AND HISTORY OF OPERATION	2-1
2.2	SUMMARY OF PREVIOUS INVESTIGATIONS	2-4
2.2.1	Battelle Environmental Contamination Survey and Assessment	2-4
2.2.2	Century Environmental Services and Century West Engineering, Groundwater Monitoring Reports	2-5
2.2.3	ANA-LAB Corp., Groundwater Monitoring Reports	2-6
2.2.4	Roy F. Weston, Inc., UMDA RI, 1989	2-6
2.3	CURRENT INVESTIGATION, DAMES & MOORE	2-7
3.0	SAMPLING INVESTIGATION RESULTS AND CONTAMINATION ASSESSMENT	3-1
3.1	SOIL ANALYTICAL RESULTS	3-1
3.2	GROUNDWATER FLOW AND ANALYTICAL MONITORING RESULTS	3-11
3.2.1	Groundwater Flow Summary	3-11
3.2.2	Groundwater Monitoring Results Summary	3-11
3.3	CORRELATION BETWEEN SOIL AND GROUNDWATER DATA	3-21
4.0	IDENTIFICATION OF POTENTIAL CONTAMINANTS OF CONCERN	4-1
4.1	SELECTION OF POTENTIAL CONTAMINANTS OF CONCERN	4-1

CONTENTS (cont'd)

4.2	CONSTITUENTS EXCLUDED FROM CONTAMINANTS OF CONCERN	4-1
4.2.1	Soil	4-1
4.2.2	Groundwater	4-3
5.0	EXPOSURE ASSESSMENT	5-1
5.1	LAND USE SCENARIOS	5-1
5.1.1	Current Land Use	5-1
5.1.2	Future Land Use	5-1
5.2	EXPOSURE PATHWAY ANALYSIS	5-2
5.2.1	Identification of Exposure Pathways	5-2
5.2.2	Quantification of Exposure	5-2
5.2.2.1	Soil Ingestion Exposure Pathway	5-8
5.2.2.2	Dust Inhalation Exposure Pathway	5-10
5.2.2.3	Dermal Contact With Soil Exposure Pathway	5-11
5.2.2.4	Groundwater Ingestion Exposure Pathway	5-12
6.0	TOXICITY ASSESSMENT	6-1
6.1	QUANTITATIVE TOXICITY ASSESSMENT	6-1
6.2	QUALITATIVE TOXICITY ASSESSMENT	6-5
6.2.1	1,3,5-Trinitrobenzene (1,3,5-TNB)	6-5
6.2.2	1,3-Dinitrobenzene (1,3-DNB)	6-6
6.2.3	2,4,6-Trinitrotoluene (2,4,6-TNT)	6-6
6.2.4	2,4-Dinitrotoluene (2,4-DNT)	6-7
6.2.5	2,6-Dinitrotoluene (2,6-DNT)	6-9
6.2.6	HMX	6-10
6.2.7	Nitrobenzene (NB)	6-10
6.2.8	RDX	6-11
6.2.9	Tetryl	6-12

DTIC QUALITY INSPECTED

Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS (cont'd)

7.0	RISK CHARACTERIZATION	7-1
7.1	SOIL INGESTION EXPOSURE PATHWAY	7-2
7.2	DUST INHALATION EXPOSURE PATHWAY	7-7
7.3	DERMAL CONTACT WITH SOIL EXPOSURE PATHWAY	7-13
7.4	GROUNDWATER INGESTION EXPOSURE PATHWAY	7-18
7.5	MULTIPLE PATHWAY HAZARDS/RISKS	7-21
7.6	UNCERTAINTIES	7-23
7.6.1	General Toxicity Assessment Uncertainties	7-23
7.6.2	Site-Specific Exposure Uncertainties	7-25
7.6.2.1	Definition of the Physical Setting	7-25
7.6.2.2	Model Applicability and Assumptions	7-26
7.6.2.3	Parameter Value Uncertainty	7-27
7.6.2.4	Magnification of Uncertainties	7-29
8.0	REMEDIAL ACTION CRITERIA	8-1
8.1	REMEDIAL ACTION CRITERIA FOR EXPOSURE BY SOIL INGESTION	8-4
8.2	REMEDIAL ACTION CRITERIA FOR EXPOSURE BY DUST INHALATION	8-9
8.3	REMEDIAL ACTION CRITERIA FOR EXPOSURE BY DERMAL CONTACT WITH SOIL	8-12
8.4	REMEDIAL ACTION CRITERIA IN SOIL BASED ON THE PROTECTION OF GROUNDWATER	8-16
8.4.1	Methodology for and Results of Remedial Action Criteria Calculations Based on Groundwater Protection	8-18
8.4.2	Observations Concerning the Calculation of Remedial Action Criteria Based on Groundwater Protection	8-19
8.5	REMEDIAL ACTION CRITERIA FOR MULTIPLE PATHWAY EXPOSURE	8-21
9.0	SUMMARY AND CONCLUSIONS	9-1
9.1	CONTAMINATION ASSESSMENT	9-1

CONTENTS (cont'd)

9.1.1	Soil	9-1
9.1.2	Groundwater	9-1
9.2	CONTAMINANTS OF CONCERN	9-2
9.3	EXPOSURE ASSESSMENT	9-2
9.4	RISK CHARACTERIZATION	9-3
9.5	REMEDIAL ACTION CRITERIA	9-4
10.0	REFERENCES	10-1
APPENDIX A: Explosives Environmental Fate and Transport		A-1
A.1	INTRODUCTION	A-1
A.2	ENVIRONMENTAL PROCESSES	A-1
A.2.1	Photolysis	A-1
A.2.2	Oxidation/Reduction	A-5
A.2.3	Hydrolysis	A-6
A.2.4	Volatilization	A-6
A.2.5	Adsorption	A-7
A.2.6	Bioaccumulation	A-7
A.2.7	Biodegradation	A-9
A.2.7.1	TNT	A-9
A.2.7.2	TNB, DNB, and NB	A-13
A.2.7.3	RDX and HMX	A-14
A.2.7.4	Tetryl	A-14
A.3	ENVIRONMENTAL BIOAVAILABILITY	A-14
A.4	SUMMARY OF FATE IN ENVIRONMENTAL MEDIA	A-15
A.4.1	Air	A-15
A.4.2	Water	A-17
A.4.3	Soil	A-17
A.5	REFERENCES	A-19

CONTENTS (cont'd)

APPENDIX B: Assessment of the Concentrations of Site-Related Airborne Chemicals at Points of Potential Exposure	B-1
B.1 WIND EROSION EMISSIONS MODEL	B-1
B.2 DISPERSION MODELS	B-5
B.3 DISCUSSION OF EMISSION MODEL PARAMETERS	B-9
B.4 REFERENCES	B-11
APPENDIX C: Methodology for Developing Remedial Action Criteria for Soil Based on the Protection of Groundwater	C-1
C.1 MODELING APPROACH AND RESULTS	C-1
C.2 UNCERTAINTIES IN MODEL	C-6
C.3 REFERENCES	C-8

FIGURES

<u>No.</u>		<u>Page</u>
1-1	Components of a Baseline Risk Assessment	1-3
2-1	Location of Explosive Washout Lagoons (Site 4) at Umatilla Depot Activity	2-2
2-2	Explosive Washout Lagoons (Site 4) and Washout Plant Area	2-3
3-1	Site 4, Explosive Washout Lagoons, Locations of Soil Borings	3-6
3-2	RDX, HMX, and TNT Concentrations in Soil, Site 4, Explosive Washout Lagoons, 0-2' Interval	3-8
3-3	Subsurface TNT, HMX, and RDX Concentrations ($\mu\text{g/g}$), Explosive Washout Lagoons Area	3-9
3-4	Subsurface TNT, HMX, and RDX Concentrations ($\mu\text{g/g}$), Explosive Washout Lagoons Area	3-10
3-5	Site 4, Explosive Washout Lagoons and Vicinity, Monitoring Well Locations	3-18
3-6	Time Trends for RDX and TNT Concentrations, Well 9	3-19
3-7	Site 4, Explosive Washout Lagoons Area, Maximum RDX Concentrations ($\mu\text{g/L}$) Detected in Monitoring Wells	3-20

TABLES

<u>No.</u>		<u>Page</u>
3-1	Explosive Washout Lagoons, Summary of Soil Analytical Results	3-2
3-2	Explosive Washout Lagoons, Summary of Groundwater Analytical Results	3-13
4-1	Potential Contaminants of Concern in Soil and Groundwater at the Explosive Washout Lagoons (Site 4)	4-2
5-1	Quantitative Summary of Soil Ingestion Exposure Pathway	5-3
5-2	Quantitative Summary of Dust Inhalation Exposure Pathway	5-4
5-3	Quantitative Summary of Dermal Contact With Soil Exposure Pathway	5-5
5-4	Quantitative Summary of Groundwater Ingestion Exposure Pathway	5-7
6-1	Health Effects Criteria for Contaminants of Concern, Explosive Washout Lagoons (Site 4)	6-2
6-2	Oral Absorption Factors for Contaminants of Concern, Explosive Washout Lagoons (Site 4)	6-3
6-3	Dermal Absorption Factors for Contaminants of Concern, Explosive Washout Lagoons (Site 4)	6-4
7-1	Summary of Exposure Point Concentrations and Intakes, Incidental Ingestion of Soil, Residential Land Use Scenario	7-3
7-2	Summary of Risks and Hazards, Incidental Ingestion of Soil, Residential Land Use Scenario	7-4
7-3	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Incidental Ingestion of Soil, Light Industrial Land Use Scenario	7-5
7-4	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Incidental Ingestion of Soil, Military Land Use Scenario	7-6
7-5	Modeled Concentrations of Total Dust and Associated Contaminants in Air at a Variety of Receptor Locations Due to Wind Erosion	7-8

TABLES (cont'd)

<u>No.</u>		<u>Page</u>
7-6	Summary of Risks and Hazards, Inhalation of Dust, Residential Land Use Scenario	7-10
7-7	Summary of Risks and Hazards, Inhalation of Dust, Light Industrial Land Use Scenario	7-11
7-8	Summary of Risks and Hazards, Inhalation of Dust, Military Land Use Scenario	7-12
7-9	Summary of Exposure Point Concentrations and Intakes, Dermal Contact With Soil, Residential Land Use Scenario	7-14
7-10	Summary of Risks and Hazards, Dermal Contact With Soil, Residential Land Use Scenario	7-15
7-11	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Dermal Contact With Soil, Light Industrial Land Use Scenario	7-16
7-12	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Dermal Contact With Soil, Military Land Use Scenario	7-17
7-13	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Exposure by Ingestion of Ground- water, Residential Land Use Scenario	7-19
7-14	Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards, Exposure by Ingestion of Ground- water, Light Industrial Land Use Scenario	7-20
7-15	Summary of Results of Multiple Pathway Risks and Hazards, Explosive Washout Lagoons (Site 4)	7-22
8-1	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Incidental Soil Ingestion, Residential Land Use Scenario	8-5
8-2	Remedial Action Criteria (Action Levels) for the Explo- sive Washout Lagoons (Site 4), Incidental Soil Ingestion, Light Industrial Land Use Scenario	8-7
8-3	Remedial Action Criteria (Action Levels) for the Explo- sive Washout Lagoons (Site 4), Incidental Soil Ingestion, Military Land Use Scenario	8-8

TABLES (cont'd)

<u>No.</u>		<u>Page</u>
8-4	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Inhalation of Dust, Residential Land Use Scenario	8-10
8-5	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Inhalation of Dust, Light Industrial Land Use Scenario	8-11
8-6	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Inhalation of Dust, Military Land Use Scenario	8-13
8-7	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Dermal Contact With Soil, Residential Land Use Scenario	8-14
8-8	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Dermal Contact With Soil, Light Industrial Land Use Scenario	8-15
8-9	Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4), Dermal Contact With Soil, Military Land Use Scenario	8-17
8-10	Remedial Action Criteria for Multiple Pathway Exposures (PPLVs) for the Explosive Washout Lagoons (Site 4), Residential Land Use Scenario	8-23
8-11	Remedial Action Criteria for Multiple Pathway Exposures (PPLVs) for the Explosive Washout Lagoons (Site 4), Light Industrial Land Use Scenario	8-24
8-12	Remedial Action Criteria for Multiple Pathway Exposures (PPLVs) for the Explosive Washout Lagoons (Site 4), Military Land Use Scenario	8-25
9-1	Summary of Results of Risk Characterization, All Exposure Pathways and All Land Use Scenarios, Explosive Washout Lagoons (Site 4)	9-5
9-2	Summary of Remedial Action Criteria for Multiple Pathway Exposures (PPLVs) for the Explosive Washout Lagoons (Site 4) for All Three Land Use Scenarios	9-6

LIST OF ACRONYMS AND ABBREVIATIONS

2-A	2-Amino-4,6-dinitrotoluene
4-A	4-Amino-2,6-dinitrotoluene
ADA	Army Depot Activity
AT	Averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
4,4'-AZ	2,2',6,6'-Tetranitro-4,4'-azoxytoluene
2,2'-AZ	4,4',6,6'-Tetranitro-2,2'-azoxytoluene
2,4'A-AZ	2,4',6,6'-Tetranitro-2,4'-azoxytoluene
BCF	Bioconcentration factor
BRAC	Base Realignment and Closure
BW	Body weight
°C	degrees Celsius
CA	Concentration in air
CAG	Carcinogen Assessment Group, EPA
CDI	Chronic daily intake
CF	Conversion factor
C _l	Concentration of contaminant in leachate
C _o	Initial contaminant concentration in groundwater
CS	Concentration in soil
CW	Concentration in water
2,4-DA	2,4-Diamino-6-nitrotoluene
2,6-DA	2,6-Diamino-4-nitrotoluene
2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
DOD	U.S. Department of Defense
ED	Exposure duration
EF	Exposure frequency
EPA	U.S. Environmental Protection Agency

LIST OF ACRONYMS AND ABBREVIATIONS (cont'd)

EPIC	Environmental Photographic Information Center
ET	Exposure time
FI	Fraction ingested from contaminated source
gpd/ft	Gallons per day per foot
gpd/ft ²	Gallons per day per square foot
g/cm ³	grams per cubic centimeter
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HMX	High Melting Explosive (cyclotetramethylenetetranitramine)
I	Intake
IR	Ingestion or Inhalation Rate
IRIS	Integrated Risk Information System
K _s	soil/water partition coefficient
K _{ow}	Octanol/water partition coefficient
LGWF	Lateral groundwater flow
LD ₅₀	Lethal dose at which 50 percent mortality occurs
mg/g	micrograms per gram
mg/kg	milligrams per kilogram
mmHg	millimeters of mercury
NB	Nitrobenzene
NPL	National Priorities List
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
pg/m ³	picograms per cubic meter
PHRED	Public Health Risk Evaluation Data Base
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAGS	Risk Assessment Guidance for Superfund

LIST OF ACRONYMS AND ABBREVIATIONS (cont'd)

RDX	Royal Demoliton Explosive (hexahydro-1,3,5-trinitro-1,3,4-triazine)
RfD	Reference dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable maximum exposure
RTECS	Registry of Toxic Effects of Chemical Substances
SF	Slope factor
STEL	Short term exposure level
STIB	Superfund Toxic Integration Branch
TLV	Threshold limit value
1,3,5-TNB	1,3,5-Trinitrobenzene
2,4,6-TNT	2,4,6-Trinitrotoluene
TWA	Time-weighted average
µg/g	micrograms per gram
µg/l	micrograms per liter
UMDA	Umatilla Depot Activity
USABRDL	U.S. Army Biomedical Research and Development Laboratory
USARDC	U.S. Army Research and Development Command
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency

1.0 INTRODUCTION

This document is the Risk Assessment (RA) for the Explosive Washout Lagoons (Site 4) at Umatilla Depot Activity (UMDA). This report represents partial fulfillment of the Baseline RA requirements for UMDA as specified by Delivery Order No. 3--Remedial Investigation/Feasibility Study (RI/FS) of UMDA, Hermiston, Oregon. It is being submitted to the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) under Contract No. DAAA15-88-D-008.

1.1 PURPOSE

The purpose of this RA is to assess the potential future health risks posed by explosives-contaminated soils and groundwater associated with the Explosive Washout Lagoons (Site 4) in the absence of remediation, and to identify safe residual explosives concentrations (remedial action criteria or action levels) in soils if remediation is determined to be a requirement. The primary focus of the RA is to develop remedial action criteria for explosives in Site 4 soils for use in evaluating the feasibility of implementing a remedial action for contaminated soils at the site. The RA is not intended to address the remediation of contaminated groundwater. Contaminated groundwater is addressed only to the extent that contaminants present in Site 4 soils are affecting groundwater quality. The potential remediation of contaminated groundwater is addressed in the installation-wide Baseline RA for UMDA.

1.2 RISK ASSESSMENT PROCESS

The RA has been conducted in accordance with U.S. Environmental Protection Agency (EPA) guidance, as described in the EPA Region X Statement of Work, RI/FS Risk Assessment Deliverables (USEPA, 1990b); Risk Assessment Guidance for Superfund (RAGS) (USEPA, 1989g); Exposure Factors Handbook (USEPA, 1989b); Superfund Exposure Assessment Manual (USEPA, 1988b); and other UMDA-specific guidance/comments provided by EPA Region X (e.g., USEPA Region X Technical Memorandum No. 1A, Umatilla Army Depot Activity RI/FS Workplan Guidance (USEPA, 1989f); EPA Region X Technical Review Comments on the Draft Interim

Risk Assessment for the Explosive Washout Lagoons (Site 4), Umatilla Depot Activity (USEPA, 1991d), dated September 1991. Subsequent to preparation of the draft RA, supplemental guidance to RAGS concerning standard default exposure assumptions (USEPA, 1991c) and Region X supplemental guidance (USEPA, 1991e) became available. However, because the results of the RA are consistent with and often more conservative than results that would be obtained using the exposure algorithms and assumptions presented in the newly released supplemental guidance, this document does not reflect the newest guidance.

The RA is based on historical Site 4 environmental contamination information, such as described in the Battelle environmental contamination survey and assessment (Battelle, 1982), the Weston RI (Roy F. Weston, 1989), and other available environmental reports; and additional data obtained during implementation of the present RI/FS. Not all of the additional data being collected for the ongoing RI/FS were available at the time of the writing of this report. The additional data include all of the soils chemical data and most of the additional groundwater chemical data available as of June 25, 1991. All data collected by Dames & Moore--particularly all chemical data for groundwater and hydrogeologic data--will be included in the Baseline RA for the overall RI/FS.

Specific objectives of the RA at Site 4 are to:

- Provide an analysis of baseline risk and help determine the need for remedial action.
- Provide a means for determining residual explosives levels in soil that are adequately protective of public health.
- Provide a consistent process for evaluating and documenting potential public health threats.

To accomplish these objectives, five principal components of the RA, summarized in Figure 1-1, have been conducted as described below:

- Data collection and contamination assessment

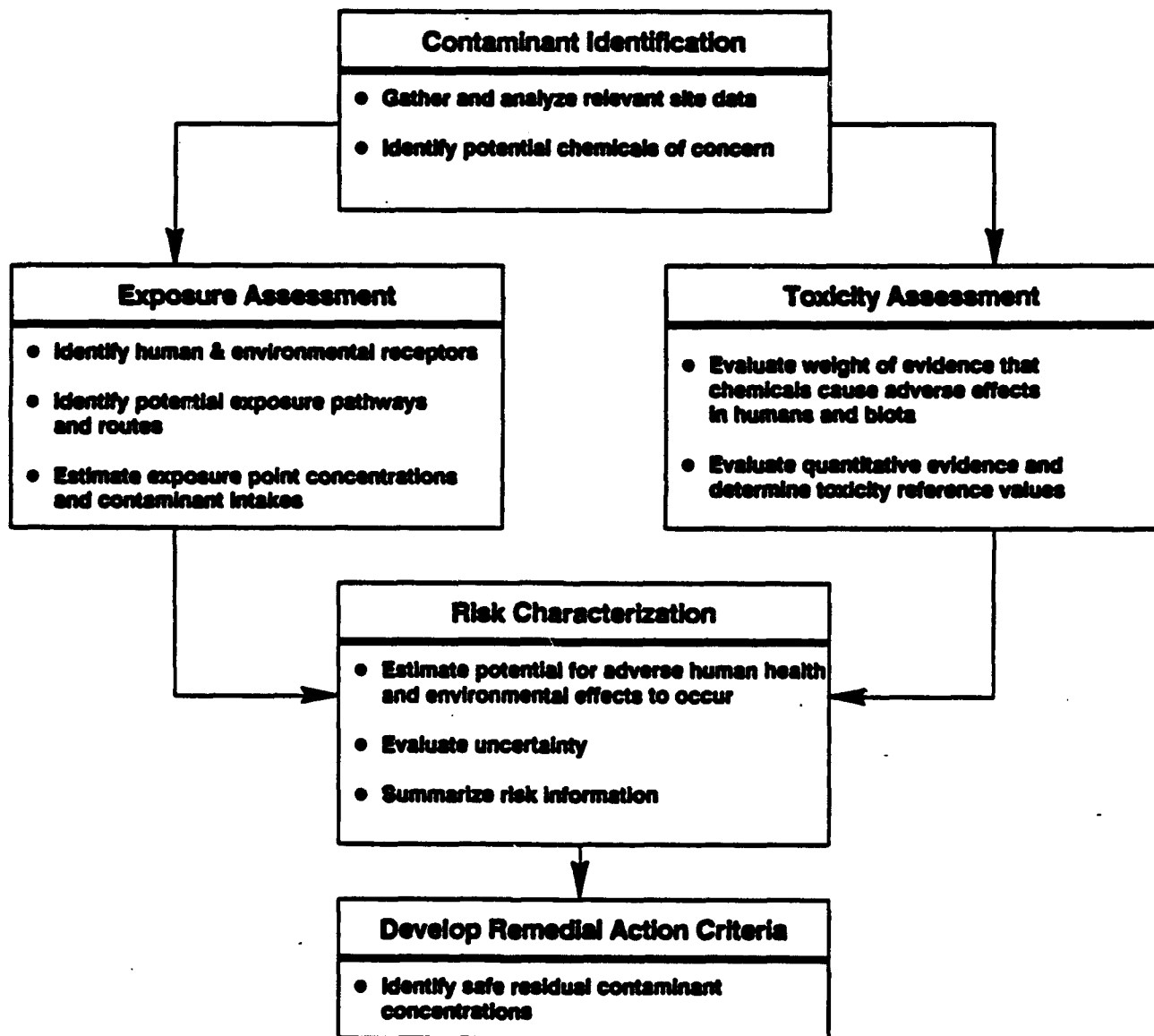


FIGURE 1-1
COMPONENTS OF A BASELINE RISK ASSESSMENT

- Exposure assessment
- Toxicity assessment
- Risk characterization
- Development of remedial action objectives.

The principal objective of this RA is to develop human health-based remedial action criteria. These criteria are based entirely on the protection of human health and do not take into account potential ecological effects. A complete ecological evaluation will be included in the installation-wide Baseline RA.

1.2.1 Data Collection and Contamination Assessment

The data collection and analysis step consists of two key tasks:

- Gathering and review of relevant site data
- Identification of potential contaminants of concern.

Gathering and analysis of relevant site data include acquisition, review, and synthesis of existing RI data. The review of historic RI data is a particularly important component of the RA because of the amount of work already conducted at the Explosive Washout Lagoons.

Potential contaminants of concern are site- and media-specific chemicals that best represent contamination present at the site. The approach recommended by EPA (USEPA, 1989g) to ensure that additive effects of exposure are considered involves the assessment of all chemicals known or suspected to be site related. Using this approach, the list of potential contaminants of concern would include chemicals that were:

- Positively detected in at least one medium.
- Detected at concentrations significantly elevated above levels of the same chemicals detected in associated blank samples.
- Detected at concentrations significantly elevated above naturally occurring concentrations.

- Only tentatively identified, but expected to be associated with the site based on site history data or previous monitoring data.

1.2.2 Exposure Assessment

Five key tasks are required in the exposure assessment step:

- Analysis of contaminant releases
- Identification of potentially exposed populations
- Identification of potential exposure pathways and routes
- Estimation of exposure point concentrations
- Estimation of contaminant intakes.

Release of contaminants from the source represents the contaminant input to the exposure pathway. Potentially exposed populations are evaluated for onsite and offsite populations, under future land use scenarios. Potential exposure pathways and routes are identified by integrating the findings of contaminant release and exposed populations analysis. Media addressed by the pathways analysis include groundwater and soil. Exposure routes considered are uptake by the oral, dermal, and inhalation routes. Estimation of exposure point concentrations involves the statistical manipulation of chemical data and some analytical modeling to estimate contaminant transport from the source to the receptor.

1.2.3 Toxicity Assessment

Four key tasks make up the toxicity assessment step of the RA:

- Gathering qualitative and quantitative toxicity information for the contaminants of concern.
- Identifying exposure periods for which toxicity values are necessary.
- Determining toxicity values for noncarcinogenic effects.
- Determining toxicity values for carcinogenic effects.

Qualitative toxicity information is acquired from various sources, which include Dames & Moore's files of toxicity profiles generated in support of past and ongoing risk assessment projects, Toxicity Profiles published by the Agency for Toxic Substances and Disease Registry (ATSDR), Drinking Water Criteria documents, Health Effects Assessment documents, Ambient Water Quality Criteria documents, and associated updates to the above publications. Quantitative toxicity data from many of these documents have been extracted, reviewed, and summarized by EPA and are maintained on the three principal data bases operated by various EPA offices. The three EPA data bases used to support the RA are the Integrated Risk Information System (IRIS), maintained in Cincinnati, Ohio; the Health Effects Assessment Summary Tables (HEAST), distributed by the EPA Superfund Toxic Integration Branch (STIB); and the Public Health Risk Evaluation Database (PHRED), also distributed by STIB. Generally, these data bases lack information relative to less common contaminants such as explosives. To acquire explosives toxicity data, we rely on data generated by the U.S. Army Biomedical Research and Development Laboratory (USABRDL) and Dames & Moore's explosives toxicity data base compiled during conduct of numerous RAs for military installations where explosives were contaminants of concern. Exposure periods for which toxicity values are applicable are a function of the individual exposure pathways.

1.2.4 Risk Characterization and Development of Remedial Action Objectives

Risk characterization is facilitated by integrating the results of the exposure and toxicity assessments. For noncarcinogens, a hazard index is calculated by summing the ratios of the reference doses (RfD) to the intake estimates. For carcinogens, the risk associated with potential exposure to an individual chemical is estimated by multiplying the slope factor by the exposure estimate. The chemical-specific risks are then summed to give the overall pathway risk estimate. If the estimated risks/hazards indicate that remedial alternatives may be considered, then remedial action objectives are developed using the fate and transport and the exposure equations associated with

the pathway that drives the health risks and assuming several different target risk levels.

2.0 SITE DESCRIPTION, HISTORY OF OPERATION, AND PREVIOUS INVESTIGATIONS

2.1 SITE DESCRIPTION AND HISTORY OF OPERATION

Site 4 consists of two adjacent lagoons located in the central portion of UMDA (Figure 2-1). They were formerly used as infiltration ponds for liquid wastes from bomb-washing operations in the washout plant. The measured dimensions of the flat bottoms of the two lagoons are 30 by 80 feet and 40 by 80 feet, each with a depth of about 6 feet. The lagoons have sandy bottoms and gravelly sides and are currently empty.

The entire explosives washout plant system was drained, flushed, and cleaned approximately once each week from the mid-1950s until 1965. The lagoons received all of the approximately 150,000 gallons of waste generated during the weekly turnarounds. It is estimated that a total of up to 85 million gallons of pink water may have been discharged to the lagoons during this period of operation. Former UMDA employees have indicated that both lagoons have been rebuilt over the years.

The two lagoons were operated in an alternating manner. Washout wastes from Building 489--also known as pink water because of their characteristic color--were accumulated in one of the lagoons, while the wastes in the other lagoon were allowed to infiltrate/dry (Figure 2-2). Wastewater was accumulated in a given lagoon until the depth was approximately 3.5 feet or the rate of infiltration was substantially reduced by the accumulation of solids. The washout wastewater was then directed to the other lagoon by a movable flume at the discharge end of the rectangular trough. The trough has a concrete, in-line settling sump between the washout plant and the lagoons. During washout operations, the sump collected washwater/solids, which were pumped two to three times per week into a 500-gallon tank. The moist sludge was then placed on top of boxes (used to enhance combustion) to dry out. After drying, the residual solids were transported to the ammunition demolition activity (ADA) area

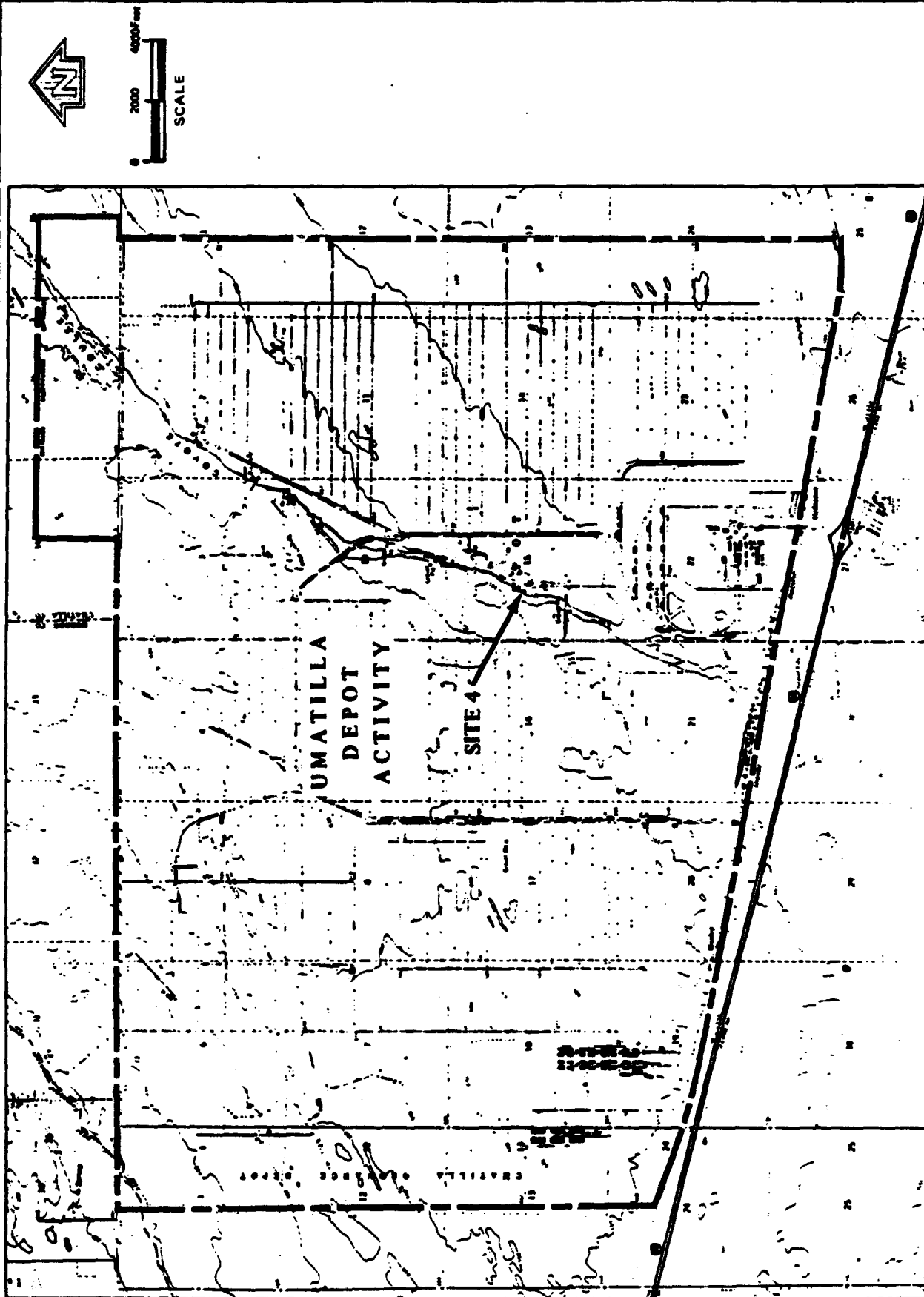
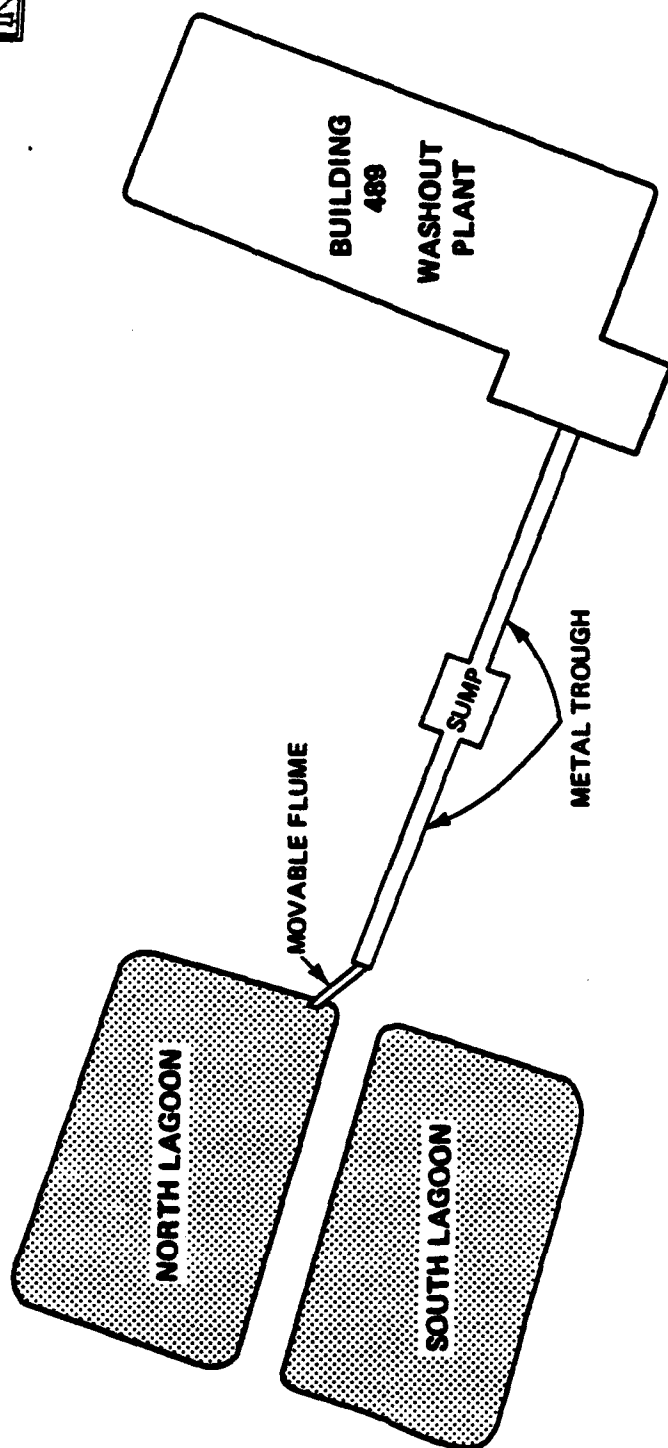


FIGURE 2-1
LOCATION OF EXPLOSIVE WASHOUT LAGOONS (SITE 4)
AT UMATILLA DEPOT ACTIVITY



NOT TO SCALE

FIGURE 2- 2
EXPLOSIVE WASHOUT LAGOONS (SITE 4)
AND WASHOUT PLANT AREA

at UMDA for open burning. Burning operations reportedly took place at a site several miles west of the washout lagoons.

Liquid wastes from the bomb washing operations consisted mainly of TNT and composition B series materials (RDX, TNT, and wax). From approximately 1964 to 1965, the washout plant worked on tritonal bombs--which are composed of a mixture of aluminum powder and TNT.

TNT was mostly used during the early years of the plant's operation. After the plant was overhauled in the 1960s, composition B materials were mostly used. For a short time, the Army ran armor piercing rounds through the washout plant. These rounds contained amatol, which is a mixture of ammonium nitrate and TNT. The period during which amatol was handled could not be determined.

In 1980, the Environmental Photographic Interpretation Center (EPIC) listed the Explosive Washout Lagoons as a potentially hazardous site (USEPA, 1981). Aerial photographs were compared from 1958 to 1970, and it was determined that significant impacts or changes to the environment had occurred during this period. The Explosive Washout Lagoons at UMDA were placed on the National Priorities List (NPL) in late 1987.

2.2 SUMMARY OF PREVIOUS INVESTIGATIONS

Previous investigations conducted at Site 4 are summarized in the sections that follow. Dames & Moore's current investigation of Site 4, which is part of the overall RI/FS of UMDA, is also discussed. The results of each of the investigation programs are presented in Section 3.0.

2.2.1 Battelle Environmental Contamination Survey and Assessment

In 1981, Battelle performed an environmental survey at UMDA. The survey included the installation of groundwater monitoring wells and the collection of surface and subsurface soil samples from the area of the Explosive Washout Lagoons. Details of the sampling investigation are outlined below:

- Four monitoring wells (numbered 6 through 9) were installed in the alluvial aquifer. These wells were sampled in April, July, and November 1981. The samples were analyzed for explosives contaminants, including 2,4-DNT, 2,6-DNT, 2,4,6-TNT, RDX, and tetryl. The November sampling also included analyses for nitrate concentration and pH.
- Wells 21 through 25 were subsequently installed and sampled during the confirmatory phase of the Battelle investigation in November 1981. The groundwater samples were analyzed for 2,4,6-TNT, 2,4-DNT, 2,6-DNT, RDX, tetryl, nitrate, and pH.
- One surface soil sample was collected from each lagoon. Each sample was analyzed for 2,4-DNT, 2,6-DNT, 2,4,6-TNT, RDX, and tetryl. In addition, the sample collected from the northern lagoon was analyzed for nitrate content. The exact locations from which the surface soil samples were collected were not identified in the Battelle report.
- Two subsurface soil samples were collected from the washout lagoon area at depths of 2.5 and 7.5 feet. The samples were analyzed for 2,4-DNT, 2,6-DNT, 2,4,6-TNT, RDX, and tetryl. Again, the sampling locations were not clearly described in the Battelle report.

2.2.2 Century Environmental Services and Century West Engineering. Groundwater Monitoring Reports

In March and August 1986, Century Environmental Services (1986a; 1986b) conducted groundwater sampling and analysis on the pre-existing Battelle wells. Analyses were performed on the following parameters--pH, TNT, DNT, RDX, HMX, tetryl, and nitrate/nitrite.

In February and August 1987, Century West Engineering Corp. (1987a; 1987b) conducted additional groundwater sampling and analysis on the same wells. Analyses were performed on the same parameters mentioned above.

2.2.3 ANA-LAB Corp., Groundwater Monitoring Reports

In August and November 1988, Ana-Lab Corp. (1988) completed groundwater monitoring studies at UMDA. The groundwater samples were analyzed for nitrogen as nitrate + nitrite, TNT, DNT, tetryl, RDX, and specific conductivity.

2.2.4 Roy F. Weston, Inc., UMDA RI, 1989

In April and May 1988, Roy F. Weston, Inc., conducted an RI field investigation at the Explosive Washout Lagoons that included the following activities:

- Installation of five alluvial aquifer monitoring wells (26 through 30) and three shallow basalt aquifer monitoring wells (SB-1, 2, and 3), with analysis for nitrogen as nitrate + nitrite and nine explosives.
- Collection of groundwater samples from all 17 monitoring wells, with analysis for nitrogen as nitrate + nitrite and nine explosives contaminants.
- Collection of subsurface soil samples from four separate boring locations--(EWL-1, 2, 3, and 4)--at depths of 3.1, 5.1, 7.1, and 10.2 feet, and thereafter at 10-foot intervals until saturated alluvium was encountered, with analysis for nitrogen as nitrate + nitrite and nine explosives.
- Collection of a composite surface soil sample (EWLOVRFW-1) from the overflow area southwest of the washout plant, with analysis for nine explosives and nitrogen as nitrate + nitrite. This area was considered to be a possible groundwater discharge location.
- Short-term (2-hour) aquifer tests in two of the alluvial monitor wells (26 and 29) to estimate hydraulic parameters of the alluvial aquifer system.

In October 1989, Roy F. Weston, Inc., collected eight additional soil samples (A-1 through A-8) from the washout lagoons. These samples were collected as a prelude to a proposed pilot test to provide for treatment of the explosives

contamination in the soils by composting. Four soil samples were collected from each lagoon, at depths ranging from the soil surface to 10 inches below the surface. Each sample was analyzed for HMX, RDX, and 2,4,6-TNT content.

2.3 CURRENT INVESTIGATION. DAMES & MOORE

Dames & Moore's field investigation at the Explosive Washout Lagoons commenced in June 1990. The principal field activities associated with this investigation include:

- Collection and chemical analysis (for explosives and nitrogen as nitrate + nitrite) of 48 soil samples (and two duplicates) from eight borings near the washout lagoons, and three surface soil samples from three locations in a gully that appears to run between the washout lagoons and the "overflow" area.
- Water and sludge sampling in the concrete sump located near the bottom of the flume.
- Installation of 17 new wells, consisting of 16 4-inch monitoring wells and one 8-inch pumping well. Thirteen wells were completed in the flood gravels and four in the basalt.
- Determination of soil (flood gravel) retardation coefficients for explosives and nitrate/nitrite.
- Two rounds of groundwater sampling of 17 new and 17 existing wells for nine explosives and nitrogen as nitrate + nitrite.
- Two rounds of groundwater sampling of the four new basalt wells and four adjacent existing flood gravel wells for inorganic ions (Ca^{+2} , Mg^{+} , Na^{+} , K^{+} , Cl^{-} , F^{-} , NO_3/NO_2 , SO_4^{2-} , and carbonate species (i.e., alkalinity) and for tritium.
- Aquifer testing
 - A 3- to 7-day pumping test performed on the 8-inch well.

- **8-hour pumping tests performed in each of four well clusters to investigate the degree of connection between aquifers.**
- **Slug tests performed in all wells.**
- **A tracer test conducted in conjunction with the 3- to 7-day pumping test to estimate aquifer dispersion and porosity.**

3.0 SAMPLING INVESTIGATION RESULTS AND CONTAMINATION ASSESSMENT

Section 3.0 discusses the soil and previous groundwater sampling results for the Explosive Washout Lagoons area. Section 3.1 describes soil contamination, and Section 3.2 discusses groundwater flow direction and presents a summary of groundwater contamination. Section 3.3 presents a discussion of the correlation between soil and groundwater data. Because no natural streams occur within UMDA or proximate to Site 4, and drainage patterns are very poorly developed due to the highly permeable soils, low precipitation, and recent formation of the landscape, the potential for contamination of surface water does not appear to exist and is not discussed further in this RA.

3.1 SOIL ANALYTICAL RESULTS

As discussed in Section 2.2, four separate soil sampling investigations have been conducted at the Explosive Washout Lagoons. The first investigation was performed by Battelle in 1981. The second and third investigations were conducted by Roy F. Weston, Inc., in 1988 and 1989. The most recent investigation was performed by Dames & Moore in 1990.

Table 3-1 presents all laboratory analysis data from soil sampling investigations at the Explosive Washout Lagoons. Constituents detected at concentrations greater than the detection limit are highlighted in Table 3-1 by shading. Soil sampling locations are illustrated in Figure 3-1. Locations for Dames & Moore samples S4-9 through S4-11 and Weston composite sample EWLOVRFW-1 are not illustrated in Figure 3-1, because these samples were collected from the overflow area approximately 1,000 feet south of the washout lagoons. No explosives contaminants were detected in these samples. Furthermore, the Battelle sampling locations are not identified in Figure 3-1, because these sampling locations were not clearly described in the Battelle report.

TABLE 3-1

Site ID	Date	(Ref.)	Depth (m)	Wt (kg)	135TNR	150NR	245TNT	240NT	280NT	HMX	FOX	MB	TETRYL	
84-1	28-Jun-1990	(DAM)	0	16.10	32.00	<0.50	340.00	<0.42	<0.52	27.20	600.00	<0.41	<0.73	
			2	12.00	25.00	<0.50	50.00	0.55	<0.52	13.10	120.00	27.10	<0.73	
			4	8.35	1.00	<0.50	1.00	<0.42	<0.52	2.00	10.00	<0.41	<0.73	
			6	12.00	18.00	0.85	1.75	<0.42	<0.52	15.00	20.00	3.00	<0.73	
			8	12.00	45.00	0.54	1.04	<0.42	<0.52	10.00	7.57	<0.41	<0.73	
84-2	28-Jun-1990	(DAM)	0	0.51	2.10	<0.50	1.07	<0.42	<0.52	4.04	37.00	<0.41	<0.73	
			2	3.24	<0.40	<0.50	<0.40	<0.42	<0.52	3.04	11.40	<0.41	<0.73	
			4	2.43	<0.40	<0.50	<0.40	<0.42	<0.52	1.50	3.75	<0.41	<0.73	
			6	1.50	<0.40	<0.50	<0.40	<0.42	<0.52	0.50	3.40	<0.41	<0.73	
			8	1.10	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	3.10	<0.41	<0.73	
84-3	28-Jun-1990	(DAM)	0	1.05	<0.40	<0.50	<0.40	<0.42	<0.52	4.70	13.00	<0.41	<0.73	
			2	2.10	<0.40	<0.50	<0.40	<0.42	<0.52	5.00	16.70	<0.41	<0.73	
			4	<0.50	<0.40	<0.50	<0.40	<0.42	<0.52	1.35	0.51	<0.41	<0.73	
			6	0.50	<0.40	<0.50	<0.40	<0.42	<0.52	2.25	0.00	<0.41	<0.73	
			8	1.41	<0.40	<0.50	<0.40	<0.42	<0.52	1.50	0.22	<0.41	<0.73	
84-4	28-Jun-1990	(DAM)	0	5.55	1.00	<0.50	3.00	<0.42	<0.52	21.00	110.00	<0.41	<0.73	
			2	2.05	<0.40	<0.50	2.05	<0.42	<0.52	7.00	31.00	<0.41	<0.73	
			4	2.40	<0.40	<0.50	0.72	<0.42	<0.52	0.37	20.00	<0.41	<0.73	
			6	0.57	<0.40	<0.50	<0.40	<0.42	<0.52	0.72	0.00	<0.41	<0.73	
			8	0.50	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	2.00	<0.41	<0.73	
84-4 Dup.	28-Jun-1990	(DAM)	8	0.52	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	3.05	<0.41	<0.73	
84-5	28-Jun-1990	(DAM)	0	11.20	20.00	<0.50	3400.00	12.00	<0.50	65.00	450.00	<0.41	<0.73	
			2	15.00	47.00	<0.50	5000.00	<11.00	<0.50	51.00	450.00	<0.41	<0.73	
			4	9.54	31.00	0.55	3000.00	<11.00	<0.50	47.00	250.00	<0.41	<0.73	
			6	0.75	16.00	<0.50	1100.00	<11.00	<0.50	15.00	50.00	<0.41	<0.73	
			8	12.50	9.19	<0.50	1.53	0.51	<0.52	1.25	22.40	<0.41	<0.73	
84-6	28-Jun-1990	(DAM)	0	0.05	<0.40	<0.50	0.07	<0.42	<0.52	1.30	0.75	<0.41	<0.73	
			2	<0.50	<0.40	<0.50	<0.40	<0.42	<0.52	0.00	<0.50	<0.41	<0.73	
			4	<0.50	<0.40	<0.50	<0.40	<0.42	<0.52	0.72	<0.50	<0.41	<0.73	
			6	<0.50	<0.40	<0.50	<0.40	<0.42	<0.52	0.75	<0.50	<0.41	<0.73	
			8	<0.50	<0.40	<0.50	<0.40	<0.42	<0.52	1.33	0.31	<0.41	<0.73	
84-6	28-Jun-1990	(DAM)	20	3.91	<0.40	<0.50	0.75	<0.42	<0.52	<0.57	0.53	<0.41	<0.73	
			30	5.53	<0.40	<0.50	0.51	<0.42	<0.52	<0.57	22.50	<0.41	<0.73	
			40	2.33	17.00	<0.50	5.00	1.05	<0.52	<0.57	7.04	11.30	<0.41	<0.73
			50	2.34	22.00	<0.50	17.50	2.05	<0.52	<0.57	12.45	3.01	<0.41	<0.73

TABLE 3-1 (cont'd)
Explosive Washout Lagoons
Summary of Soil Analytical Results (ug/g)

Site ID	Date	Depth (ft)	MTL (g)	15STNG	18DNB	24STNT	24DNIT	28DNIT	MDX	BDX	MR	YRTRY
24-7	28-Jun-1993	(DAM)	0	2.14	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	<0.59	<0.73
			2	1.88	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	<0.59	<0.73
			4	0.88	<0.40	<0.50	<0.40	<0.42	<0.52	0.88	<0.59	<0.73
			6	1.06	0.53	<0.50	<0.40	<0.42	<0.52	0.94	<0.59	<0.73
24-7 Dup.	28-Jun-1993	(DAM)	8	1.19	0.59	<0.50	<0.40	<0.42	<0.52	1.21	<0.59	<0.73
			8	0.58	0.57	<0.50	<0.40	<0.42	<0.52	<0.57	0.79	<0.73
24-8	28-Jun-1993	(DAM)	0	4.20	3.89	<0.50	53.00	<0.42	<0.52	11.20	100.00	<0.73
			2	1.87	<0.40	<0.50	0.52	<0.42	<0.52	1.27	4.55	<0.73
			4	1.48	<0.40	<0.50	<0.40	<0.42	<0.52	0.51	2.02	<0.73
			6	1.06	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	1.53	<0.73
			8	1.08	<0.40	<0.50	<0.40	<0.42	<0.52	0.71	2.04	<0.73
			20	2.47	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	0.12	<0.73
			30	2.47	<0.40	<0.50	<0.40	<0.42	<0.52	<0.57	18.70	<0.73
			40	4.31	11.40	<0.50	8.28	1.10	<0.52	4.90	28.00	<0.73
A-1	05-Oct-1993	(WES)	0-1"	-	-	-	45582	-	-	<127.9	<38	-
			0-6"	-	-	-	918	-	-	0.7	2.13	-
			0-1"	-	-	-	57023	-	-	483	781	-
			0"	-	-	-	318	-	-	0.88	<0.58	-
			0-6"	-	-	-	14.3	-	-	18.4	5.1	-
			8-10"	-	-	-	<1.82	-	-	2.38	204	-
			0-6"	-	-	-	1618	-	-	57.6	246	-
			0-1"	-	-	-	4.43	-	-	<1.57	0.52	-

TABLE S-1 (cont'd)
Explosive Washout Lagoons
Summary of Soil Analytical Results (ug/g)

Site ID	Date	Grid	Depth (ft)	MTL (g)	136TNR	152DNR	246TNI	246DNI	380DNI	HAHX	POX	ME	TEHPAL
EWL-1	27-apr-1998	(WES)	3.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	3.00	<0.42	<0.25
			5.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<2.10	<0.42	<0.25
			7.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	3.00	<0.42	<0.25
			10.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			20.3	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	2.00	<0.42	<0.25
			20.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	1.00	<0.42	<0.25
			40.7	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
EWL-2	20-apr-1998	(WES)	50.2	<500	<2.00	<0.50	0.54	0.52	<0.40	3.00	3.00	<0.42	<0.25
			3.1	<500	3.20	<0.50	4.40	0.50	<0.40	1.50	3.50	<0.42	<0.25
			5.1	<500	2.10	<0.50	<1.92	<0.42	<0.40	<1.57	2.10	<0.42	<0.25
			7.1	<500	<0.50	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			10.1	<500	1.10	<0.50	<1.92	<0.42	<0.40	<1.57	1.10	<0.42	<0.25
			20.3	<500	7.00	<0.50	<1.92	0.57	<0.40	5.40	7.00	<0.42	<0.25
			20.1	<500	0.50	<0.50	12.00	0.50	<0.40	3.00	0.50	<0.42	<0.25
EWL-3	27-apr-1998	(WES)	40.7	<500	10.00	<0.50	11.00	0.75	<0.40	4.40	10.00	<0.42	<0.25
			3.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			5.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			7.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			10.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			20.3	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			20.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
EWL-4	27-apr-1998	(WES)	40.7	<500	12.00	<0.50	8.50	1.50	<0.40	10.00	8.50	<0.42	<0.25
			3.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			5.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			7.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			10.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			20.3	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
			20.1	<500	<2.00	<0.50	<1.92	<0.42	<0.40	<1.57	<0.90	<0.42	<0.25
Mag: S-54	00-mar-1991	(BAT)	40.7	<500	4.00	<0.50	4.40	0.50	<0.40	7.00	0.50	<0.42	<0.25
			50.2	<500	<2.00	<0.50	4.40	0.57	<0.40	<1.57	<0.90	<0.42	<0.25
Mag: S-51	00-mar-1991	(BAT)	0"	100"	NA	NA	35	<0.41	<0.30	NA	300	NA	<0.75
			0"	NA	NA	NA	2000	4.5	5.4	NA	<0.9	NA	12
S-125	22-mar-1991	(BAT)	2.5"	NA	NA	NA	100	<0.41	<0.30	NA	300	NA	<0.75

TABLE 3-1 (cont'd)
Explosive Washout Lagoons
Summary of Soil Analytical Results (up'd)

Site ID	Date	Depth (m)	NT (g)	195TNR	192NR	249TNT	240TNT	HMX	RDX	ME	TETRYL
8-127	22-mar-1981 (BAT)	7.5"	NA	NA	NA	38	<0.41	<0.30	NA	NA	<0.75
Samples from overflow area:											
EWLOPFW-1	04-may-1983 (WES)	0-9"	NA	<2.00	<0.80	<1.82	<0.42	<0.40	<0.86	<0.42	<0.25
84-9	13-Jul-1980 (DJA)	0	3.20	<0.40	<0.80	<0.40	<0.42	<0.82	<0.80	<0.41	<0.73
84-10	13-Jul-1980 (DJA)	0	1.53	<0.40	<0.80	<0.40	<0.42	<0.82	<0.80	<0.41	<0.73
84-11	13-Jul-1980 (DJA)	0	3.85	<0.40	<0.80	<0.40	<0.42	<0.82	<0.80	<0.41	<0.73

• - Only HCG was analyzed.

(a) = When a single value is listed the depth indicated represents the top of the sampling interval.

(b) = Nitrogen as nitrate + nitrite.

(c) = Data was collected by Play Weston, Inc. but is not published.

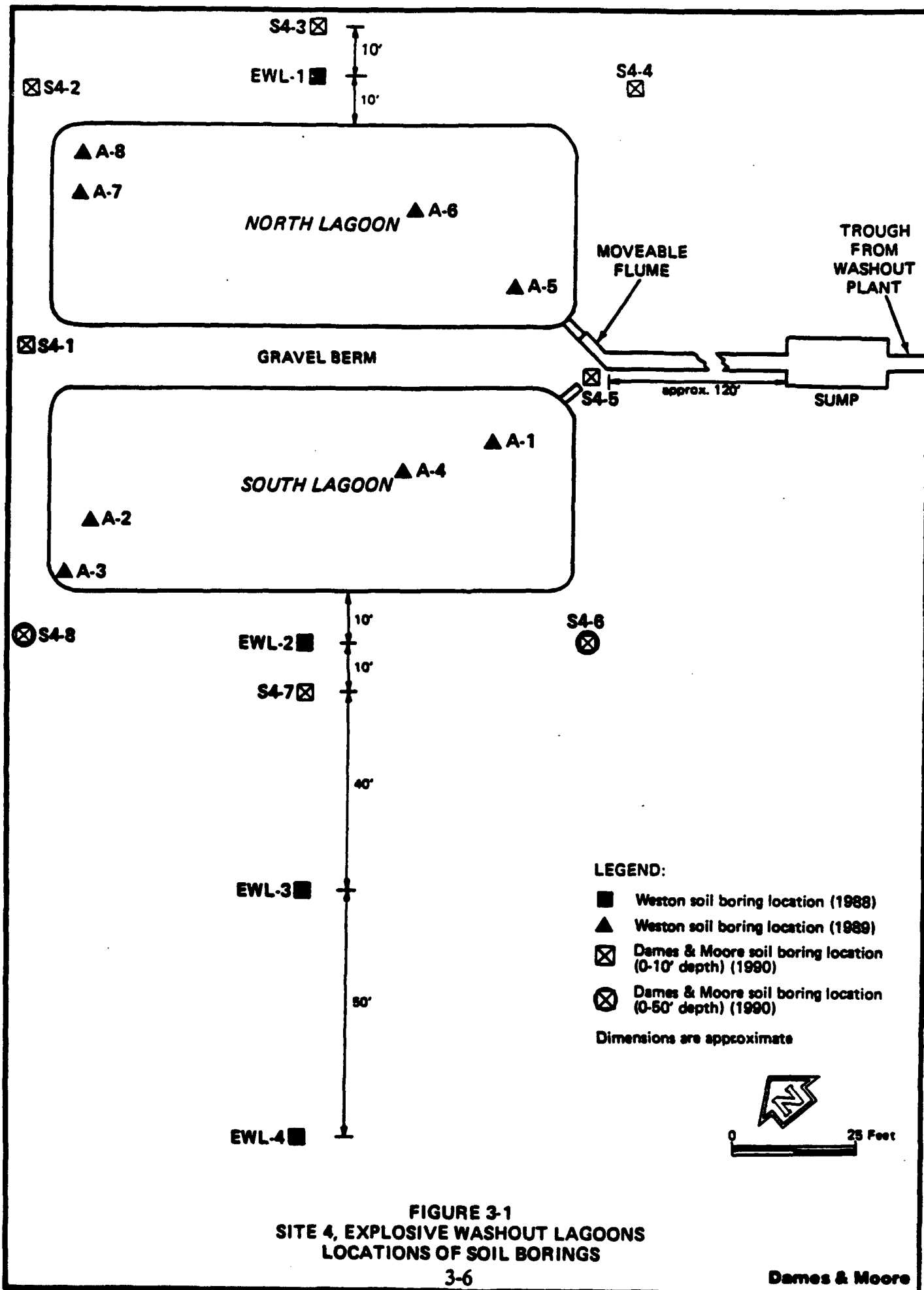
BAT = Battelle Final Report, 1992, Environmental Contamination Survey and Assessment of Unsettled Army Depot Activity.

D&M= Dames & Moore, unpubl. data from the Remedial Investigation/Feasibility Study of the Unanilla Depot Activity, Environmental Survey and Assessment at Commerce Party Depot Activity.

WES= Roy F. Weston, Inc., March 1988, Draft Final Report, Task Order 7, Unsettled Army Depot Activity Remedial Investigation.

NA = Not Analyzed.

Data detected at concentrations greater than the detection limit are highlighted by shading for easy observation.



A review of the soil sampling data presented in Table 3-1 indicates that 2,4,6-TNT, HMX, and RDX were consistently detected at concentrations well above their respective detection limits. Nitrogen (as nitrate + nitrite) was also detected in many samples at low-to-moderate concentrations, and 1,3,5-TNB was detected at moderate concentrations in a few samples. Other explosives contaminants found in the soils were generally at low levels and limited to only a few samples.

In general, the highest concentrations of 2,4,6-TNT, HMX, and RDX were detected in soil samples collected from depths 0 to 2 feet below the surface (see Figure 3-2). The contamination of soils within the 0- to 2-foot-depth interval appears to be fairly well distributed throughout the washout lagoons and surrounding areas; however, the highest concentrations were detected from samples in the lagoons. Analysis of deeper soil samples indicate that contaminant concentrations generally decrease with increasing depth until a depth of approximately 40 to 50 feet. A slight increase in contaminant concentrations was noted in some samples at the 40- to 50-foot range. It is possible that contaminants present in the alluvial aquifer may be contributing to contamination of the soils at this depth. Cross-sectional presentations of contamination with respect to depth are provided in Figures 3-3 and 3-4. These figures also include approximate elevations of groundwater in the alluvial aquifer. Figure 3-3 provides a northeastern/southwestern cross-sectional view transecting both lagoons and includes borings S4-3, EWL-1, EWL-2, S4-7, EWL-3, and EWL-4. Figure 3-4 provides an east/west cross-sectional view tangential to the southern lagoon and includes borings S4-6, EWL-2, and S4-8. Both figures depict TNT, HMX, and RDX soil contamination at depths of up to 50 feet, with HMX and RDX more evenly distributed. The coincidence of elevated concentrations of explosives at depths of 40 to 50 feet in some soil borings (Figures 3-3 and 3-4) suggests that groundwater contamination may contribute to soil contamination.

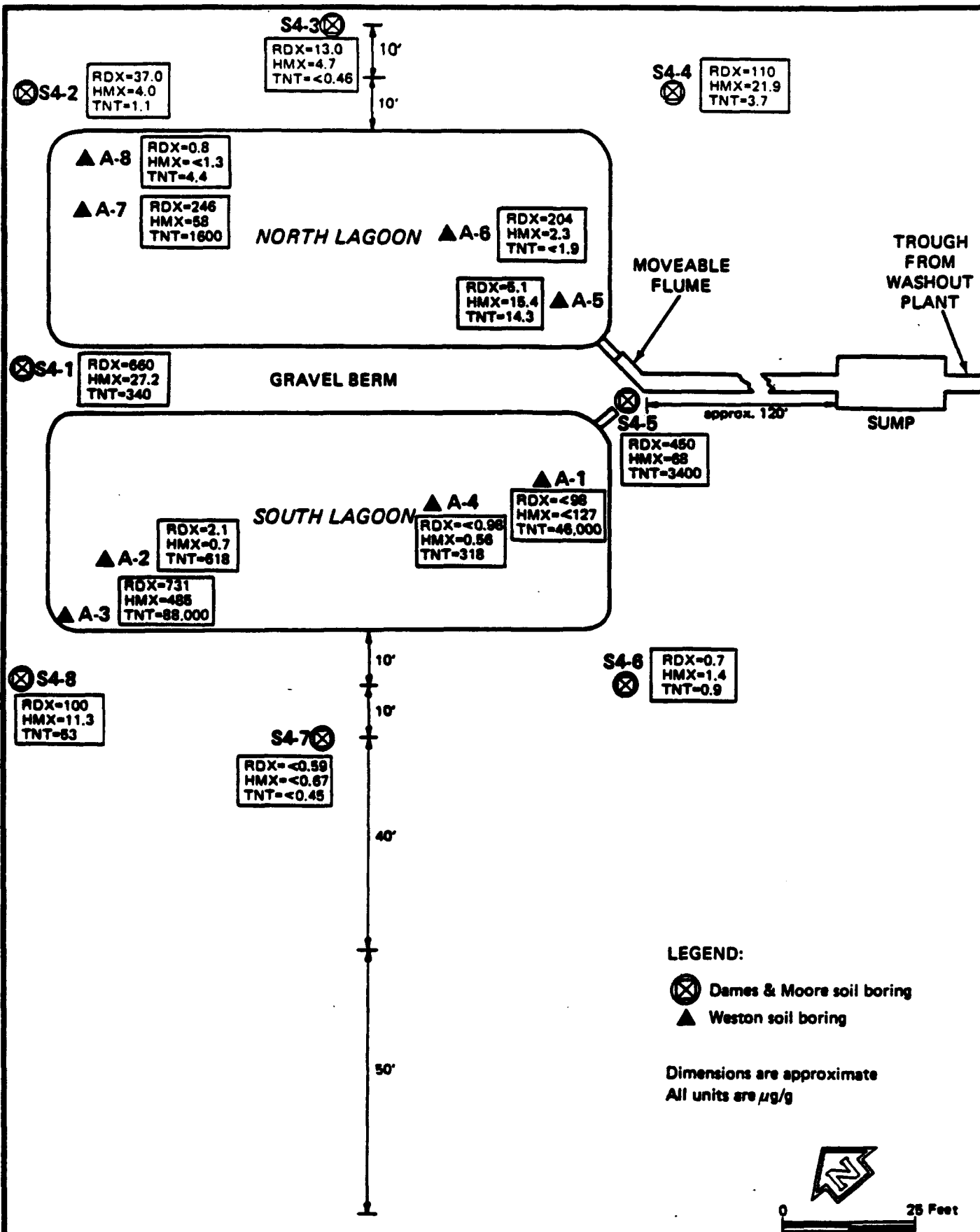
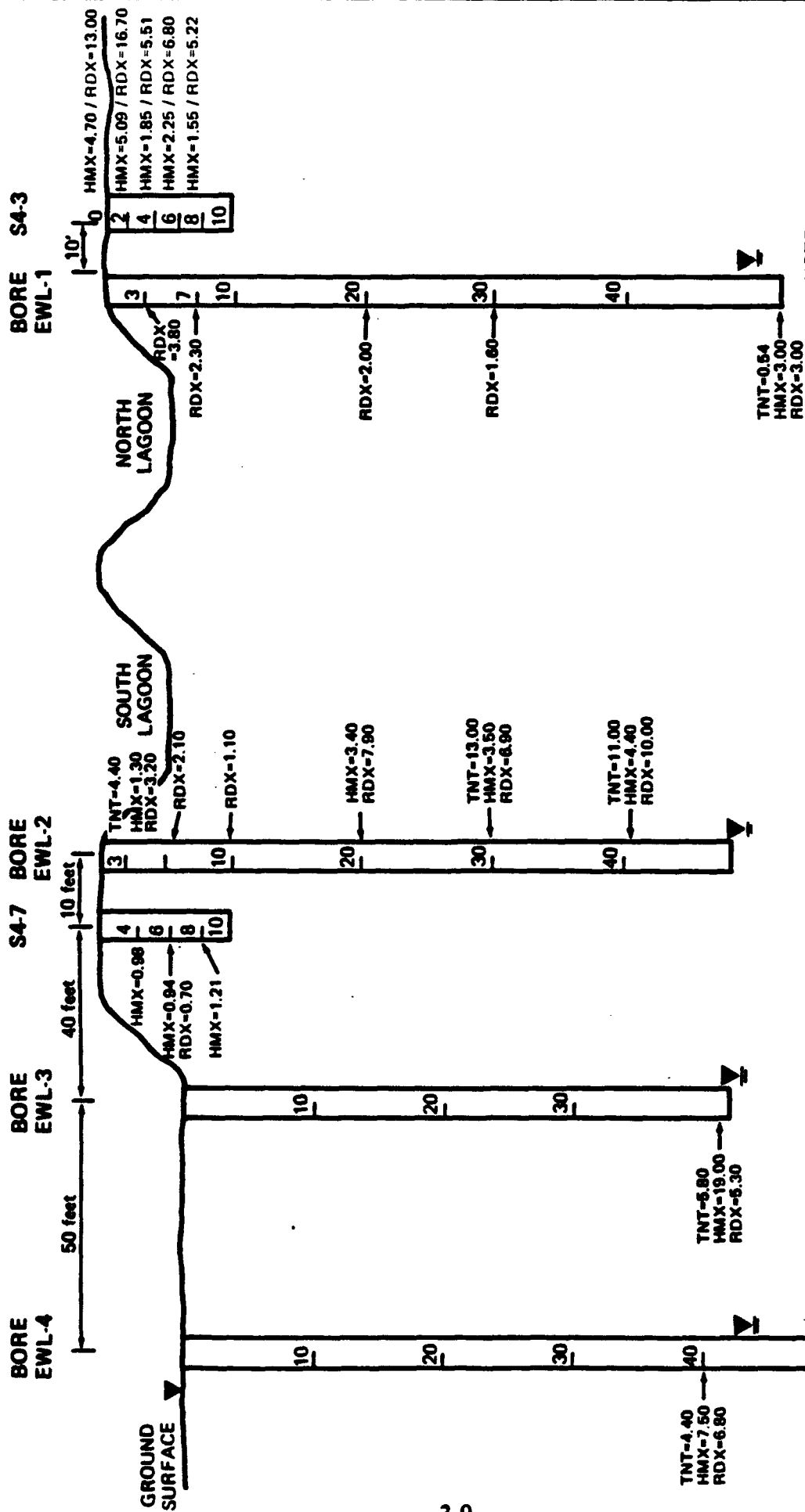


FIGURE 3-2
RDX, HMX and TNT CONCENTRATIONS IN SOIL
SITE 4, EXPLOSIVE WASHOUT LAGOONS
0-2' INTERVAL



NOTE:
Intervals with no data
indicate results are below
detection limits.

FIGURE 3-3
SUBSURFACE TNT, HMX and RDX CONCENTRATIONS (µg/g)
EXPLOSIVE WASHOUT LAGOONS AREA

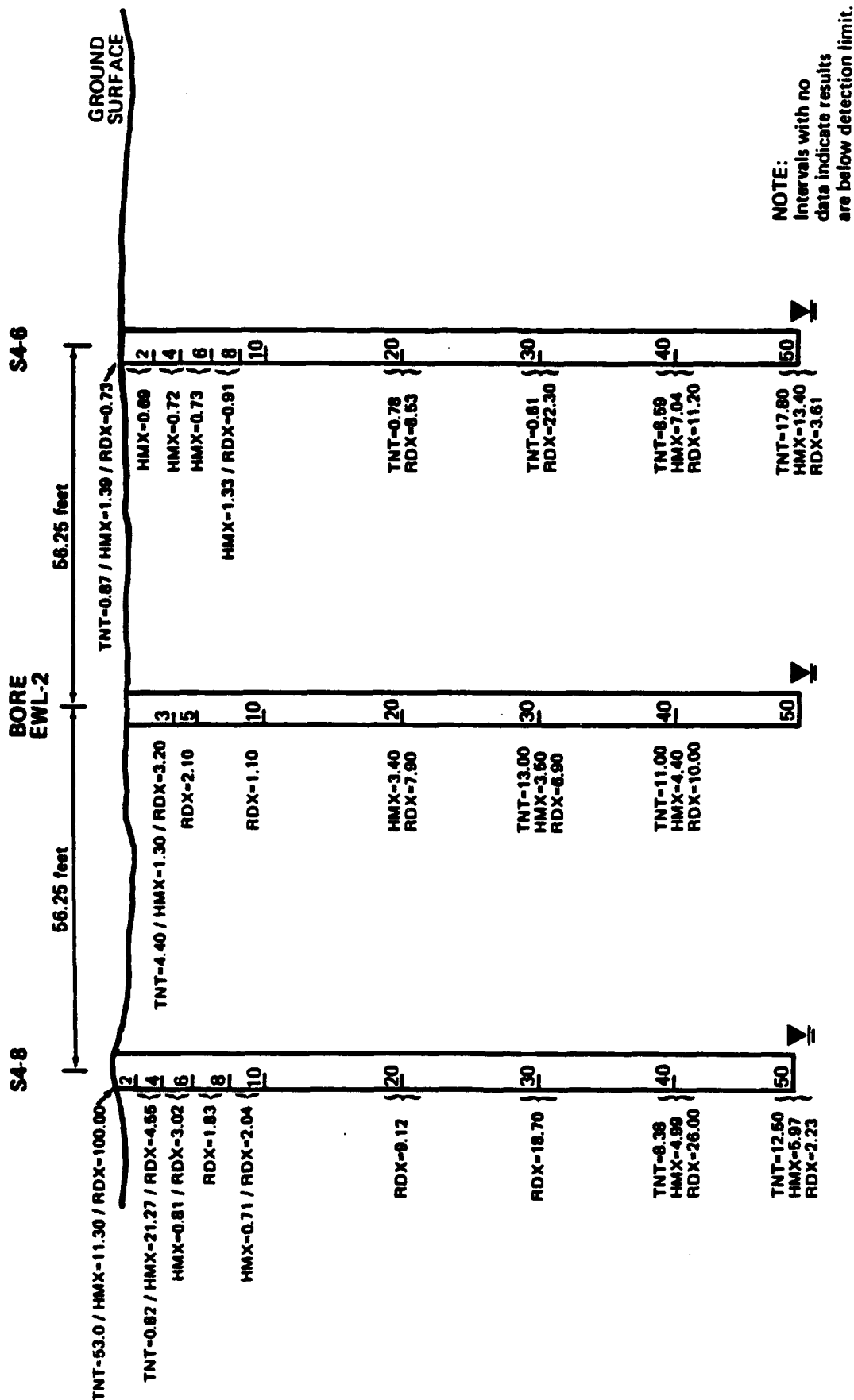


FIGURE 3-4
SUBSURFACE TNT, HMX and RDX CONCENTRATIONS (µg/g)
EXPLOSIVE WASHOUT LAGOONS AREA

3.2 GROUNDWATER FLOW AND ANALYTICAL MONITORING RESULTS

3.2.1 Groundwater Flow Summary

Century Environmental Service's March and August 1986, and Century West Engineering Corp.'s February and August 1987 groundwater monitoring reports indicated that--for all of UMDA--groundwater flow is predominantly to the northwest.

The short-term aquifer tests performed by Roy F. Weston, Inc. (1989) in the area of the explosive lagoons indicated a wide range in aquifer permeability. Transmissivity values ranged from 700 to 200,000 gallons per day per foot (gpd/ft) and hydraulic conductivity ranged from 90 to 22,000 gpd/ft².

Weston's water level measurements indicated that the alluvial aquifer and the uppermost basalt zone are hydraulically connected, which implies that alluvial aquifer contamination has the potential to migrate into the uppermost basalt. Based on Dames & Moore's review of groundwater analytical data, the deep basalt aquifer penetrated by four Dames & Moore wells appears to be hydraulically connected to the upper zones.

Weston's studies also determined that the groundwater flow system in the area of the Explosive Washout Lagoons is apparently affected by groundwater pumpage during the summer and fall irrigation seasons. The water table was calculated to have a slight gradient of approximately 0.0004 toward the south/southeast during the summer and fall months. A similar gradient toward the north was calculated for the winter and spring months. The normal alluvial groundwater flow direction is reported to be toward the northwest, with a gradient of 0.002.

3.2.2 Groundwater Monitoring Results Summary

As discussed in Section 2.2, since 1981 there have been five studies performed at the Explosive Washout Lagoons area that discuss groundwater contamination. As discussed in Section 1.1, contaminated groundwater is addressed in this RA only to the extent that contaminants present in Site 4 soils are affecting groundwater quality. Therefore, this discussion is limited to explosives, nitrate, and nitrite. The complete

groundwater analytical results will be presented and discussed in the installation-wide Baseline RA for UMDA. Table 3-2 is a compilation of available explosives, nitrate, and nitrite data for the Explosive Washout Lagoons, including Dames & Moore groundwater results available as of June 26, 1991. The table presents analytical results for each well, organized chronologically. Figure 3-5 shows monitoring well locations for pre-existing and new (Dames & Moore) wells.

A review of the monitoring well data presented in Table 3-2 indicates that wells 9, 4-1, and 4-18 in the Explosive Washout Lagoon area exhibit the highest degree of contamination. Well 9 was installed in 1981, and wells 4-1 and 4-18 were installed by Dames & Moore in 1990 during the current RI. Concentrations of TNT and HMX generally decrease with time in well 9. DNT, tetryl, and RDX concentrations in well 9 vary inconsistently. Figure 3-6 graphically portrays the time trends of contamination concentrations in well 9 for the two explosives detected the most frequently and at the highest concentrations--2,4,6-TNT and RDX. Concentrations of explosives detected during Dames & Moore's two rounds of sampling of wells 4-1 and 4-18 were similar.

In other wells, TNT, HMX, and RDX (especially RDX) were detected most often. Twenty-eight of the 34 wells exhibited RDX contamination of varying concentrations.

Figure 3-7 presents the maximum concentration of RDX detected in each monitoring well. The figure indicates a relatively extensive groundwater plume of contamination, with RDX having potentially travelled at least 2,000 feet (or about 600 meters) from the lagoons (based on the presence of RDX in well 4-3). Although the plume is not well defined, the data indicate a predominantly southerly direction of transport, with high concentrations of RDX in wells 9, 21, 22, 28, 4-1, 4-13, and 4-18 and the absence of RDX in wells to the northwest (wells 7, 26, 29, and 4-2). This apparent transport direction contradicts the dominant groundwater flow direction (based on water level elevations), which is to the northwest. Only in wells MW-26, MW-29, 4-2, 4-15, and 4-16 were nitroaromatics not detected in the samples.

TABLE 3-2

Explosive Washout Lagoons
Summary of Groundwater Analytical Results (ug/l)

Site ID	Depth	Date	(Ref.)	NIT (g)	NO3	NO2	135TNB	13DNB	246TNT	24DNT	28DNT	HMX	RDX	NB	TETRYL
006	Alluvial	23-apr-1981	(BAT)	NA	NA	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	15-jul-1981	(BAT)	NA	32,000	NA	NA	NA	3.3	<0.48	0.70	NA	<7.4	NA	<0.98
	Alluvial	04-nov-1981	(BAT)	NA	4,400	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	07-mar-1986	(CES)	NA	8,000	10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	15-aug-1986	(CES)	NA	2,600	<10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	26-feb-1987	(CES)	NA	9,100	10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	13-aug-1987	(CES)	NA	8,700	20	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	21-jun-1988	(WES)	7,500	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	4.37	<1.13	<0.66
	Alluvial	17-aug-1988	(ANA)	74,000	NA	NA	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	07-nov-1990	(D&M)	4,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
	Alluvial	27-feb-1991	(D&M)	5,700	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
007	Alluvial	22-apr-1981	(BAT)	NA	NA	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	15-jul-1981	(BAT)	NA	30,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	04-nov-1981	(BAT)	NA	5,600	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	07-mar-1986	(CES)	NA	4,600	<10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	15-aug-1986	(CES)	NA	3,200	<10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	26-feb-1987	(CES)	NA	5,600	<10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	13-aug-1987	(CES)	NA	5,900	10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	21-jun-1988	(WES)	5,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
	Alluvial	18-aug-1988	(ANA)	30,000	NA	NA	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	06-nov-1990	(D&M)	2,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
	Alluvial	26-feb-1991	(D&M)	185	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
008	Alluvial	21-apr-1981	(BAT)	NA	NA	NA	NA	NA	<0.47	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	16-jul-1981	(BAT)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Alluvial	04-nov-1981	(BAT)	NA	67,000	NA	NA	NA	0.73	<0.48	<0.43	NA	<7.4	NA	<0.98
	Alluvial	07-mar-1986	(CES)	NA	22,000	10	NA	NA	<1	1.6	<1	<100	<30	NA	<10
	Alluvial	15-aug-1986	(CES)	NA	16,000	<10	NA	NA	6.8	1.4	<1	297	<30	NA	<10
	Alluvial	27-feb-1987	(CES)	NA	31,000	10	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	14-aug-1987	(CES)	NA	27,000	20	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alluvial	17-jun-1988	(WES)	18,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	85	NA	<10
	Alluvial	18-aug-1988	(ANA)	250,000	NA	NA	NA	NA	<1	<1	<1	<100	46.0	<1.13	<0.66
	Alluvial	06-nov-1990	(D&M)	13,000	NA	NA	<0.63	<0.52	0.90	<0.61	<1.15	<1.65	3.04	<1.07	<0.56
	Alluvial	18-feb-1991	(D&M)	17,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	17.4	<1.07	<0.56

TABLE 3-2 (cont'd)

Explosive Washout Lagoons
Summary of Groundwater Analytical Results (ug/l)

Site ID	Depth	Date	(REL.)	NIT(g)	NO3	NO2	135TINB	13DNB	245TINI	24DNI	28DNI	HMX	FDX	NB	TETRYL
009	Altitude	22-apr-1981	(BAT)	NA	NA	NA	NA	NA	11,000	<0.48	760	NA	10,000	NA	<0.98
	Altitude	15-Jul-1981	(BAT)	NA	72,000	NA	NA	NA	8,800	4.5	680	NA	1,800	NA	0.98
	Altitude	04-nov-1981	(BAT)	NA	150,000	NA	NA	NA	6,100	3.8	360	NA	1,500	NA	0.98
	Altitude	07-mar-1988	(CES)	NA	26,000	10	NA	NA	4,350	400	5.1	1,300	7,480	NA	<10
	Altitude	15-aug-1988	(CES)	NA	12,000	<10	NA	NA	3,950	38.5	<1	2,530	6,125	NA	<10
	Altitude	27-feb-1987	(CES)	NA	94,000	10	NA	NA	3,700	<1	<1	2,000	6,900	NA	<10
	Altitude	14-aug-1987	(CES)	NA	41,000	20	NA	NA	3,110	<1	<1	1,680	7,430	NA	<10
	Altitude	07-Jul-1988	(WES)	30,700	NA	NA	420	<0.61	3,400	330	5.30	1,400	5,700	<1.13	<0.66
	Altitude	17-aug-1988	(ANA)	45,000	NA	NA	NA	NA	610	<1	250	820	13,000	NA	1,600
W021	Altitude	08-nov-1990	(D&M)	45,000	NA	NA	420	17.9	3,100	340	<1.15	590	2,800	15.7	<0.56
	Altitude	19-feb-1991	(D&M)	48,000	NA	NA	441	8.62	3,158	431	<1.15	1,288	3,643	<1.07	<0.56
	Altitude	05-nov-1981	(BAT)	NA	46,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	1,500	NA	<0.98
	Altitude	08-Jul-1988	(WES)	20,300	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	9.88	2,900	<1.13	<0.66
	Altitude	20-aug-1988	(ANA)	94,000	NA	NA	NA	NA	<1	<1	<1	<100	4,200	NA	<10
W022	Altitude	13-nov-1990	(D&M)	40,000	NA	NA	1.98	<0.52	<0.59	<0.61	<1.15	31.8	2,200	<1.07	<0.56
	Altitude	05-mar-1991	(D&M)	28,000	NA	NA	1.89	<0.52	<0.59	<0.61	<1.15	32.2	2,468	<1.07	<0.56
	Altitude	04-nov-1981	(BAT)	NA	160,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	960	NA	<0.98
	Altitude	07-Jul-1988	(WES)	31,500	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	1.91	0.68	<1.13	<0.66
	Altitude	18-aug-1988	(ANA)	400,000	NA	NA	NA	NA	<1	<1	<1	<100	<30	NA	<10
W023	Altitude	07-nov-1990	(D&M)	25,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	54	<1.07	<0.56
	Altitude	19-feb-1991	(D&M)	30,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	123	<1.07	<0.56
	Altitude	04-nov-1981	(BAT)	NA	43,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	140	NA	<0.98
	Altitude	07-Jul-1988	(WES)	21,100	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	230	<1.13	<0.66
	Altitude	18-aug-1988	(ANA)	42,000	NA	NA	NA	NA	<1	<1	<1	<100	40	NA	<10
W024	Altitude	08-nov-1990	(D&M)	15,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	260	<1.07	<0.56
	Altitude	19-feb-1991	(D&M)	10,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	200	<1.07	<0.56
	Altitude	05-nov-1981	(BAT)	NA	340,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	270	NA	<0.98
	Altitude	07-Jul-1988	(WES)	82,600	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	100	<1.13	<0.66
	Altitude	18-aug-1988	(ANA)	64,000	NA	NA	0.79	<0.52	<0.59	<0.61	<1.15	<1.65	220	NA	<10
	Altitude	15-nov-1990	(D&M)	17,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	200	<1.07	<0.56
	Altitude	28-feb-1991	(D&M)	23,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	347	<1.07	<0.56

TABLE 3-2 (cont'd)

Explosive Washout Lagoons
Summary of Groundwater Analytical Results (ug/l)

Site ID	Depth	Date	(Ref.)	MIT (g)	NO ₃	NO ₂	135TNE	13DNE	245TNI	24DNI	28DNI	HMX	RDX	NB	TETRYL
WO25	Alkuvial	04-nov-1981	(BAT)	NA	430,000	NA	NA	NA	<0.47	<0.48	<0.43	NA	310	NA	<0.98
	Alkuvial	07-Jul-1988	(WES)	57,200	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	560	<1.13	<0.66
	Alkuvial	18-aug-1988	(ANA)	59,000	NA	NA	NA	NA	<1	<1	<1	<100	<30	NA	<10
	Alkuvial	08-nov-1990	(D&M)	18,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	220	<1.07	<0.56
	Alkuvial	28-feb-1991	(D&M)	6,400	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	176	<1.07	<0.56
MW-26	Alkuvial	21-Jun-1988	(WES)	50,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
	Alkuvial	02-nov-1990	(D&M)	6,500	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
	Alkuvial	13-feb-1991	(D&M)	6,400	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
MW-27	Alkuvial	22-Jun-1988	(WES)	11,800	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	83	<1.13	<0.66
	Alkuvial	05-nov-1990	(D&M)	13,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	3.49	<1.07	<0.56
	Alkuvial	26-feb-1991	(D&M)	13,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	6.52	<1.07	<0.56
MW-28	Alkuvial	17-Jun-1988	(WES)	13,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	1,000	<1.13	<0.66
	Alkuvial	05-nov-1990	(D&M)	26,000	NA	NA	2.40	1.57	<0.59	<0.61	<1.15	15.6	5,000	<1.07	<0.56
	Alkuvial	14-feb-1991	(D&M)	37,000	NA	NA	3.37	0.64	<0.59	<0.61	<1.15	17.4	2,115	<1.07	<0.56
MW-29	Alkuvial	17-Jun-1988	(WES)	<5,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
	Alkuvial	08-nov-1990	(D&M)	5,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
	Alkuvial	15-feb-1991	(D&M)	4,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
MW-30	Alkuvial	21-Jun-1988	(WES)	5,800	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	0.91	<1.13	<0.66
	Alkuvial	05-nov-1990	(D&M)	9,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
	Alkuvial	14-feb-1991	(D&M)	8,400	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
SB-1	Sh. Basalt	20-Jun-1988	(WES)	<5,000	NA	NA	<0.56	<0.61	2.91	<0.60	<0.55	<1.30	<0.63	<1.13	<0.66
	Sh. Basalt	02-nov-1990	(D&M)	37.5	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	4.81	<1.07	<0.56
	Sh. Basalt	13-feb-1991	(D&M)	<10.0	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
SB-2	Sh. Basalt	17-Jun-1988	(WES)	<5,000	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	2.16	<1.13	<0.66
	Sh. Basalt	04-nov-1990	(D&M)	51.6	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	76	<1.07	<0.56
	Sh. Basalt	19-feb-1991	(D&M)	16.4	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	3.97	10.1	<1.07	<0.56

TABLE 3-2 (cont'd)

Explosive Washout Lagoons
Summary of Groundwater Analytical Results (ug/l)

Site ID	Depth	Date	(Ref.)	NT (a)	NO3	NO2	135TNB	130N8	246TNT	240NT	280NT	HMX	RDX	NB	TETRYL
SB-3	Sh. Basalt	16-jun-1988	(WES)	5,800	NA	NA	<0.56	<0.61	<0.78	<0.60	<0.55	<1.30	0.65	<1.13	<0.66
	Sh. Basalt	04-nov-1990	(D&M)	13,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	8.26	<1.07	<0.56
	Sh. Basalt	19-feb-1991	(D&M)	12,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	5.32	<1.07	<0.56
4-1	Flood Gravel	06-nov-1990	(D&M)	4,800	NA	NA	320	15.7	3,400	340	<1.15	1,300	2,700	13.1	<0.56
4-1	Flood Gravel	19-feb-1991	(D&M)	39,000	NA	NA	441	1.92	2,573	371	<1.15	1,288	2,585	<1.07	<0.56
4-2	Flood Gravel	05-nov-1990	(D&M)	7,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-2	Flood Gravel	19-feb-1991	(D&M)	7,800	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-3	Flood Gravel	04-nov-1990	(D&M)	12,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	120	<1.07	<0.56
4-3	Flood Gravel	20-feb-1991	(D&M)	11,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	112	<1.07	<0.56
4-4	Flood Gravel	04-nov-1990	(D&M)	8,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	36.2	<1.07	<0.56
4-4	Flood Gravel	18-feb-1991	(D&M)	7,100	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	45.9	<1.07	<0.56
4-5	Flood Gravel	02-nov-1990	(D&M)	8,500	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	590	<1.07	<0.56
4-5	Flood Gravel	20-feb-1991	(D&M)	9,300	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	1.93	523	<1.07	<0.56
4-6	Flood Gravel	02-nov-1990	(D&M)	7,500	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	270	<1.07	<0.56
4-6	Flood Gravel	28-feb-1991	(D&M)	7,400	NA	NA	<0.63	<0.52	0.89	<0.61	<1.15	<1.65	411	<1.07	<0.56
4-7	Flood Gravel	04-nov-1990	(D&M)	23,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	510	<1.07	<0.56
4-7	Flood Gravel	20-feb-1991	(D&M)	22,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	558	<1.07	<0.56
4-8	Basalt	16-oct-1990	(D&M)	380	NA	NA	<0.63	<0.52	0.83	1.49	<1.15	10.8	44.8	<1.07	<0.56
4-8	Basalt	28-feb-1991	(D&M)	4,100	NA	NA	39.2	0.85	392	59.9	<1.15	349	646	<1.07	<0.56
4-9	Basalt	21-oct-1990	(D&M)	30,000	NA	NA	<0.63	<0.52	1.67	<0.61	<1.15	1.88	1,100	<1.07	<0.56
4-9	Basalt	01-mar-1991	(D&M)	34,000	NA	NA	0.78	1.01	<0.59	<0.61	<1.15	8.31	5,640	<1.07	<0.56
4-10	Basalt	16-oct-1990	(D&M)	42.5	NA	NA	1.32	<0.52	0.95	<0.61	<1.15	<1.65	27.4	<1.07	<0.56
4-10	Basalt	27-feb-1991	(D&M)	14.7	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	1.86	129	<1.07	<0.56
4-12	Flood Gravel	06-nov-1990	(D&M)	35.3	NA	NA	<0.63	<0.52	1.51	<0.61	<1.15	<1.65	6.6	<1.07	<0.56
4-12	Flood Gravel	20-feb-1991	(D&M)	25.6	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56

TABLE 3-2 (cont'd)

Explosive Washout Lagoons
Summary of Groundwater Analytical Results (ug/l)

Site ID	Depth	Date	(Ref.)	MIT(a)	NO3	NO2	135TNE	130MNB	246TNT	24DNT	280DNT	HMX	RDX	NE	TETRYL
4-13	Flood Gravel	05-nov-1990	(D&M)	34,000	NA	NA	<0.63	<0.52	0.75	0.79	<1.15	8.33	2,400	<1.07	0.78
4-13	Flood Gravel	20-feb-1991	(D&M)	36,000	NA	NA	<0.63	1.04	<0.59	0.77	<1.15	11.16	2,115	<1.07	<0.56
4-14	Flood Gravel	02-nov-1990	(D&M)	71	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	2.74	<1.07	<0.56
4-14	Flood Gravel	26-feb-1991	(D&M)	70	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-15	Flood Gravel	05-nov-1990	(D&M)	135	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-15	Flood Gravel	20-feb-1991	(D&M)	23.3	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-16	Flood Gravel	02-nov-1990	(D&M)	6,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-16	Flood Gravel	26-feb-1991	(D&M)	6,000	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	<1.65	<2.11	<1.07	<0.56
4-17	Basalt	16-oct-1990	(D&M)	<10.0	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	3.33	16.8	<1.07	<0.56
4-17	Basalt	26-feb-1991	(D&M)	26.9	NA	NA	<0.63	<0.52	<0.59	<0.61	<1.15	2.72	98.7	<1.07	<0.56
4-18	Flood Gravel	05-nov-1990	(D&M)	23,000	NA	NA	270	7.84	3,900	430	<1.15	1,400	1,800	15.8	<0.56
4-18	Flood Gravel	27-feb-1991	(D&M)	43,000	NA	NA	257	2.51	3,626	497	<1.15	1,449	2,056	<1.07	<0.56

(a) = Nitrogen as nitrate + nitrite.

ANA= ANA-LAB Corp., Groundwater Monitoring Report: August, 1988; November, 1988.

BAT= Battelle Final Report, 1982, Environmental Contamination Survey and Assessment of Umatilla Army Depot Activity.

CES= Century Environmental Services, Groundwater Monitoring Reports: March, 1986; August, 1986; February, 1987 and August, 1987.

WES= Roy F. Weston, Inc., March 1989, Draft Final Report, Task Order 7, Umatilla Army Depot Activity Remedial Investigation.

D&M= Dames & Moore, current investigation.

NA = Not Analyzed.

Data detected at concentrations greater than the detection limit are highlighted by shading for easy observation.

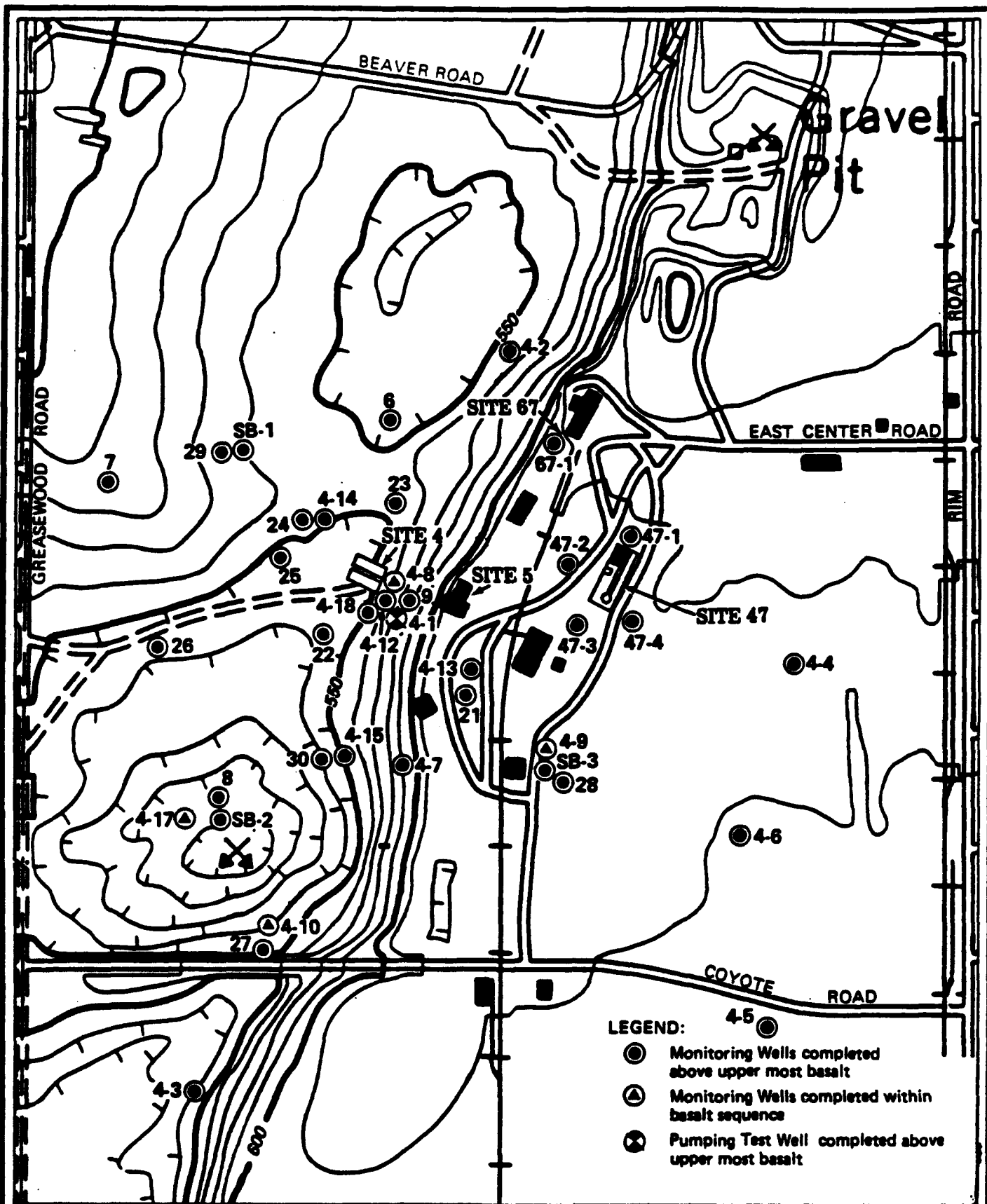


FIGURE 3-5
SITE 4, EXPLOSIVE WASHOUT LAGOONS AND VICINITY
MONITORING WELL LOCATIONS

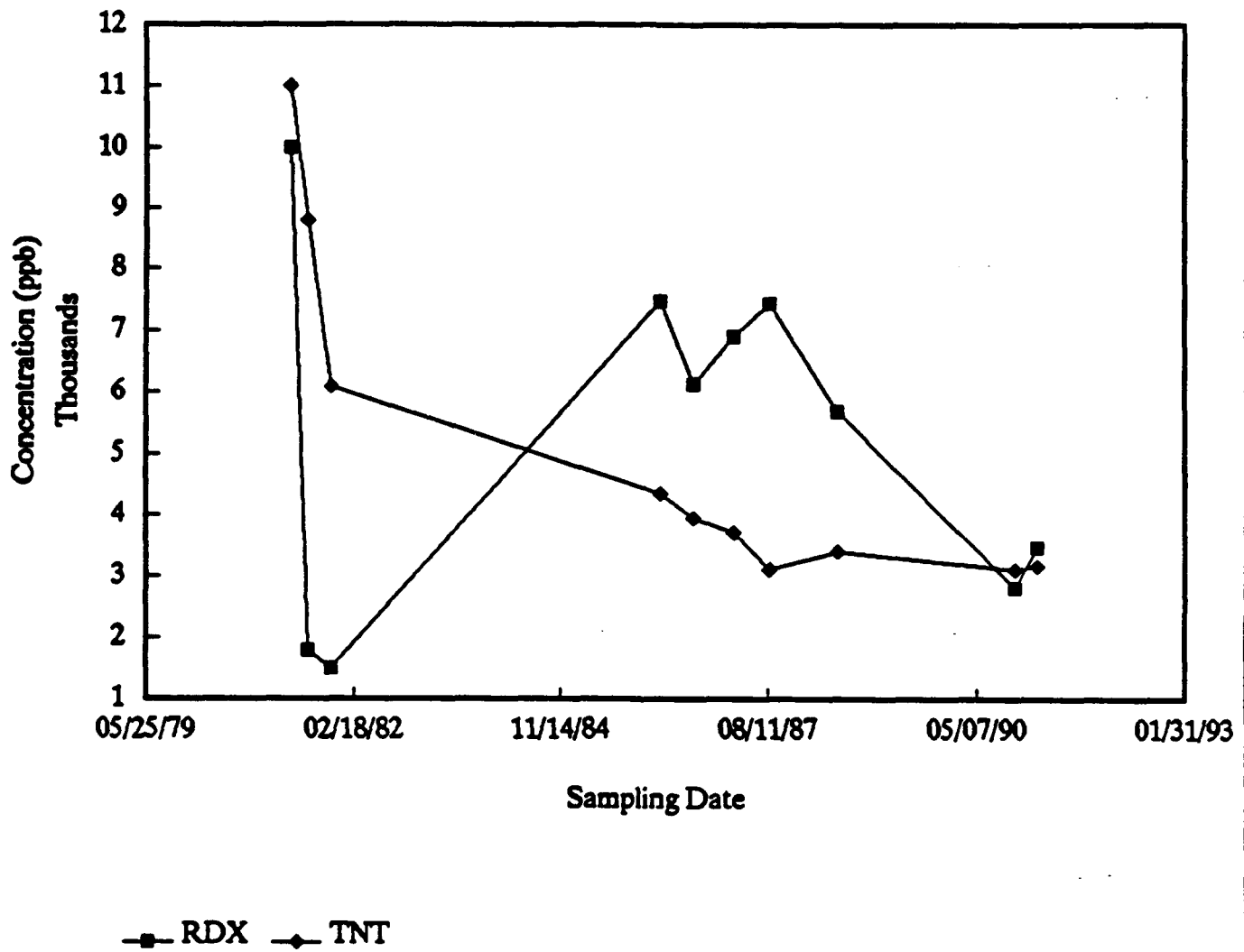
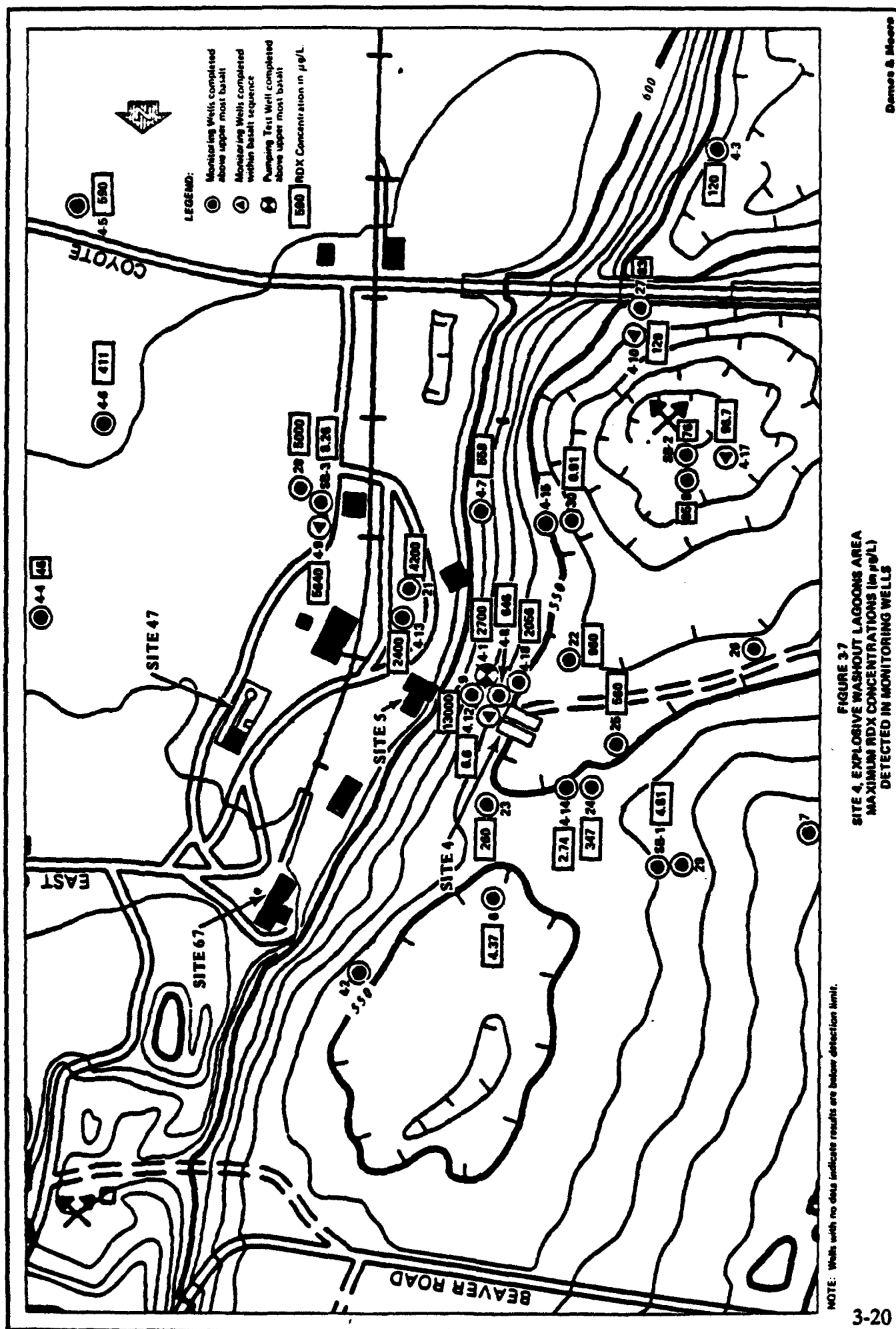


FIGURE 3-6
TIME TRENDS FOR RDX AND TNT CONCENTRATIONS, WELL 9



NOTE: Wells with no data indicate results are below detection limits.

Very low explosives concentrations were detected in each of the three upper basalt zone monitoring wells, installed in 1988 by Weston. Explosives contamination was also detected in the four basalt monitoring wells (4-8, 4-9, 4-10, and 4-17) installed in 1990 by Dames & Moore. These data indicate that the deep basalt aquifer may be hydraulically connected to the upper zones.

3.3 CORRELATION BETWEEN SOIL AND GROUNDWATER DATA

There is no obvious correlation between soil and groundwater contamination at the Explosive Washout Lagoons area. However, the following observations can be made:

- Based on Weston results, wells 9, 4-1, and 4-18, southeast of the lagoons, are the most heavily contaminated groundwater wells, though previous hydrologic studies indicated that groundwater flow was predominantly to the northwest. Soil samples collected within and west of the lagoons were the most heavily contaminated.
- Comparison of chemical data from borings EWL-1, EWL-3, and S4-6 to alluvial well 9 suggests that explosives contamination in the deep boring samples may be influenced by contaminants in groundwater. Contaminant concentrations in the boring samples collected nearest to the water table were higher than in soil samples collected at depths of 10 feet above the water table.
- HMX, RDX, and 2,4,6-TNT are the explosives contaminants most frequently found in the soil and groundwater samples. 2,4,6-TNT and RDX were detected at the highest concentrations in groundwater. 2,4,6-TNT was detected at the highest concentrations in soil.
- Perhaps the most striking observation is the general lack of correlation between soil and groundwater data. 2,4,6-TNT is present in soil at much higher concentrations than any other explosives contaminants. However, 2,4,6-TNT in groundwater--though present in high concentrations in

monitoring wells close to the lagoons--is not well distributed. RDX, on the other hand, is widely distributed in groundwater, with a well-developed plume. In soil, RDX is quite widespread but is found at concentrations considerably less than 2,4,6-TNT. Therefore, the existing chemical data suggest that groundwater contamination may have resulted from processes independent of soil leaching. This is discussed in more detail in Section 8.4.2.

4.0 IDENTIFICATION OF POTENTIAL CONTAMINANTS OF CONCERN

4.1 SELECTION OF POTENTIAL CONTAMINANTS OF CONCERN

The potential contaminants of concern for Site 4 are presented in Table 4-1. The contaminants listed are all explosives detected in at least one sample considered acceptable for use in this study from the media of concern. As discussed in Section 1.1, this RA focuses on potential future health risks posed by explosives-contaminated soils associated with Site 4. Therefore, only explosives are considered as potential contaminants of concern in this report. However, all data will be discussed in the installation-wide Baseline RA, and the potential risks associated with exposure to other potential contaminants of concern will be evaluated.

Not all data from Tables 3-1 and 3-2 are considered acceptable for use in this investigation. Data collected from soil samples by Battelle are excluded from consideration in the RA because the locations of the samples are unknown, and because the USATHAMA quality assurance/quality control (QA/QC) criteria have changed significantly since 1981. Likewise, for groundwater, only the Roy F. Weston, Inc. (1989) and Dames & Moore data are considered acceptable for consideration in the RA because they were collected in accordance with recent USATHAMA QA/QC procedures.

4.2 CONSTITUENTS EXCLUDED FROM CONTAMINANTS OF CONCERN

4.2.1 Soil

2,6-DNT and tetryl were not detected in any soil sample considered acceptable for use in this investigation and, therefore, were excluded as potential contaminants of concern at Site 4. In addition, tetryl and 2,6-DNT were detected in only one soil sample (S-51) collected during the Battelle investigation, at low concentrations (12 $\mu\text{g/g}$ and 5.4 $\mu\text{g/g}$, respectively). Nitrogen (as nitrate + nitrite) was the only nonexplosives analyte included in Site 4 soil samples. It was not included as a potential contaminant of concern because the focus of the RA is on explosives;

TABLE 4-1

**Potential Contaminants of Concern in Soil and Groundwater
at the Explosive Washout Lagoons (Site 4), UMDA**

<u>Soil</u>	<u>Groundwater</u>
1,3,5-TNB	1,3,5-TNB
1,3-DNB	1,3-DNB
2,4,6-TNT	2,4,6-TNT
2,4-DNT	2,4-DNT
HMX	2,6-DNT
NB	HMX
RDX	NB
	RDX
	Tetryl

however, the potential risks associated with exposure to nitrate and nitrite will be evaluated in the installation-wide Baseline RA.

4.2.2 Groundwater

All explosives detected in groundwater during either the Weston or Dames & Moore investigations were selected as potential contaminants of concern. These include all nine analyzed explosives. Nitrogen, analyzed as nitrate + nitrite or as the individual anions, was not included as a potential contaminant of concern for the reason cited in Section 4.1.

5.0 EXPOSURE ASSESSMENT

The purpose of the exposure assessment is to identify potential human receptors, identify and evaluate potential current and future exposure pathways, and determine the extent of exposure or intake of contaminants under site-specific current and future land use scenarios.

5.1 LAND USE SCENARIOS

5.1.1 Current Land Use

Although potential receptors such as UMDA security personnel, base trespassers, and sampling crews could potentially be exposed to contamination at Site 4, for the purpose of this RA, the current exposure of these receptors to contaminants present at Site 4 is considered to be minimal. Therefore, this issue is not discussed further. Because of the potential excessing of UMDA properties under the U.S. Department of Defense (DOD) Base Realignment and Closure (BRAC) Program, it is assumed that future land uses would present much greater potential exposure to receptors than current land uses.

5.1.2 Future Land Use

In the future, potential land use at Site 4 may include a mix of residential, industrial, military, agricultural, and recreational uses. Potential receptors could include children, farmers, military personnel, hunters, and factory workers, for example. For purposes of this RA, three basic future land use scenarios are evaluated--residential use (conservative scenario), military use (most probable scenario), and light industrial use. These land use scenarios and associated exposure pathways are discussed in Section 5.2.

5.2 EXPOSURE PATHWAY ANALYSIS

5.2.1 Identification of Exposure Pathways

For each of the three basic future land use scenarios identified in Section 5.1, the possibility that exposure may occur by any of the following four primary exposure pathways is evaluated:

- Incidental ingestion of soil
- Dust inhalation
- Dermal contact with soil
- Groundwater ingestion.

Although exposure by other pathways--such as ingestion of game or livestock that may forage on vegetation growing in contaminated soil--is possible, the potential magnitude of such indirect exposure is low when compared to direct exposure by inhalation, ingestion, and dermal absorption. As discussed in Appendix A, which presents the environmental fate of explosives contaminants and their degradation products, the bioaccumulation of TNT (which is the predominant soil contaminant) from soil by plants does not appear to be significant (Simmers, 1991). In addition, bioaccumulation (via ingestion) is expected to be minor or negligible for terrestrial organisms that may come into contact with soil or sediment to which the explosives are adsorbed. Trabalka and Garten (1982) have reported that chemicals with $\log K_{ow}$ values of less than 3.5 do not accumulate in mammals or fish. The values for $\log K_{ow}$ of the explosives are all less than 3.5 (see Appendix A), indicating that they are not expected to accumulate in animal receptors. Therefore, such indirect exposure pathways are excluded from the present assessment.

5.2.2 Quantification of Exposure

Tables 5-1, 5-2, 5-3, and 5-4 summarize the quantitative details necessary to calculate estimated intake of contaminants by each of the four exposure pathways for each of the three future land use scenarios. These tables provide the intake formulas, definition of the parameters within the intake formulas, and specific assumptions used

TABLE 5-1

Quantitative Summary of Soil Ingestion Exposure Pathway

Description:	Ingestion of contaminated soil by children and adults.
Exposure Point Concentration:	95 percent upper confidence limit on the arithmetic mean chemical concentration.
Intake Formula:	$\text{Intake} = \frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT}$
Parameter Definitions and Units:	Intake in (mg/kg-day) CS = Exposure point chemical concentration in soil (mg/kg) IR = Ingestion rate (mg soil/day) CF = Conversion factor (kg/mg) FI = Fraction ingested from contaminated source (unitless) EF = Exposure frequency (days/year) ED = Exposure duration (years) BW = Body weight (kg) AT = Averaging time (days)
Assumptions:	
Residential:	IR = 100 mg/day for adults and 6-16 year olds (USEPA, 1990b) = 200 mg/day for 0-6 year olds (USEPA, 1990b) CF = $1E-06$ kg/mg FI = 1.0 EF = 62 days/yr, adult; 365 days/yr, 0-6 yrs; 164 days/yr, 6-16 yrs (USEPA, 1990b) ED = 67 years for adults; 3 years for each childhood age period (USEPA, 1990b) BW = 70 kg, adult; 12 kg, 0-3 yrs; 17 kg, 3-6 yrs; 25 kg, 6-9 yrs; 36 kg, 9-12 yrs; 51 kg, 12-15 yrs; 61 kg, 15-18 yrs (USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1990g; 1990b) = ED years x 365 days/year = 20,805 days for adults (noncarcinogens; USEPA, 1990g) = 1,095 days for each childhood age period (USEPA, 1990b)
Light Industrial:	IR = 100 mg/day (USEPA, 1990b) CF = $1E-06$ kg/mg FI = 0.44 EF = 300 days/yr (for an overall exposure frequency ($FI \times (EF/365)$) of 0.38; USEPA, 1990b; 1991d) ED = 40 years (USEPA, 1990b) BW = 70 kg (USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1990g; 1990b) = ED (40 years) x 365 days/year = 14,600 days for adults (noncarcinogens; USEPA, 1990g)
Military Land Use:	IR = 100 mg/day (USEPA, 1990b) CF = $1E-06$ kg/mg FI = 1 hr/8 hrs (site specific estimate) = 0.125 EF = 280 days/yr (USEPA, 1991c) ED = 3 years BW = 75 kg (USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1990g; 1990b) = ED years x 365 days/year = 1,095 days (noncarcinogens; USEPA, 1990g)
Sample Calculation:	
Residential Adult:	$\text{Intake} = \frac{CS \text{ (mg/kg)} \times 100 \text{ (mg/day)} \times 1E-06 \text{ (kg/mg)} \times 1.0 \times 62 \text{ (days/yr)} \times 67 \text{ (yr)}}{70 \text{ (kg)} \times 27,375 \text{ (or } 20,805) \text{ (days)}}$ = CS x $1.56E-07$ (carcinogens) = CS x $2.04E-07$ (noncarcinogens)

TABLE 5-2

Quantitative Summary of Dust Inhalation Exposure Pathway

Description:	Inhalation of contaminated soil as dust.
Exposure Point Concentration:	Determined by analytical model.
Intake Formula:	$\text{Intake} = \frac{\text{CA} \times \text{IR} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{CF}}$
Parameter Definitions and Units:	Intake in (mg/kg-day) CA = Contaminant concentration in air (pg/m³) IR = Inhalation rate (m³/hr) ET = Exposure time (hr/day) EF = Exposure frequency (days/year) ED = Exposure duration (years) BW = Body weight (kg) AT = Averaging time (days) CF = Conversion factor (pg/mg)
Assumptions:	
Residential:	IR = 1.25 m³/hr (USEPA, 1990b) CF = 1E+09 pg/mg ET = 24 hr/day (USEPA, 1990b) EF = 365 days/yr (USEPA, 1990b) ED = 75 years (USEPA, 1990b) BW = 70 kg (adult; USEPA, 1990b) AT = 75 years x 365 days/yr = 27,375 days (USEPA, 1990g; 1990b)
Light Industrial:	IR = 3.3 m³/hr (USEPA, 1990b) CF = 1E+09 pg/mg ET = 10 hr/day (USEPA, 1991d) EF = 300 days/yr (for an overall exposure frequency ((ET/24) x (EF/365)) of approximately 30%; USEPA, 1990b; 1991d) ED = 40 years (USEPA, 1990b) BW = 70 kg (adult; USEPA, 1990b) AT = 75 years x 365 days/yr = 27,375 days (carcinogens; USEPA, 1990g; 1990b) = 40 years x 365 days/yr = 14,600 days (noncarcinogens; USEPA, 1990g)
Military Land Use:	IR = 1.25 m³/hr (USEPA, 1990b) CF = 1E+09 pg/mg ET = 8 hr/day EF = 250 days/yr (USEPA, 1991c) ED = 3 years BW = 75 kg (USEPA, 1990b) AT = 75 years x 365 days/yr = 27,375 days (carcinogens; USEPA, 1990g; 1990b) = 3 years x 365 days/yr = 1,095 days (noncarcinogens; USEPA, 1990g)
Sample Calculation:	
Residential:	$\text{Intake} = \frac{\text{CA} \times 1.25 \text{ (m}^3\text{/hr)} \times 24 \text{ (hr/day)} \times 365 \text{ (days/yr)} \times 75 \text{ (yrs)}}{70 \text{ (kg)} \times 27,375 \text{ (days)} \times 1\text{E}+09 \text{ (pg/mg)}}$ $= \text{CA} \times 4.3\text{E}-10$

TABLE 5-3

Quantitative Summary of Dermal Contact With Soil Exposure Pathway

Description:	Absorption of contaminants following dermal contact with soil.
Exposure Point Concentration:	95 percent upper confidence limit on the arithmetic mean chemical concentration.
Intake Formula:	$\text{Absorbed dose} = \frac{\text{CS} \times \text{CF} \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{FC} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$
Parameter Definitions and Units:	Absorbed dose (mg/kg-day) CS = Exposure point chemical concentration in soil (mg/kg) CF = Conversion factor (kg/mg) SA = Skin surface area available for contact (cm²/day) AF = Soil to skin adherence factor (mg/cm²) ABS = Absorption factor (ratio of dermal absorption to oral absorption; unitless) FC = Fraction of soil in contact with skin from the contaminated source (unitless) EF = Exposure frequency (days/year) ED = Exposure duration (years) BW = Body weight (kg) AT = Averaging time (days)
Assumptions	
Residential:	CF = 1E-06 kg/mg SA = 3,000 cm²/day, adult; 1,100 cm²/day, 0-3 yrs; 1,400 cm²/day, 3-6 yrs; 1,700 cm²/day, 6-9 yrs; 2,100 cm²/day, 9-12 yrs; 2,700 cm²/yr 12-15 yrs; and 3,500 cm²/day, 15-18 yrs (USEPA, 1990b) AF = 0.90 mg/cm² (USEPA, 1990b) ABS = chemical specific; assumed to be 0.5 for all explosives except RDX (USEPA, 1991d); RDX is not quantitatively evaluated because of insufficient evidence of dermal absorption (USEPA, 1991d). FC = 1.0 EF = 52 days/yr, adult; 365 days/yr, 0-6 yrs; 154 days/yr, 6-18 yrs (USEPA, 1990b) ED = 57 years for adults; 3 years for each childhood age period (USEPA, 1990b) BW = 70 kg, adult; 12 kg, 0-3 yrs; 17 kg, 3-6 years; 25 kg, 6-9 yrs; 36 kg, 9-12 yrs; 51 kg, 12-15 yrs; 61 kg, 15-18 yrs (USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1989g; 1990b) = ED years x 365 days/year = 20,805 days for adults (noncarcinogens; USEPA, 1989g) = 1,095 days for each childhood age period (USEPA, 1990b)
Light Industrial:	CF = 1E-06 kg/mg SA = 3,000 cm²/day, adult (USEPA, 1990b) AF = 0.9 mg/cm² (USEPA, 1990b) ABS = chemical specific (see residential scenario) FC = 0.44 EF = 300 days/yr, adult (for an overall exposure frequency (FC x (EF/365)) of 38%; USEPA, 1990b; 1991d) ED = 40 years (USEPA, 1990b) BW = 70 kg, adult (USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1989g; 1990b) = ED years x 365 days/year = 14,600 days for adults (noncarcinogens; USEPA, 1989g)
Military:	CF = 1E-06 kg/mg SA = 3,000 cm²/day, adult (USEPA, 1990b) AF = 0.9 mg/cm² (USEPA, 1990b) ABS = chemical specific (see residential scenario) FC = 1 hr/8 hr (site specific) = 0.125 EF = 250 days/yr, adult (USEPA, 1991c) ED = 3 years BW = 75 kg (USEPA, 1989b) AT = 75 years x 365 days/year = 27,375 days (carcinogens; USEPA, 1989g; 1990b) = ED years x 365 days/year = 1095 days for adults (noncarcinogens; USEPA, 1989g)

TABLE 5-3 (cont'd)

Quantitative Summary of Dermal Contact With Soil Exposure Pathway

Sample Calculation:

Residential Adult:

$$\text{Absorbed dose} = \frac{\text{CS (mg/kg)} \times 1\text{E-06 (kg/mg)} \times 6,200 \text{ (cm}^2\text{/day)} \times 0.90 \text{ (mg/cm}^2\text{)} \times \text{ABS} \times 1.0 \times 32 \text{ (days/yr)} \times 57 \text{ (yrs)}}{70 \text{ (kg)} \times 27,378 \text{ (or 20,800) (days)}}$$

$$= \text{CS} \times \text{ABS} \times 4.2\text{E-06 (carcinogens)}$$

$$= \text{CS} \times \text{ABS} \times 5.6\text{E-06 (noncarcinogens)}$$

TABLE 5-4

Quantitative Summary of Groundwater Ingestion Exposure Pathway

Description:	Ingestion of contaminated groundwater.
Exposure Point Concentration:	95 percent upper confidence limit on the arithmetic average chemical concentration.
Intake Formula:	$\text{Intake} = \frac{\text{CW} \times \text{IR} \times \text{EF} \times \text{ED} \times \text{FI}}{\text{BW} \times \text{AT}}$
Parameter Definitions and Units:	Intake in (mg/kg-day) CW = Exposure point chemical concentration in water (mg/l) IR = Ingestion rate (l/day) EF = Exposure frequency (days/year) ED = Exposure duration (years) FI = Fraction ingested from contaminated source (unitless) BW = Body weight (kg) AT = Averaging time (days)
Assumptions:	
Residential:	IR = 2 l/day (USEPA, 1990b) EF = 365 days/year (USEPA, 1990b) ED = 75 years (USEPA, 1990b) FI = 1.0 BW = 70 kg (adult; USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (USEPA, 1989g; 1990b)
Light Industrial:	IR = 2 l/day (USEPA, 1990b) FI = 0.7 (USEPA, 1991d) EF = 300 days/year (for an overall exposure frequency (FI x (EF/365)) of 60%; USEPA, 1990b; 1991d) ED = 40 years (USEPA, 1990b) BW = 70 kg (adult; USEPA, 1990b) AT = 75 years x 365 days/year = 27,375 days (USEPA, 1989g; 1990b) = 40 years x 365 days/year = 14,600 days (USEPA, 1989g)
Sample Calculation:	
Residential:	Intake = $\frac{\text{CW (mg/l)} \times 2 \text{ (l/day)} \times 365 \text{ (days/year)} \times 75 \text{ (yrs)}}{70 \text{ (kg)} \times 27,375 \text{ (days)}}$ = CW (mg/l) x 2.86E-02

for the parameters for each exposure scenario. One parameter common to all of the exposure pathways and land use scenarios--shown in Tables 5-1, 5-2, 5-3, and 5-4--is the averaging time (AT). The averaging time selected depends on the type of toxic effect being assessed. When evaluating noncarcinogenic contaminants, intakes are calculated by averaging the intake over the period of exposure. For carcinogens, intakes are calculated by averaging over a lifetime. This distinction between carcinogens and noncarcinogens relates to the currently held scientific opinion that--for carcinogens--a higher dose over a shorter exposure time is equivalent to a corresponding low dose spread over a lifetime (USEPA, 1989g).

5.2.2.1 Soil Ingestion Exposure Pathway. This exposure pathway (see Table 5-1) requires direct contact with contaminated soil onto hands, or onto lips as dust, followed by inadvertent hand-to-mouth contact or licking of lips. The intake of the various contaminants of concern is estimated by relating the measured contaminant concentrations in surface soil to the estimated soil ingestion rate (IR), modified by the other parameters in the intake formula. The soil concentration of the contaminants of concern (CS) for all three land use scenarios is determined by the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep) from Site 4. (Nondetects are replaced with detection level for calculating exposure point concentrations.)

The TNT, RDX, and HMX exposure point concentrations are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1989 by Roy F. Weston, Inc., and are considered "maximum" concentrations. Although 1,3-DNB and NB were not detected in surface soil samples (samples less than 2 feet deep) from Site 4, because these compounds were detected in several deeper soil samples, the surface soil concentrations will conservatively be assumed to be one-half of the detection limits. The exposure point concentrations for 1,3,5-TNB and 2,4-DNT are based on eight surface soil samples collected from the berms (S4-1 to S4-8) outside the lagoons, because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are

conservatively assumed to be the the exposure point soils concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

Under the residential land use scenario, it is assumed that receptors live in the immediate vicinity of the site and are exposed to contaminated soil by ingestion for an entire 75-year lifetime. The assumptions used for this scenario are the EPA Region X's "reasonable maximum exposure" (RME) residential values (USEPA, 1990c). The soil IR is an average, constant rate determined by tracer studies for different age groups and is assumed to be applicable for all receptor activities. The FI term (fraction ingested from contaminated source) accounts for the proportion of the IR that is source-related versus that which is nonsource-related (i.e., a ratio of "dirty" soil to total ("dirty" + "clean") soil ingested). For the residential land use scenario, it is assumed that all ingested dirt is source-related; thus, an FI of 1.0 was used.

The light industrial land use scenario is less conservative than the residential scenario and may be considered to be a more realistic estimate of future exposure at the site. In this scenario, the workplace is assumed to be near the site and adults are the only receptors. The exposure assumptions used for this scenario are the EPA Region X's RME industrial values (see Table 5-1; USEPA, 1990c). The IR used is for adults who work outside some portion of the workday. The time terms (EF and ED) are reduced from the residential land use scenario, because one does not work every day of the year and a working career is less than a lifetime. EF is assumed to be 300 days/year (6 days/week for 50 weeks/year) and a career is assumed to be 40 years (USEPA, 1990c). An FI term of 0.44 is used in this scenario, resulting in an overall exposure frequency $((EF/365) \times FI)$ of approximately 36 percent (USEPA, 1991d).

The most probable future military land use scenario is for members of the National Guard, who may use the area for laser range finding training with tanks. It is similar to the light industrial land use scenario, except that the National Guard stint (and thus ED) is assumed to be 3 years; the FI term is used to account for actual

estimated exposure to contaminants of concern at the site (USEPA, 1989g), which is assumed to be 1 hour/workday (0.125); the EF is assumed to be 250 days/year (USEPA, 1991c); and the body weight is assumed to be slightly greater to account for young, primarily male, military personnel (USEPA, 1989b).

5.2.2.2 Dust Inhalation Exposure Pathway. This exposure pathway (see Table 5-2) is used to estimate the intake of contaminants in soil by breathing air in which contaminant-bearing soil particles are suspended as dust. The intake of contaminants of concern is estimated by relating modeled concentrations of contaminants in air (CA) at various exposure points and an assumed inhalation rate (IR) of receptors, modified by the other parameters in the intake formula. The emission of soil from Site 4 as wind-eroded dust, and the dispersion of the dust downwind, is estimated using analytical models as explained in detail in Appendix B. The input data for contaminant concentrations in soil to be eroded in the model are the exposure point concentrations that were calculated using the same samples and procedures as indicated in Section 5.2.2.1 for the soil ingestion pathway.

EPA Region X RME exposure assumptions are used under the residential land use scenario (USEPA, 1990c). It is assumed for this exposure pathway that only adult receptors are in proximity to the site for their entire lifetime (24 hours/day, 365 days/week for 75 years), inhaling contaminated dust that has been eroded from the surface soil. Exposure by children is not accounted for separately because, unlike soil ingestion, the uptake rate (or IR in both exposure pathways) is directly proportional to body weight rather than inversely proportional. Thus, exposure by inhalation is not a strong function of the age of the receptor.

The light industrial land use scenario (based on occupational exposure) includes the assumptions of only adult receptors, a greater inhalation rate (3.3 m³/hr), and shorter durations for the exposure time parameters (ET, EF, and ED) than are used for residential exposure. The Region X RME industrial values were used for these parameters (USEPA, 1990c; 1991d).

The most probable military land use scenario, for members of the National Guard, uses the same assumptions as the residential land use scenario, with the exception of the exposure time parameters (ET, EF, and ED) and body weight assumptions.

5.2.2.3 Dermal Contact With Soil Exposure Pathway. This exposure pathway (see Table 5-3) is used to estimate the intake of contaminants in soil resulting from direct contact and subsequent absorption of contaminants. The absorbed dose of the various contaminants of concern is estimated by relating the measured contaminant concentrations in soil to the rates of human dermal contact with soil (skin surface area available for contact (SA)) and soil-to-skin adherence factor (AF), modified by consideration of the chemical-specific soil absorption factor (ABS) (see Section 6.2), fraction of soil in contact with skin from the contaminated source (FC), EF, ED, AT, and BW. The chemical-specific soil absorption factor is used to reflect the degree to which the desorption of the chemical from soil and the adsorption of the chemical across the skin and into the blood stream occurs (USEPA, 1989g). Because only limited data are available on absorption factors for explosives, dermal absorption for all explosives except RDX is assumed to be 50 percent and oral absorption is assumed to be 100 percent (USEPA, 1991d). (Oral absorption is also an important factor to consider, because the exposure pathway equation in Table 5-3 produces an absorbed dose and the toxicity values to which it is compared (see Section 6.0) are generally based on administered dose. Therefore, to match the exposure estimate with the toxicity values, the values must be adjusted if the oral absorption is less than 100 percent (USEPA, 1989g).) RDX is not quantitatively evaluated because of insufficient evidence of dermal absorption in humans and limited evidence of very low absorption efficiency in animals (McNamara et al., 1974; USEPA, 1991d). The soil concentrations for the contaminants of concern (CS) were calculated using the same samples and procedures as indicated in Section 5.2.2.1 for the soil ingestion pathway.

Under the residential land use scenario, EPA Region X RME exposure assumptions are used (USEPA, 1990c). It is assumed that receptors live in the vicinity

of the site and are exposed to contaminated soil by ingestion for an entire lifetime. Because the skin surface area available for contact (SA), EF, and BW are age dependent, risks for children are calculated separately from adults. An FC of 1.0 is assumed for the residential land use scenario.

The light industrial land use scenario (based on occupational exposure) includes the assumptions of only adult receptors and shorter durations for the exposure time parameters (ET, EF, and ED) than are used for residential exposure. The Region X RME industrial values were used for these parameters (USEPA, 1990c; 1991d). An FC term of 0.44 is used in this scenario, resulting in an overall exposure frequency $((EF/365) \times FI)$ of approximately 36 percent (USEPA, 1991d).

The most probable military land use scenario, for members of the National Guard, uses the same assumptions as the residential land use scenario, with the exception of the exposure time parameters (ET, EF, and ED) and body weight assumptions. An FC term of 1 hour/workday (0.125) is assumed to account for the fact that only a portion of the receptors' time would be expected to actually be spent at the site.

5.2.2.4 Groundwater Ingestion Exposure Pathway. This exposure pathway (see Table 5-4) is used to estimate the intake of contaminants present in groundwater by ingestion. Although it is unlikely that drinking water wells will be installed in the contaminated aquifer in the future, for the purposes of this RA, it is assumed that drinking water wells will be installed in the contaminated aquifer proximate to Site 4 (i.e., at a location somewhere within the plume). (The chemical data suggest that the groundwater flow direction is southerly, while the hydrogeologic data primarily indicate flow to the northwest. As a result, groundwater flow direction specific receptor locations were not selected for determination of exposure point locations. Instead, the more general case of "proximate to Site 4" was assumed.) The exposure point concentration (CW) is estimated by using the 95 percent upper confidence limit on the arithmetic mean of the groundwater chemical data collected by Weston and

Dames & Moore. Some of this data is for samples collected by Weston and Dames & Moore from monitoring wells previously installed by Battelle.

The exposure assumptions for both the residential and light industrial land use scenarios are shown in Table 5-3. The Region X RME residential and industrial values were used for these parameters, respectively (USEPA, 1990c; 1991d). The only different assumptions between the residential scenario and the light industrial land use scenario are the EF, ED, and FI (USEPA, 1990c; 1991d). These differences reflect the fact that occupational exposure will be less frequent and over a shorter duration than residential exposure. Children are not included as potential receptors for this exposure pathway, because the intake of contaminants by groundwater ingestion is not strongly age dependent.

Groundwater ingestion is not considered for the most probable military land use scenario, because it is assumed that--because there are currently no drinking water wells present near the site--the Army would not be likely to install any in the future.

6.0 TOXICITY ASSESSMENT

6.1 QUANTITATIVE TOXICITY ASSESSMENT

The health effects criteria (slope factors (SF) for carcinogenic effects and RfDs for noncarcinogenic effects) for the potential contaminants of concern are presented in Table 6-1. Also presented in this table are the weight of evidence classification and type of cancer(s) for chemicals with SFs, and the confidence level, critical effect(s), and uncertainty factors for chemicals with RfDs. SFs and RfDs are human health-based criteria developed on the basis of data from ongoing toxicological studies. The SF is the slope of the dose-response curve for carcinogenic compounds. It is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a potential carcinogen. RfDs for noncarcinogenic effects are equivalent to the point along the dose-response curve above which a toxic effect of exposure is first observed, as modified by the application of uncertainty factors intended to account for unknown quantities such as cross-species variability, human population variability, and less-than-lifetime duration of the laboratory animal experiments used to test the toxicity of the chemical in question.

Although EPA develops health effects criteria for exposure by oral and inhalation routes, for the explosives contaminants of concern at Site 4 health effects criteria have been developed only for exposure by the oral route. Therefore, in this RA, the health effects criteria for oral exposure will be used for exposure by both oral and inhalation routes. For exposure by the dermal route, oral and dermal absorption data were reviewed by the EPA Office of Research and Development, Environmental Criteria and Assessment Office, to facilitate oral-to-dermal extrapolations for toxicity values for the contaminants of concern. The ratio of dermal absorption to oral absorption can be used to adjust the oral dose to an equivalent dermal dose. Available oral and dermal absorption factors provided by EPA (USEPA, 1991b) are presented in Tables 6-2 and 6-3, respectively. Because only limited data are available on absorption factors for explosives, dermal absorption of all explosives except RDX is assumed to be 50 percent and oral absorption is assumed to be 100 percent

TABLE 6-1

**Health Effects Criteria for Contaminants of Concern
Explosive Washout Lagoons (Site 4), UMDA**

Contaminant of Concern	Slope Factor $\frac{\text{mg/kg-day}}{\text{mg/kg-day}}$	Weight of Evidence Classification	Source	Cancer Type	Reference		Critical Effect	Uncertainty Factor	Confidence Level
					Dose $\frac{\text{mg/kg-day}}$	Source			
1,3,5-Trinitrobenzene					5.00E-05	IRIS	Increased splenic weight	10,000	low
1,3-Dinitrobenzene					1.00E-04	IRIS	Increased splenic weight	3,000	low
2,4,6-Trinitrotoluene	0.030	C	IRIS	urinary bladder papillomas	5.00E-04	IRIS	liver effects	1,000	medium
2,4-Dinitrotoluene	0.060	B2	HEAST	liver, mammary gland	2.00E-03	Brower, 1992	neurotoxicity and biliary tract hyperplasia	100	NA
2,6-Dinitrotoluene	0.060	B2	HEAST	(a)	1.00E-03	USEPA, 1991a	liver, kidney, neurological, reproductive and hematological effects	3,000	low
HMX					5.00E-02	IRIS	hepatic lesions	1,000	low
Nitrobenzene					5.00E-04	IRIS	hematologic, adrenal, renal, and hepatic lesions	10,000	low
RDX	0.110	C	HEAST	hepatocellular carcinomas and adenomas	3.00E-03	IRIS	Inflammation of prostate	100	high
Tetryl					1.00E-02	USEPA, 1990a	hematological and histological effects	10,000	low

Sources: IRIS - Integrated Risk Information System, January, 1991.

(a) - Based on potential carcinogenicity of 2,4-DNT.

NA - Not available.

TABLE 6-2

**Oral Absorption Factors for Contaminants of Concern
Explosive Washout Lagoons (Site 4), UMDA**

CHEMICAL	EPA DOCUMENTS	ATSDR PROFILES (1989)
Dinitrotoluenes (DNTs): 2,4-DNT; 2,6-DNT; 2,4/2,6-DNT mixture (technical grade DNT)	U.S. EPA, 1987: Animals: 60-90% for various DNTs with 2,4-DNT absorbed more readily than 2,6-DNT. 8-12% for 2,4-DNT in mice. 75-85% for 2,4-DNT in rats, rabbits, dogs, and monkeys.	Animals: Based on urinary excretion data: Absorption was at least 55-90% for DNTs in rats, rabbits, beagle dogs, and rhesus monkeys; at least 50% for 2,6-DNT in mice; at least 10% for 2,4-DNT in mice.
HMX	No EPA documents.	No ATSDR profile for this chemical.
RDX	U.S. EPA, 1989a: Animals: Almost completely absorbed in rats.	No ATSDR profile for this chemical.
Trinitrobenzene	U.S. EPA, 1989b: No quantitative data. Some absorption is inferred based on oral LD50 values.	No ATSDR profile for this chemical.
TNT (2,4,6-Trinitrotoluene)	U.S. EPA, 1990: Animals: Absorption in several species ranges from at least 42% to at least 74% (based on urinary excretion data). U.S. EPA 1989c: Animals: Absorption in several species ranges from at least 45% to at least 82% (based on urinary excretion and tissue levels).	No ATSDR profile for this chemical.

REFERENCES:

ATSDR. 1989. Toxicological Profile for 2,4- and 2,6-Dinitrotoluene. Agency for Toxic Substances and Disease Registry. U.S. Public Health Service. Atlanta, GA.

U.S. EPA. 1987. Health Effects Assessment for 2,4- and 2,6-Dinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Emergency and Remedial Response, Washington, DC.

U.S. EPA. 1989a. Health and Environmental Effects Document for RDX Cyclonite. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1989b. Health and Environmental Effects Document for 1,3,5-Trinitrobenzene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1989c. Trinitrotoluene. Health Advisory. Office of Drinking Water, Washington DC.

U.S. EPA. 1990. Health and Environmental Effects Document for 2,4,6-Trinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

Source: USEPA, 1991b.

TABLE 6-3

**Dermal Absorption Factors for Contaminants of Concern
Explosive Washout Lagoons (Site 4), UMDA**

CHEMICAL	EPA DOCUMENTS	ATSDR PROFILES (1989)
Dinitrotoluenes (DNTs): 2,4-DNT; 2,6-DNT; 2,4/2,6-DNT mixture (technical grade DNT)	U.S. EPA, 1986: Limited data suggest that 2,4-DNT is readily absorbed through the skin, but the extent of absorption has not been reported.	Two studies of occupational exposure to 2,4/2,6-DNT mixture have suggested that dermal absorption can be a significant route of entry for these isomers in humans.
MX	No EPA documents.	No ATSDR profile for this chemical.
RDX	U.S. EPA, 1989a: Not absorbed through the skin. Further information or documentation was not provided.	No ATSDR profile for this chemical.
Trinitrobenzene	U.S. EPA, 1989b: No data. No other EPA documents.	No ATSDR profiles for this chemical.
Trinitrotoluene	U.S. EPA, 1990: Animals: Absorption of 16-18% in the dog, 23-25% in the rat, 42% in the mouse and 57-68% in the rabbit. U.S. EPA 1989c: Animals: Same as U.S. EPA, 1990.	No ATSDR profile for this chemical.

REFERENCES:

ATSDR. 1989. Toxicological Profile for 2,4- and 2,6-Dinitrotoluene. Agency for Toxic Substances and Disease Registry. U.S. Public Health Service. Atlanta, GA.

U.S. EPA. 1986. Health and Environmental Effects Profile for Dinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1989a. Health and Environmental Effects Document for RDX Cyclonite. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1989b. Health and Environmental Effects Document for 1,3,5-Trinitrobenzene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1989c. Trinitrotoluene. Health Advisory. Office of Drinking Water, Washington DC.

U.S. EPA. 1990. Health and Environmental Effects Document for 2,4,6-Trinitrotoluene. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

Source: USEPA, 1991b.

(USEPA, 1991d). RDX is not quantitatively evaluated because of insufficient evidence of dermal absorption in humans and limited evidence of very low absorption efficiency in animals (McNamara *et al.*, 1974; USEPA, 1991d).

6.2 QUALITATIVE TOXICITY ASSESSMENT

A brief qualitative discussion of the toxicity of each of the potential contaminants of concern, including the basis for the health effects criteria (RfDs and SFs), is presented below. The extent of oral and dermal absorption of each compound is also briefly discussed, supplemented by the oral and dermal absorption data presented in Tables 6-2 and 6-3.

6.2.1 1,3,5-Trinitrobenzene (1,3,5-TNB)

Data indicate that 1,3,5-TNB is very toxic when administered in subacute and chronic doses and moderately toxic in acute doses (USARDC, 1978). The main biochemical activity of 1,3,5-TNB is the formation of methemoglobin.

Because of the paucity of toxicity data for 1,3,5-TNB, EPA derived an RfD by analogy to 1,3-DNB (USEPA, 1991a). This analogy is considered an acceptable and appropriate method because of the structural similarity of the two compounds and the fact that 1,3,5-TNB is less toxic on an acute basis than 1,3-DNB. The RfD for 1,3,5-TNB is based on a study by Cody *et al.* (1981) where increased spleen weights were observed in both sexes of rats treated with 8 ppm 1,3-DNB. No treatment-related effects were found at 3 ppm. Based on water consumption and body weight data, the 3-ppm DNB corresponds to a mean daily intake of 0.40 mg DNB/kg in males. The equivalent intake for 1,3,5-TNB, adjusted for molecular weight differences, is 0.51 mg 1,3,5-TNB/kg/day. An uncertainty factor of 10,000 was then used to account for subchronic-to-chronic extrapolation, sensitive human subgroups, inter-species extrapolation, and derivation by analogy, resulting in a RfD of 5.0×10^{-5} mg/kg/day (USEPA, 1991a). Application of 1,3,5-TNB to the shaved skin of mice resulted in hyperemia, edema, and hemorrhages (USEPA, 1989c). Eye irritation has also been observed following ocular exposure (USEPA, 1989c). Thus, these limited data on the dermal toxicity of trinitrobenzene suggest that portal-of-entry effects may occur

following dermal exposure. It is clear that the lack of toxicity data for 1,3,5-TNB is effecting a highly conservative evaluation of its RfD. The actual RfD value is likely greater than currently estimated. Additional toxicity studies are warranted to better evaluate the 1,3-TNB RfD.

6.2.2 1,3-Dinitrobenzene (1,3-DNB)

1,3-DNB is rapidly absorbed through the skin. The toxicity of 1,3-DNB to industrial workers is well documented, and chronic exposure produces weakness, cyanosis, and anemia (Fairhall, 1969). Both the blood and the liver have been shown to be affected by 1,3-DNB (Beritic, 1956).

1,3-DNB can also enter the body orally or through the lungs and appears to be rapidly metabolized (Parke, 1961). Mutagenicity and carcinogenicity evaluations have not been conducted; however, the American Conference of Governmental Industrial Hygienists (ACGIH, 1977) presents an Occupational Safety and Health Administration (OSHA)-adopted exposure threshold limit value (TLV) of 1 mg/m³. (The TLV is the guideline that represents conditions under which nearly all workers may be repeatedly exposed without adverse health effects.)

A reference dose of 1.0×10^{-4} mg/kg/day for oral exposure has been developed by EPA for 1,3-DNB (USEPA, 1991a), based on the Cody *et al.* (1981) study (see 1,3,5-TNB). The mean daily intake of 0.40 mg 1,3-DNB/kg/day was divided by an uncertainty factor of 3,000 to account for subchronic-to-chronic extrapolation, interspecies extrapolation, sensitive human subgroups, and the lack of subchronic and reproductive toxicity data (USEPA, 1991a).

6.2.3 2,4,6-Trinitrotoluene (2,4,6-TNT)

2,4,6-TNT may enter the mammalian body by adsorption through the gastrointestinal tract, the skin, or the lungs (Voegtlin *et al.*, 1921; Neal *et al.*, 1944; Haythorn, 1920). TNT is transported to the liver, kidneys, and blood and extensively metabolized prior to being eliminated, primarily via urine (Gordon and Hartley, 1989).

Lee (1975) reported that small doses of 2,4,6-TNT are rapidly detoxified by the liver and the metabolic products excreted by the kidneys.

Reproductive effects may include testicular atrophy and degeneration of the seminiferous tubular epithelium (Levine *et al.*, 1984). Acute 2,4,6-TNT poisoning in humans induces toxic jaundice and toxic hepatitis. Chronic exposures to 2,4,6-TNT were reported to cause occupational cataract formation, pathological changes in peripheral blood, neurasthenia, and polyneuritis (Soboleva, 1969). Long-term exposure effects include lesions of the central nervous and vascular systems (Ermakov *et al.*, 1969).

2,4,6-TNT can cause toxic hepatitis, aplastic anemia, methemoglobinemia, and sensitization dermatitis. The skin, hair, and nails of exposed workers may be stained yellow. There is evidence that 2,4,6-TNT is both a carcinogen and a mutagen (Weston, 1987; Whong and Edwards, 1984; and Gordon and Hartley, 1989). An oral RfD of 5.0×10^{-4} for 2,4,6-TNT was developed by EPA (USEPA, 1991a) based on a LOAEL of 0.5 mg/kg/day for liver effects observed in a 26-week dog feeding study, and an uncertainty factor of 1,000 to account for interspecies extrapolation, subchronic-to-chronic extrapolation, sensitive human subgroups, and LOAEL-to-NOAEL extrapolator. 2,4,6-TNT has been classified as a Group C (possible human) carcinogen, and an oral slope factor of 3.0×10^{-2} (mg/kg/day)⁻¹ was developed by EPA based on urinary bladder papillomas and squamous cell carcinomas observed in Fisher 344 female rats during a 2-year feeding study (USEPA, 1991a).

6.2.4 2,4-Dinitrotoluene (2,4-DNT)

2,4-DNT is absorbed mainly by inhalation of vapors or by absorption through the skin from organic solutions during industrial exposures (USEPA, 1980a; Woollen *et al.*, 1985). Ingestion is likely to be the dominant exposure route for environmental exposures. Absorption of 2,4-DNT causes anoxia due to the formation of methemoglobin, and jaundice and anemia have been reported. Schut *et al.* (1982) state that both oxidative and reductive metabolism of 2,4-DNT occur primarily in the

liver and small intestine. Elimination of 2,4-DNT occurs predominantly via the urine (USEPA, 1980a).

Epidemiological data indicate that 2,4-DNT is not carcinogenic, but may cause atherosclerosis. However, increasing evidence from laboratory animal studies indicates that 2,4-DNT is a cancer promoter (Leonard *et al.*, 1983), though it is not an initiator of hepatocarcinogenicity (Popp and Leonard, 1983; Popp and Leonard, 1985; Rickert *et al.*, 1984).

Mutagenic effects of 2,4-DNT in mammalian cell cultures indicate that it is weakly mutagenic (Couch *et al.*, 1981). Other studies using mammalian cell structures and animals (Rickert *et al.*, 1984; Lane *et al.*, 1985; Soares and Lock, 1980) revealed no additional data. Studies by Lee *et al.* (1978) and Ellis *et al.* (1979) demonstrated depressed spermatogenesis, anemia, and neuromuscular effects in dogs, rats, and mice. Epidemiological studies on men exposed to 2,4-DNT did not indicate effects on fertility or reproductive health (Ahrenholz and Channing, 1980; Hammill *et al.*, 1982). Target areas for 2,4-DNT toxicity include the blood, liver, and neuromuscular systems. Hepatotoxic effects in rats and neuromuscular effects in dogs have also been demonstrated by Ellis *et al.* (1979). Limited data on dermal exposure in animals indicate that 2,4-DNT is a mild dermal irritant in rabbits (USEPA, 1986a).

To quantify human health effects, EPA classified 2,4-DNT as Group B2 (probable human carcinogen; USEPA, 1991a). A carcinogenic SF for 2,4-DNT of 6.8×10^{-1} (mg/kg/day)⁻¹ was developed by EPA based on a 2-year rat dietary study in which an increased incidence of liver and mammary gland tumors was observed (USEPA, 1990a).

A provisional RfD for 2,4-DNT was developed by EPA (Brower, 1992) based on a study conducted by Ellis *et al.* (1985), where a dog NOAEL of 0.2 mg/kg/day was identified. The next highest dose--1.5 mg/kg/day--was associated with neurotoxicity and biliary tract hyperplasia. An uncertainty factor of 100 for interspecies and intraspecies extrapolation was applied to the NOAEL, resulting in an RfD of 2E-03 mg/kg/day (Brower, 1992).

6.2.5 2,6-Dinitrotoluene (2,6-DNT)

Absorption of 2,6-DNT is primarily through the skin and through inhalation of vapors during industrial exposures (USEPA, 1980a; Woollen *et al.*, 1985); it is subsequently distributed throughout the body (Lee *et al.*, 1978). Although ingestion is likely to be the dominant exposure route for environmental exposures, occupational studies indicate that dermal absorption may be a significant route of entry in humans (ATSDR, 1989). 2,6-DNT is metabolized primarily in the liver and small intestine (Schut *et al.*, 1983), where both oxidative and reductive reactions occur. Elimination of 2,6-DNT and its metabolites from the body occurs primarily via the urine (USEPA, 1980a).

Evidence from laboratory animal studies indicates that 2,6-DNT is an initiator and promoter of hepatocarcinogenicity (Popp and Leonard, 1983); however, data are not available to evaluate the carcinogenic effect of 2,6-DNT in humans. Weak mutagenic effects have been noted in mammalian cell structures (Couch *et al.*, 1981; Woodruff *et al.*, 1985), but mutagenic effects on humans are uncertain. Decreased spermatogenesis is noted in animal tests by Lee *et al.* (1978), though the blood, liver, and neuromuscular systems are the primary target areas for 2,6-DNT toxicity (Lee *et al.*, 1978; Ellis *et al.*, 1979). Studies by Ahrenholz and Channing (1980) and Hammill *et al.* (1982) of men exposed to 2,6-DNT showed no evidence of effects related to fertility or reproductive health.

Limited data on dermal exposure in animals indicate that 2,6-DNT is a mild dermal irritant in rabbits and a mild dermal sensitizer in guinea pigs (USEPA, 1986a).

To quantify human health effects, EPA classified 2,6-DNT as Group B2 (probable human carcinogen; USEPA, 1990a). The carcinogenic slope factor of 6.8×10^{-1} (mg/kg/day)⁻¹ developed for 2,4-DNT has been adopted by EPA (USEPA, 1990a) for 2,6-DNT. An RfD was developed for 2,6-DNT by EPA (USEPA, 1991b) based on a study conducted by Lee *et al.* (1976), where a NOAEL in dogs of 4 mg 2,6-DNT/kg/day for liver, kidney, neurological, reproductive, and hematological effects was observed. An uncertainty factor of 3,000 (10 for interspecies extrapolation, 10 for

the use of subchronic data, 10 to protect sensitive subpopulations, and 3 for lack of reproductive/developmental toxicity data) was applied to the NOAEL, resulting in an RfD of 1.0E-03 mg/kg/day (USEPA, 1991b).

6.2.6 HMX

Several unpublished National Institute for Occupational Safety and Health (NIOSH) documents list HMX oral LD₅₀ values for laboratory animals (guinea pigs and mice) as ranging from 28 to 1,500 mg/kg. Intravenous application of HMX to dogs produced an LD₅₀ value of 40 mg/kg. Whong *et al.*, (1980) noted that HMX did not exhibit any mutagenic activity in Salmonella typhimurium using the Ames test. No data has been identified on dermal exposure to HMX.

An RfD of 0.05 mg/kg/day for HMX has been developed by EPA (USEPA, 1991a) based on a 13-week feeding study involving Fischer 344 rats (Everett *et al.*, 1985), where a NOAEL of 50 mg/kg/day was observed for toxic liver effects. An uncertainty factor of 1,000 was applied to account for interspecies extrapolation, sensitive human subgroups, and subchronic-to-chronic extrapolation. HMX is not presently classified (Group D) as to human carcinogenicity (McLellan *et al.*, 1988).

6.2.7 Nitrobenzene (NB)

Nitrobenzene may cause eye and skin irritation upon cutaneous or mucous membrane exposure (Clayton *et al.*, 1981). A dosage of 500 mg over a 24-hour period was reported to cause mild eye irritation and moderate skin irritation in the rabbit (RTECS, 1981). Acute exposures to nitrobenzene can affect the central nervous system. Chronic exposure can lead to spleen and liver damage. Nitrobenzene is a powerful methemoglobin former and may cause cyanosis. Anemia and Heinz bodies in the red cells have been observed (Clayton *et al.*, 1981).

In experimental animal studies, LD₅₀ values have been reported to range from 640 to 2,100 mg/kg/body weight (RTECS, 1981). The OSHA permissible exposure limit (PEL) for nitrobenzene is 1 ppm. An oral RfD of 5.0×10^{-4} mg/kg/day has been developed by EPA (USEPA, 1990a) based on a LOAEL of 4.6 mg/kg/day in a

subchronic mouse inhalation study where hemtologic, adrenal, renal, and hepatic lesions were observed. An uncertainty factor of 10,000 was applied to account for subchronic-to-chronic extrapolation, intraspecies and interspecies variability, and extrapolation from a LOAEL to a NOAEL.

6.2.8 RDX

In humans, oral and inhalation exposure to RDX results in seizures, lethargy, nausea, sleeplessness, irritability, and loss of memory (USEPA, 1991a). In addition to these CNS effects, oral RDX exposure results in inflammation of the prostate, hepatotoxicity, myocardial degeneration, mild renal toxicity, and lenticular cataracts in animals (USEPA, 1991a). Decreased fetal body weight and length have also been observed (USEPA, 1991a). Available information indicates that RDX is not absorbed through the skin (USEPA, 1991a). No clinical signs of toxicity were observed in rabbits receiving a single dermal application of 2 g RDX/kg body weight, and no signs of irritation were observed in a volunteer who had wet gauze containing RDX taped to his skin for 2 days (USEPA, 1989d).

Metabolism of RDX occurs primarily in the liver, and metabolites are excreted in urine or exhaled as CO₂ (Schneider *et al.*, 1977). RDX may concentrate in the kidneys, though metabolism appears to be fairly complete (Schneider *et al.*, 1977).

In laboratory studies with test animals, CNS effects were signs of acute toxicity (Ellis *et al.*, 1980). An oral RfD of 3.0×10^{-3} mg/kg/day was developed by EPA based on a 2-year rat feeding study in which a NOEL of 0.3 mg/kg/day was observed for inflammation of the prostate (USEPA, 1991a). An uncertainty factor of 100 was applied to account for interspecies extrapolation and sensitive human subgroups.

Some laboratory animal studies indicate noncarcinogenicity and nonmutagenicity (Hart, 1976). However, RDX significantly increased the incidence of combined hepatocellular carcinomas and adenomas in female B6C3F1 mice as compared to control groups (Lish *et al.*, 1984); therefore, RDX is classified as Group C, possible human carcinogen (USEPA, 1990a). The human SF was estimated by EPA to be 1.1×10^{-1} mg/kg/day⁻¹ (USEPA, 1990a), based on the study by Lish *et al.*

(1981) where hepatocellular carcinomas and adenomas were observed in female B6C3F1 mice. No evidence of teratogenicity or reproductive effects exists from tests conducted with laboratory animals (Ellis *et al.*, 1980).

6.2.9 Tetryl

The toxic effects of tetryl can result from introduction into the body by absorption through the skin and by inhalation. Impacted areas typically include the respiratory tract, liver, and blood (NIOSH/OSHA, 1985). In animal studies, liver and kidney damage, as well as respiratory difficulties, have been reported (NIOSH/OSHA, 1985). EPA derived an oral RfD of $1.0E-02$ mg/kg/day for tetryl (USEPA, 1990c) based on the findings of adverse hematological and histological effects in rats (Fati and Daniele, 1965). The LOAEL of 125 mg/kg/day was divided by an uncertainty factor of 10,000 (10 for the exposure duration, 10 for extrapolation from a LOAEL to a NOAEL, and 10 each for interspecies and intraspecies extrapolation). Confidence in the RfD is rated low because only a select number of endpoints was investigated, a dose-response relationship was not established, and no supporting data base is available.

7.0 RISK CHARACTERIZATION

Estimated intakes of contaminants of concern, calculated with the use of the exposure pathways presented in Section 5.2, are combined with health effects criteria presented in Table 6-1 to calculate potential carcinogenic risks and noncarcinogenic toxic health hazards.

Potential carcinogenic risk is estimated from EPA (1989g) as:

$$\text{Risk} = \text{CDI} \times \text{SF}$$

where:

CDI = chronic daily intake averaged over 75 years (mg/kg/day)

SF = slope factor (mg/kg/day)⁻¹.

Potential carcinogenic risks are calculated for cumulative lifetime effects that would be expected in a large population of receptors. EPA uses the risk range of 10⁻⁴ to 10⁻⁶ as a "target range" within which it strives to manage risks as part of a Superfund cleanup (Clay, 1991).

For noncarcinogens, the human health hazards related to exposure are estimated from EPA (1989g) as:

$$\text{HI} = \text{I/RfD}$$

where:

HI = hazard index or quotient.

I = intake or exposure level (mg/kg/day)

RfD = reference dose (mg/kg/day)

EPA guidance suggests that remediation may be a requirement where hazard indices exceed 1.0 (USEPA, 1989g).

Using these two equations, the risks and hazards associated with the four human exposure pathways under each of the three future land use scenarios (residential, military, and light industrial) are calculated for each of the contaminants

of concern. As identified in Section 5.2.1, the four primary exposure pathways are incidental ingestion of soil, dust inhalation, dermal contact with soil, and groundwater ingestion.

In accordance with recommended EPA methodology (USEPA, 1989g), the pathway-specific total risk and total hazard indices for all contaminants of concern are also presented. These totals for each pathway are probably overestimated because combining risk and hazard indices assumes the additivity of toxic effects within the human body. In fact, chemicals with different mechanisms of toxic action may act independently.

The exposure point concentrations, intake levels, and potential risks and hazards for the three exposure scenarios and for exposure pathways are presented in Tables 7-1 through 7-14.

7.1 SOIL INGESTION EXPOSURE PATHWAY

Tables 7-1 through 7-4 present the results of the intake, risk, and hazard index calculations for the three land use scenarios as a result of exposure by soil ingestion. The total risk value is 1.77×10^{-3} (see Table 7-2) for exposure under the residential land use scenario. Because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario, the hazard indices calculated for children 0 to 3 years old and 3 to 6 years old are averaged to estimate the hazard index for children 0 to 6 years old. The average hazard index for children 0 to 6 years old for exposure under the residential land use scenario is 1,120. The total risk and hazard index values of 3.33×10^{-4} and 40.5, respectively (Table 7-3), for exposure under the light industrial land use scenario are significantly reduced as compared to the residential land use scenario. The total risk and hazard index values are 5.52×10^{-6} and 9.0, respectively (Table 7-4), for the military land use scenario.

Exposure to 2,4,6-TNT accounts for the greatest contribution to total risk and hazard index for all three land use scenarios, primarily because of the high exposure point concentration of 2,4,6-TNT relative to the other contaminants of concern. This

TABLE 7-1

Summary of Exposure Point Concentrations and Intakes
Incidental Ingestion of Soil
Residential Land Use Scenario

		INTAKES--CARCINOGENIC (b)									
Exposure Point	Concentration (a)	Adult	0-3 yrs	3-9 yrs	9-12 yrs	12-15 yrs	15-18 yrs	18-24 yrs	24-30 yrs	30-35 yrs	35-40 yrs
Analyte	(mg/kg)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)
135TNB	32	—	—	—	—	—	—	—	—	—	—
130NB	0.25	—	—	—	—	—	—	—	—	—	—
240TNT	30435	0.01E-03	2.00E-02	1.00E-02	2.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
240DNT	12	1.00E-06	0.00E-06	0.00E-06	0.10E-07	0.00E-07	0.00E-07	0.00E-07	0.00E-07	0.00E-07	0.00E-07
HMX	190	—	—	—	—	—	—	—	—	—	—
NB	1.21	—	—	—	—	—	—	—	—	—	—
RDX	320	0.00E-06	2.10E-04	1.00E-04	2.20E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06

		INTAKES--NONCARCINOGENIC									
Exposure Point	Concentration (a)	Adult	0-3 yrs	3-9 yrs	9-12 yrs	12-15 yrs	15-18 yrs	18-24 yrs	24-30 yrs	30-35 yrs	35-40 yrs
Analyte	(mg/kg)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/day)
135TNB	32	0.01E-06	0.30E-04	0.70E-04	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06
130NB	0.25	0.00E-06	4.17E-06	2.04E-06	4.20E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07
240TNT	30435	7.00E-03	0.47E-01	4.07E-01	0.00E-03	0.00E-03	0.00E-03	0.00E-03	0.00E-03	0.00E-03	0.00E-03
240DNT	12	2.00E-06	2.00E-06	1.01E-04	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06
HMX	190	4.00E-06	3.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06
NB	1.21	2.00E-07	2.00E-07	1.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06	2.00E-06
RDX	320	0.70E-06	0.40E-06	0.30E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06	0.40E-06

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). Non-detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1989 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNB and 2,4-DNT are based on the eight surface soil samples collected from the berms (S4-1 to S4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

(b) - The carcinogenic intakes for each age group are not actual intakes for each age group, but rather incremental intakes that are prorated over a lifetime.

"—" No intake was calculated because the relevant health effects criteria were unavailable.

TABLE 7-2

Summary of Risks and Hazards
Incidental Ingestion of Soil
Residential Land Use Scenario

Analyte	RISK						Total
	(Adults)	(0-9 yrs)	(0-9 yrs)	(0-9 yrs)	(12-15 yrs)	(16-18 yrs)	
135TNS	—	—	—	—	—	—	—
130NB	—	—	—	—	—	—	—
246TNT	1.80E-04	7.77E-04	6.40E-04	7.80E-06	6.40E-06	3.22E-06	1.71E-03
240NT	1.20E-06	6.44E-06	3.04E-06	6.61E-07	2.70E-07	2.20E-07	1.80E-06
HMX	—	—	—	—	—	—	—
NB	—	—	—	—	—	—	—
POX	6.00E-06	2.41E-06	1.70E-06	2.44E-06	1.70E-06	1.00E-06	6.91E-06
Total	1.87E-04	9.04E-04	5.80E-04	9.18E-06	5.97E-06	4.00E-06	1.77E-03

HAZARD INDEX							Average for Children 0-9 and 3-9 years (a)
Analyte	(Adults)	(0-9 yrs)	(0-9 yrs)	(0-9 yrs)	(0-12 yrs)	(13-15 yrs)	
135TNS	1.30E-01	1.97E-01	7.63E-00	1.00E-00	7.60E-01	4.43E-01	9.10E-00
130NB	6.00E-04	4.17E-02	2.04E-02	4.22E-03	2.00E-03	1.70E-03	3.60E-02
246TNT	1.60E-01	1.20E-03	9.14E-02	1.31E-02	9.10E-01	6.37E-01	1.10E-03
240NT	1.22E-03	1.00E-01	7.00E-02	1.91E-02	7.00E-03	4.00E-03	8.90E-02
HMX	6.00E-04	6.00E-02	4.00E-02	6.00E-03	4.04E-03	2.74E-03	6.00E-02
NB	4.00E-04	4.00E-02	2.00E-02	4.04E-03	2.00E-03	1.07E-03	3.44E-02
POX	2.20E-02	1.60E-00	1.20E-00	1.60E-01	1.20E-01	7.00E-02	1.60E-00
Total	15.06	1307.24	922.76	132.37	91.82	64.89	1.12E+03

(a) - Because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario, the hazard indices calculated for children 0-3 years old and 3-9 years old are averaged to determine the hazard index for 0-9 year old children.

"—" No risk or hazard index was calculated because the relevant health effects criteria were unavailable.

TABLE 7-3

**Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Incidental Ingestion of Soil
Light Industrial Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNS	32	—	—
13DNB	0.25	—	—
246TNT	38835	1.07E-02	3.21E-04
24DNT	12	3.31E-06	2.25E-06
HMX	186	—	—
NB	1.21	—	—
RDX	329	9.07E-06	9.97E-06
Total			3.33E-04

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNS	32	1.66E-06	3.31E-01
13DNB	0.25	1.29E-07	1.29E-03
246TNT	38835	2.01E-02	4.01E+01
24DNT	12	6.20E-06	3.10E-03
HMX	186	1.02E-04	2.06E-03
NB	1.21	6.25E-07	1.25E-03
RDX	329	1.70E-04	3.67E-02
Total			40.5

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). Non-detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1998 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNS and 2,4-DNT are based on the eight surface soil samples collected from the berms (B4-1 to B4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNS and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

— No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

TABLE 7-4

**Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Incidental Ingestion of Soil
Military Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Adult Carcinogenic Intake (mg/kg/day)</u>	<u>Risk (Adult)</u>
135TNB	32	--	--
13DNB	0.25	--	--
246TNT	38835	1.77E-04	5.32E-06
24DNT	12	5.48E-08	3.73E-08
HMX	198	--	--
NB	1.21	--	--
RDX	329	1.50E-06	1.65E-07
Total			5.52E-06

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Adult Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index (Adult)</u>
135TNB	32	3.65E-06	7.31E-02
13DNB	0.25	2.85E-08	2.85E-04
246TNT	38835	4.43E-03	8.87E+00
24DNT	12	1.37E-06	6.85E-04
HMX	198	2.26E-05	4.52E-04
NB	1.21	1.38E-07	2.76E-04
RDX	329	3.76E-05	1.25E-02
Total			9.0

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). Non-detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1989 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNB and 2,4-DNT are based on the eight surface soil samples collected from the berms (B4-1 to B4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

-- No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

is true even though the carcinogenic classification of 2,4,6-TNT is Group C (see Section 6.0), implying that carcinogenic effects in humans are not confirmed. Although the value of the slope factor for 2,4,6-TNT is low compared to other more potent carcinogens such as 2,6-DNT, this low value is overwhelmed by the extensive occurrence of 2,4,6-TNT at relatively high concentrations in Site 4 soils--with the net effect of high risks associated with 2,4,6-TNT.

7.2 DUST INHALATION EXPOSURE PATHWAY

Table 7-5 presents results of the emission and dispersion wind erosion modeling described in Appendix B. The model output is total source-derived dust concentrations calculated at locations arranged in a radial grid at 100-meter contours and 45-degree bearings from the site (see Figure B-1 in Appendix B). The first heading of Table 7-5 presents the total source-derived dust concentrations estimated by the models at a number of potential receptor locations and is identical to the data presented in Figure B-1 of Appendix B. Table 7-5 also shows the estimated concentrations of the contaminants of concern in picograms of contaminant per cubic meter of air at the appropriate compass bearings and distances from the site. The contaminant concentrations in air are simply the product of the total dust concentration and the contaminant concentration in surface soil (i.e., the 95 percent upper confidence limit on the arithmetic mean). The assumption made is that the contaminants are distributed in the air in the same proportion as they are in the surface soil.

Tables 7-6 to 7-8 present results of the intake, risk, and hazard index calculations for the three land use scenarios. The calculations were performed using only exposure point concentrations in air at an assumed receptor location very near the site. The receptor location "very near the site" is essentially a worst case dust concentration, modeled 15 meters downwind (enough distance for site-derived dust to achieve respirable height). Therefore, a compass direction and distance from the site are not really necessary for its description. (The exposure point concentration at the next nearest distance (100 meters) from the site in the direction of the prevailing wind

TABLE 7-5

**Modeled Concentrations of Total Dust and Associated Contaminants
In Air at a Variety of Receptor Locations due to Wind Erosion**

Distance from Source	Total Source-Derived Dust Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	1.00E+07							
100 m	305102	312000	300000	120000	207400	140700	40000	70000
200 m	130702	80017	107202	30004	80000	41000	10000	20004
300 m	60000	40000	52110	10170	40000	10700	6070	10001
400 m	30001	20000	31001	10000	20001	11000	3000	5000
500 m	20000	17000	21000	7000	17100	7700	2410	5000

Distance from Source	TNT Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	701100							
100 m	18047	12100	13000	8000	11101	8001	1007	2000
200 m	4001	3047	4100	1000	2004	1017	300	500
300 m	2077	1700	2004	700	1043	700	207	300
400 m	1000	1010	1010	410	501	404	142	200
500 m	510	570	510	270	500	302	54	100

Distance from Source	RDX Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	0442.5							
100 m	120.0	102.0	110.1	42.5	84.5	47.2	16.1	20.0
200 m	30.7	30.0	30.2	12.0	20.0	10.7	4.5	7.2
300 m	10.0	14.0	17.1	0.0	10.0	0.5	2.0	3.4
400 m	11.0	0.0	10.0	0.0	0.4	0.0	1.2	2.0
500 m	7.0	0.7	0.0	2.0	0.7	2.0	0.0	1.0

Distance from Source	HMX Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	3004.7							
100 m	70.0	61.0	71.2	20.0	57.0	20.0	0.7	10.7
200 m	20.0	10.0	21.2	7.7	17.2	0.0	2.7	4.4
300 m	11.0	0.0	10.0	0.0	0.4	0.0	1.4	2.0
400 m	7.0	0.2	0.2	2.1	0.1	2.0	0.7	1.2
500 m	4.7	0.0	4.2	1.4	0.4	1.0	0.0	0.0

Distance from Source	135TNB Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	007.2							
100 m	12.00	0.00	11.00	4.14	0.00	4.00	1.07	2.00
200 m	3.07	0.01	3.40	1.04	2.77	1.00	0.43	0.71
300 m	1.00	1.02	1.07	0.00	1.00	0.00	0.00	0.00
400 m	1.10	0.04	1.00	0.04	0.02	0.07	0.12	0.10
500 m	0.70	0.00	0.07	0.00	0.00	0.00	0.00	0.10

Distance from Source	24DNT Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	004.2							
100 m	4.70	0.70	4.31	1.00	0.40	1.72	0.00	0.00
200 m	1.40	1.10	1.00	0.47	1.04	0.00	0.10	0.00
300 m	0.70	0.00	0.00	0.00	0.01	0.04	0.00	0.10
400 m	0.40	0.00	0.00	0.10	0.01	0.14	0.04	0.07
500 m	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00

TABLE 7-5 (cont'd)

Modeled Concentrations of Total Dust and Associated Contaminants
In Air at a Variety of Receptor Locations due to Wind Erosion

Distance from Source	13DNB Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	4.9							
100 m	0.10	0.06	0.09	0.06	0.07	0.04	0.01	0.02
200 m	0.09	0.02	0.09	0.01	0.02	0.01	0.00	0.01
300 m	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
400 m	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
500 m	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00

Distance from Source	NB Concentration (pg/m3)							
	NE	E	SE	S	SW	W	NW	N
near source	23.7							
100 m	0.46	0.36	0.43	0.16	0.36	0.17	0.06	0.10
200 m	0.15	0.11	0.13	0.06	0.10	0.06	0.02	0.03
300 m	0.07	0.05	0.06	0.02	0.06	0.02	0.01	0.01
400 m	0.04	0.03	0.04	0.01	0.03	0.01	0.00	0.01
500 m	0.03	0.02	0.03	0.01	0.02	0.01	0.00	0.00

TABLE 7-6

**Summary of Risks and Hazards
Inhalation of Dust
Residential Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m³)</u>	<u>Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNS	627.2	—	—
13ONS	4.9	—	—
245TNT	781163	3.28E-04	9.79E-06
24DNT	235.2	1.01E-07	6.65E-06
HMX	3884.7	—	—
NS	23.7	—	—
RDX	6442.5	2.78E-06	3.04E-07
Total			1.02E-05

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m³)</u>	<u>Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNS	627.2	2.69E-07	5.38E-03
13ONS	4.9	2.10E-08	2.10E-06
245TNT	781163	3.28E-04	6.62E-01
24DNT	235.2	1.01E-07	5.04E-06
HMX	3884.7	1.88E-06	3.33E-06
NS	23.7	1.02E-06	2.03E-06
RDX	6442.5	2.78E-06	8.20E-04
Total			0.66

(a) - Exposure point concentrations are all from a receptor location in close proximity to the site. Concentrations were determined by the use of analytical dust emission and dispersion models (Appendix B) as presented in Table 7-5. The original surface soil concentrations assumed to erode were calculated as described for the soil ingestion pathway.

"—" No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

TABLE 7-7

**Summary of Risks and Hazards
Inhalation of Dust
Light Industrial Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m3)</u>	<u>Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNS	627.2	—	—
130NS	4.9	—	—
246TNT	761163	1.57E-04	4.72E-06
240NT	236.2	4.88E-06	3.31E-06
HMX	3684.7	—	—
NS	23.7	—	—
RDX	6442.6	1.32E-06	1.46E-07
Total			4.90E-06

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m3)</u>	<u>Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNS	627.2	2.43E-07	4.86E-03
130NS	4.9	1.90E-09	1.90E-06
246TNT	761163	2.96E-04	8.90E-01
240NT	236.2	9.11E-06	4.66E-05
HMX	3684.7	1.61E-06	3.01E-06
NS	23.7	9.18E-09	1.84E-06
RDX	6442.6	2.60E-06	8.32E-04
Total			0.60

(a) - Exposure point concentrations are all from a receptor location in close proximity to the site. Concentrations were determined by the use of analytical dust emission and dispersion models (Appendix B) as presented in Table 7-6. The original surface soil concentrations assumed to erode were calculated as described for the soil ingestion pathway.

“—” No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

TABLE 7-8

**Summary of Risks and Hazards
Inhalation of Dust
Military Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m3)</u>	<u>Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNS	627.2	—	—
13ONS	4.9	—	—
245TNT	761163	2.79E-06	8.34E-08
24ONT	236.2	8.69E-10	8.84E-10
HMX	3884.7	—	—
NS	23.7	—	—
RDX	6442.6	2.36E-06	2.69E-09
Total			8.66E-08

<u>Analyte</u>	<u>Exposure Point Concentration (a) (pp/m3)</u>	<u>Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNS	627.2	6.73E-06	1.16E-03
13ONS	4.9	4.47E-10	4.47E-06
245TNT	761163	6.66E-06	1.36E-01
24ONT	236.2	2.16E-06	1.07E-06
HMX	3884.7	3.66E-07	7.10E-06
NS	23.7	2.16E-06	4.33E-06
RDX	6442.6	6.88E-07	1.66E-04
Total			0.140

(a) - Exposure point concentrations are all from a receptor location in close proximity to the site. Concentrations were determined by the use of analytical dust emission and dispersion models (Appendix B) as presented in Table 7-6. The original surface soil concentrations assumed to erode were calculated as described for the soil ingestion pathway.

"—" No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

produces a total risk of 2.5×10^{-7} for the residential land use scenario. This documents the significant decrease in source-derived contaminant concentrations at distances from the site, thus significantly reducing exposure. Therefore, in the remainder of this report, only the receptor location "very near the source" is considered.)

The total risk and hazard index values for the residential land use scenario, assuming receptors proximate to the site, are 1.02×10^{-5} and 0.66, respectively (Table 7-6). The risk value is due almost entirely to exposure to 2,4,6-TNT. The total risk and hazard index values for the light industrial land use scenario— 4.90×10^{-6} and 0.60, respectively (Table 7-7)—are less than for the residential land use scenario. The total risk and hazard index values for military land use are 8.66×10^{-8} and 0.14, respectively (Table 7-8).

7.3 DERMAL CONTACT WITH SOIL EXPOSURE PATHWAY

Tables 7-9 through 7-12 present results of the intake, risk, and hazard index calculations for the three land use scenarios as a result of exposure by dermal contact with soil. The total risk value is 8.23×10^{-3} (see Table 7-10) for exposure under the residential land use scenario.

Because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario, the hazard indices calculated for children 0 to 3 years old and 3 to 6 years old are averaged to estimate the hazard index for children 0 to 6 years old. The average hazard index for children 0 to 6 years old for exposure under the residential land use scenario is 3,067.

The total risk and hazard index values are $4.36\text{E-}03$ and 546, respectively (Table 7-11), for exposure under the light industrial land use scenario. The total risk and hazard index values are $7.23\text{E-}05$ and 120.7, respectively (Table 7-12), for the military land use scenario.

TABLE 7-9

**Summary of Exposure Point Concentrations and Intakes
Dermal Contact With Soil
Residential Land Use Scenario**

Analyte (c)	Exposure Point Concentration (a) (mg/kg)	INTAKES (mg/kg/day)--CARCINOGENIC (b)				
		0-3 YRS	3-5 YRS	6-9 YRS	9-12 YRS	12-15 YRS
135TNB	32	---	---	---	---	---
13DNB	0.25	---	---	---	---	---
246TNT	30036	0.41E-02	0.70E-02	2.01E-02	1.72E-02	1.60E-02
24DNT	12	1.00E-06	1.78E-06	0.20E-06	0.22E-06	4.82E-06
HMX	100	---	---	---	---	---
NB	1.21	---	---	---	---	---

Analyte (c)	Exposure Point Concentration (a) (mg/kg)	INTAKES (mg/kg/day)--NONCARCINOGENIC				
		0-3 YRS	3-5 YRS	6-9 YRS	9-12 YRS	12-15 YRS
135TNB	32	0.79E-06	1.10E-03	4.19E-04	3.64E-04	3.40E-04
13DNB	0.25	0.97E-07	0.20E-06	3.22E-06	2.77E-06	2.72E-06
246TNT	30036	1.07E-01	1.44E-00	5.01E-01	4.30E-01	4.23E-01
24DNT	12	3.30E-06	4.85E-04	1.65E-04	1.33E-04	1.21E-04
HMX	100	0.44E-04	7.34E-03	2.56E-03	2.10E-03	2.10E-03
NB	1.21	3.32E-06	4.40E-06	1.66E-06	1.34E-06	1.32E-06

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). Non-detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1988 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNB and 2,4-DNT are based on the eight surface soil samples collected from the berms (S4-1 to S4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

(b) - The carcinogenic intakes for each age group are not actual intakes for each age group, but rather incremental intakes that are prorated over a lifetime.

(c) - RDX is not quantitatively evaluated for this exposure pathway because of insufficient evidence of dermal absorption in humans.

--- Indicates that the relevant health effects criteria are unavailable.

TABLE 7-10
Summary of Risks and Hazards
Dermal Contact With Soil
Residential Land Use Scenario

Analyte (b)	RISK						TOTAL
	Adult	0-3 YRS	3-6 YRS	6-9 YRS	9-12 YRS	12-15 YRS	15-18 YRS
135TNB	—	—	—	—	—	—	—
13DNB	—	—	—	—	—	—	—
246TNT	2.43E-03	1.02E-03	1.73E-03	6.02E-04	5.10E-04	4.80E-04	5.00E-04
24DNT	1.70E-06	1.36E-06	1.21E-06	4.21E-06	3.61E-06	3.20E-06	3.50E-06
HMX	—	—	—	—	—	—	—
NB	—	—	—	—	—	—	—
Total	2.45E-03	1.94E-03	1.74E-03	6.06E-04	5.20E-04	4.72E-04	5.11E-04
							8.23E-03

HAZARD INDEX							
Analyte (b)	Average for Children 0-3 and 3-6 years (a)						Total
	Adult	0-3 YRS	3-6 YRS	6-9 YRS	9-12 YRS	12-15 YRS	15-18 YRS
135TNB	1.70E+00	2.64E+01	2.37E+01	8.29E+00	7.09E+00	6.43E+00	6.97E+00
13DNB	0.87E-03	1.03E-01	9.26E-02	3.23E-02	2.77E-02	2.51E-02	2.72E-02
246TNT	2.13E+02	3.20E+03	2.88E+03	1.00E+03	8.80E+02	7.91E+02	8.48E+02
24DNT	1.80E-02	2.47E-01	2.22E-01	7.75E-02	6.85E-02	6.03E-02	6.54E-02
HMX	1.00E-02	1.83E-01	1.47E-01	5.11E-02	4.39E-02	3.90E-02	4.31E-02
NB	0.05E-03	0.90E-02	8.97E-02	3.12E-02	2.89E-02	2.43E-02	2.64E-02
Total	215	3231	2803	1011	887	787	883
							3087

(a) - Because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario, the hazard indices calculated for children 0-3 years old and 3-6 years old are averaged to determine the hazard index for 0-6 year old children.

(b) - RfD is not quantitatively evaluated for this exposure pathway because of insufficient evidence of dermal absorption in humans.

— indicates that the relevant health effects criteria are unavailable.

TABLE 7-11

**Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Dermal Contact With Soil
Light Industrial Land Use Scenario**

<u>Analyte (b)</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNB	32	--	--
13DNB	0.25	--	--
246TNT	38835	1.44E-01	4.33E-03
24DNT	12	4.46E-05	3.04E-05
HMX	198	--	--
NB	1.21	--	--
Total			<u>4.36E-03</u>

<u>Analyte (b)</u>	<u>Exposure Point Concentration (a) (mg/kg)</u>	<u>Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNB	32	2.23E-04	4.46
13DNB	0.25	1.74E-06	0.02
246TNT	38835	2.71E-01	541.7
24DNT	12	8.37E-05	0.0
HMX	198	1.38E-03	0.03
NB	1.21	8.44E-06	0.02
Total			<u>546</u>

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). -- detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1990 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNB and 2,4-DNT are based on the eight surface soil samples collected from the berms (B4-1 to B4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

(b) - RDX is not quantitatively evaluated for this exposure pathway because of insufficient evidence of dermal absorption in humans.

"--" - Indicates that the relevant health effects criteria are unavailable.

TABLE 7-12

Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Dermal Contact With Soil
Military Land Use Scenario

<u>Analyte (b)</u>	<u>Exposure Point Concentration (a)</u> (mg/kg)	<u>Carcinogenic Intake</u> (mg/kg/day)	<u>Risk</u>
135TNB	32	--	--
13DNB	0.25	--	--
246TNT	38835	2.39E-03	7.18E-05
24DNT	12	7.40E-07	5.03E-07
HMX	198	--	--
NB	1.21	--	--
Total			<u>7.23E-05</u>

<u>Analyte (b)</u>	<u>Exposure Point Concentration (a)</u> (mg/kg)	<u>Noncarcinogenic Intake</u> (mg/kg/day)	<u>Hazard Index</u>
135TNB	32	4.93E-05	0.99
13DNB	0.25	3.85E-07	0.004
246TNT	38835	5.98E-02	119.7
24DNT	12	1.85E-05	0.01
HMX	198	3.05E-04	0.006
NB	1.21	1.86E-06	0.004
Total			<u>120.7</u>

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean of surface soil data (samples less than 2 feet deep). Non-detects are replaced with the detection level for calculating exposure point concentrations. The TNT, RDX, and HMX values are based on the eight surface soil samples (A-1 to A-8) from the lagoons collected in 1989 by Weston and are considered "maximum concentrations". Although 1,3-DNB and NB were not detected in surface soil samples, because these compounds were detected in several deeper soil samples from Site 4, the surface soil concentrations will conservatively be assumed to be one-half of the detection limit. The values for 1,3,5-TNB and 2,4-DNT are based on the eight surface soil samples collected from the berms (B4-1 to B4-8) outside the lagoons because these compounds were not analyzed for in the lagoon samples. Because concentrations of 1,3,5-TNB and 2,4-DNT would presumably be greater inside the lagoons than in the berms, the maximum detected concentrations in the berms are conservatively assumed to be the exposure point concentrations, rather than the 95 percent upper confidence limit on the arithmetic mean.

(b) - RDX is not quantitatively evaluated for this exposure pathway because of insufficient evidence of dermal absorption in humans.

'--' indicates that the relevant health effects criteria are unavailable.

Similar to the soil ingestion exposure pathway, exposure to 2,4,6-TNT contributes the greatest contribution to the total risk and hazard index for all three land use scenarios, primarily because of the high exposure point concentration of 2,4,6-TNT relative to the other contaminants of concern.

7.3 GROUNDWATER INGESTION EXPOSURE PATHWAY

Tables 7-13 and 7-14 present results of the intake, risk, and hazard index calculations for the residential and light industrial land use scenarios. (As previously discussed, this pathway was not considered for the military land use scenario.) These two tables also present the exposure point concentration based on data from 17 monitoring wells sampled by Roy F. Weston (1989) and 34 monitoring wells sampled by Dames & Moore. The assumed receptor location is proximate to the site (i.e., within the contaminated groundwater plume). It should be noted that the exposure point concentration for RDX is based on 13 detections in the 17 samples, while the other contaminants of concern were detected only in one to three samples.

The total risk and hazard values for residential land use are 4.15×10^{-3} and 64.8, respectively (Table 7-13). The total risk and hazard index values for light industrial land use are 1.27×10^{-3} and 37.3, respectively (Table 7-14). One observation to be drawn from Tables 7-13 and 7-14 is that, unlike the soil exposure pathways--where the majority of the total risks and hazards were from TNT exposure--over 65 percent of the total risk from groundwater ingestion is from exposure to RDX and the total hazard index is primarily from exposure to 1,3,5-TNB and TNT. RDX has a greater slope factor than TNT, and in groundwater at Site 4 RDX is present at higher concentrations. Thus, exposure to groundwater results in greater risks from RDX, while direct exposure to soil produces greater risks from TNT because of the overwhelmingly higher concentrations of TNT in soil.

TABLE 7-13

**Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Exposure by Ingestion of Groundwater
Residential Land Use Scenario**

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/l)</u>	<u>Adult Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNB	0.049	--	--
13DNB	0.0017	--	--
246TNT	0.439	1.25E-02	3.76E-04
24DNT	0.053	1.50E-03	1.02E-03
26DNT	0.0012	3.37E-05	2.29E-05
HMX	0.171	--	--
NB	0.002	--	--
RDX	0.868	2.48E-02	2.73E-03
Tetryl	0.0006	--	--
Total			4.15E-03

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/l)</u>	<u>Adult Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNB	0.049	1.41E-03	2.83E+01
13DNB	0.0017	4.71E-05	4.71E-01
246TNT	0.439	1.25E-02	2.51E+01
24DNT	0.053	1.50E-03	7.51E-01
26DNT	0.0012	3.37E-05	3.37E-02
HMX	0.171	4.90E-03	9.79E-02
NB	0.002	5.71E-05	1.14E-01
RDX	0.868	2.48E-02	8.26E+00
Tetryl	0.0006	1.69E-05	1.69E-03
Total			63.1

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean.
All values are based on data from the 17 monitoring wells sampled by Weston (1986) and the 34 monitoring wells sampled by James & Moore. For calculation purposes, non-detects were replaced with the detection level.

"--" No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

TABLE 7-14

Summary of Exposure Point Concentrations, Intakes, Risks, and Hazards
Exposure by Ingestion of Groundwater
Light Industrial Land Use Scenario

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/l)</u>	<u>Adult Carcinogenic Intake (mg/kg/day)</u>	<u>Risk</u>
135TNB	0.049	--	--
13DNB	0.0017	--	--
246TNT	0.439	3.85E-03	1.15E-04
24DNT	0.053	4.61E-04	3.14E-04
26DNT	0.0012	1.03E-05	7.03E-06
HMX	0.171	--	--
NB	0.002	--	--
RDX	0.868	7.61E-03	8.37E-04
Tetryl	0.0006	--	--
Total			1.27E-03

<u>Analyte</u>	<u>Exposure Point Concentration (a) (mg/l)</u>	<u>Adult Noncarcinogenic Intake (mg/kg/day)</u>	<u>Hazard Index</u>
135TNB	0.049	8.13E-04	1.63E+01
13DNB	0.0017	2.71E-05	2.71E-01
246TNT	0.439	7.21E-03	1.44E+01
24DNT	0.053	8.65E-04	4.32E-01
26DNT	0.0012	1.94E-05	1.94E-02
HMX	0.171	2.62E-03	5.64E-02
NB	0.002	3.29E-05	6.58E-02
RDX	0.868	1.43E-02	4.75E+00
Tetryl	0.0006	9.70E-06	9.70E-04
Total			36.3

(a) - Exposure point concentrations are the 95 percent upper confidence limit on the arithmetic mean. All values are based on data from the 17 monitoring wells sampled by Weston (1989) and the 34 monitoring wells sampled by Dames & Moore. For calculation purposes, non-detects were replaced with the detection level.

"--" No intake, risk, or hazard index was calculated because the relevant health effects criteria were unavailable.

7.4 MULTIPLE PATHWAY HAZARDS/RISKS

Multiple human exposures by two or more of the four pathways considered are possible. Exposure to site contaminants via two or more pathways would increase exposure point risk levels and, therefore, increase the potential for noncarcinogenic and carcinogenic health effects. The most conservative approach is to assume exposure by all pathways, though this is somewhat unrealistic, because most individuals will not be exposed via all pathways. It is conceivable, however, that a small portion of future residents or workers may in the future obtain drinking water from a groundwater well located onsite and be exposed to soil contamination via incidental ingestion, inhalation, and dermal contact with soil. It is also conceivable that future military personnel may be exposed to soil contamination via the three soil exposure pathways. Therefore, the potential carcinogenic risks and hazard quotients are added to derive the total potential carcinogenic risk and the total hazard quotient (USEPA, 1989g). These totals are presented in Table 7-15. As indicated in Table 7-15, the total risk and hazard index values for all four exposure pathways under the residential land use scenario are $1.42\text{E-}02$ and 4,253, respectively. The total risk and hazard index values for all four exposure pathways under the light industrial land use scenario are $5.97\text{E-}03$ and 624, respectively; and the total risk and hazard index values for all three exposure pathways under the military land use scenario are 7.79×10^{-5} and 130, respectively.

The dermal contact with soil pathway appears to pose the greatest risk and noncancer health threat for all three land use scenarios. The groundwater ingestion and soil ingestion pathways also significantly contribute to the risk and noncancer health threat, while the dust inhalation pathway poses a much lower carcinogenic risk and noncancer hazard threat.

The exposure estimates and potential carcinogenic risks described in this section are based on conservative assumptions required to assess potential human exposures by pathways discussed in Section 5.2 and to estimate exposures summarized in Tables 7-1 through 7-14. Therefore, potential associated health risks are considered upper

TABLE 7-15

**Summary of Results of Multiple Pathway Risks and Hazards
Explosive Washout Lagoons (Site 4), UMDA**

<u>Land Use Scenario</u>	<u>TOTAL RISK</u>				<u>MULTIPLE PATHWAY RISK</u>
	<u>Soil Ingestion</u>	<u>Dust Inhalation</u>	<u>Dermal Contact With Soil</u>	<u>Groundwater Ingestion</u>	
Residential	1.77E-03	1.02E-05	8.23E-03	4.15E-03	1.42E-02
Light Industrial	3.33E-04	4.90E-06	4.36E-03	1.27E-03	5.97E-03
Military	5.52E-06	8.66E-06	7.23E-05	(a)	7.79E-05

<u>Land Use Scenario</u>	<u>TOTAL HAZARD INDEX</u>				<u>MULTIPLE PATHWAY HAZARD INDEX</u>
	<u>Soil Ingestion</u>	<u>Dust Inhalation</u>	<u>Dermal Contact With Soil</u>	<u>Groundwater Ingestion</u>	
Residential	1120	0.66	3067	63.1	4250.8
Light Industrial	40.5	0.6	546	36.3	623.4
Military	9.0	0.14	120.7	(a)	129.8

(a) Exposure by groundwater ingestion was not considered for the military land use scenario because it is not expected to be different from the current use where no shallow drinking water wells are installed.

bound limits; that is, actual exposures and health risks are likely to be less than currently estimated. Also, it must be stressed that these pathways do not represent current conditions and would be viable only if the future conditions described in Section 5.1.2 occur.

7.6 UNCERTAINTIES

The risk measures used in site risk assessments usually are not fully probabilistic estimates of risk, but conditional estimates based on a considerable number of rather subjective assumptions about exposure and toxicity (e.g., risk given a particular future land use). Thus, it is important to fully specify the assumptions and uncertainties inherent in the risk assessment to place the risk estimates in proper perspective. There are generally two categories of uncertainties associated with risk assessments--the more general toxicity assessment uncertainties and site-specific exposure uncertainties.

7.6.1 General Toxicity Assessment Uncertainties

General toxicity assessment uncertainties include lack of substantial data on the toxicity of some contaminants of concern, derivation of toxicity values from animal studies, calculation of life-time cancer risks on the basis of less than lifetime exposures, and potential synergistic or antagonistic interactions with other substances affecting the same individuals.

For many contaminants of concern, the data base on potential toxic effects is very limited (e.g., 1,3,5-TNB, tetryl, and HMX, in particular) and RfDs may be derived based on only one or two animal studies. Although more toxicity data may be available for other contaminants, as indicated in Table 6-1, the confidence levels for the RfDs established for the contaminants of concern are generally low, with only 2,4,6-TNT indicating a medium confidence level and RDX indicating a high confidence level. In addition, all of the toxicity factors developed for the contaminants of concern are based on toxicity values from animal studies and require animal-to-man extrapolations. To compensate for the lack of substantial toxicity information and the requirement of animal-to-man extrapolation, uncertainty factors are applied to make

the toxicity factors more conservative (i.e., more protective of human health). Uncertainty factors are also applied to account for subchronic-to-chronic extrapolation, sensitive subgroups, LOAEL-to-NOAEL extrapolation, and lack of reproductive/developmental toxicity data, as applicable. The specific uncertainty factors for the contaminants of concern are presented in Table 6-1 and discussed in Section 6.2.

In addition to the uncertainties discussed above, inherent uncertainties exist in the derivation of slope factors for potential carcinogens, which generally involves high dose-to-low dose extrapolation and calculation of lifetime cancer risks based on less-than-lifetime exposures. The linear multistage model employed by EPA in developing slope factors is a conservative model and will generally provide a conservative (i.e., more protective of human health) slope factor. A weight of evidence classification indicates the likelihood that the chemical is a human carcinogen according to the following classes--A, human carcinogen; B1, probable human carcinogen with sufficient evidence in animals and limited human data available; B2, probable human carcinogen with sufficient evidence in animals and inadequate or no human evidence of carcinogenicity; C, possible human carcinogen with limited evidence in animals; D, not classifiable; and E, evidence of noncarcinogenicity for humans. As indicated in Table 6-1, of the contaminants of concern at Site 4, 2,4,6-TNT and RDX are designated class C carcinogens, and 2,4-DNT and 2,6-DNT are designated class B2 carcinogens.

Additional uncertainties are associated with summing risks or hazard indices for several contaminants, because the assumption of dose additivity ignores possible synergisms or antagonisms among chemicals, and assumes similarity in mechanisms of action and metabolism. Unfortunately, data in support of quantitative assessments of interactions are generally lacking. In the absence of adequate information, EPA guidelines indicate that both noncancer hazard indices and cancer risks should be treated as additive. These assumptions are implemented in this risk assessment to help prevent an underestimation of cancer risk or potential noncancer health effects at the site.

Although many uncertainties are inherent in deriving toxicity factors, conservative approaches are employed to ensure that the potential toxicity of contaminants is not underestimated. Therefore, the toxicity factors employed in this risk assessment tend to overestimate risks or hazards; the actual risks or hazards present from such contaminants may be much less than estimated.

7.6.2 Site-Specific Exposure Uncertainties

Uncertainties in the exposure assessment typically include most of the site-specific uncertainties inherent in risk characterization. The four main sources of uncertainty are definition of the physical setting, model applicability and assumptions, parameter value uncertainty, and magnification of uncertainties, as discussed below.

7.6.2.1 Definition of the Physical Setting. The initial characterization of the physical setting involves many professional judgements and assumptions. These include definition of land uses, identification of possible exposure pathways, and selection of contaminants of concern.

Uncertainties always exists in attempting to predict future conditions. As indicated in Section 5.1.2, potential future land uses at Site 4 may include residential, industrial, military, agricultural, and recreational land uses. For the purposes of this RA, three basic future land use scenarios--residential, military, and light industrial--were evaluated. The residential land use scenario was evaluated because it is the most conservative of the future scenarios; the military and light industrial land use scenarios are more feasible potential land use scenarios. Thus, when evaluating potential future risks (and remedial action criteria in Section 8.0), it must be remembered that the likelihood of residential development at Site 4 is very low.

The RA includes the pathways presenting the greatest possible exposure to potential future receptors. Four possible exposure pathways--incidental ingestion of soil, dust inhalation, dermal contact with soil contaminants, and groundwater ingestion--were evaluated for the future land use scenarios. These pathways were selected for quantification because they represent direct exposure pathways that have the potential for a higher magnitude of exposure than indirect pathways (e.g., ingestion

of game, livestock, and crops, etc.). The elimination of less important exposure pathways--where exposure and, therefore, risk/hazard would be expected to be minimal--should not significantly affect the RA. Although groundwater ingestion is included as a potential future exposure pathway, it is unrealistic to assume that drinking water wells would be installed in the heavily explosives-contaminated groundwater aquifer in the future; therefore, risks presented for the groundwater exposure pathway do not represent actual potential future risks, because it is unlikely that this exposure pathway would be complete in the future.

The elimination of contaminants as contaminants of concern may be another source of uncertainty in assessing risk. Because the purpose of this RA is to assess the potential future health risks posed by explosives-contaminated soils and groundwater associated with the Explosives Washout Lagoon (Site 4), all detected explosives were selected as contaminants of concern and were carried through the quantitative risk assessment. Other detected analytes were not included as contaminants of concern, but will be addressed in the installation-wide Baseline RA.

7.6.2.2 Model Applicability and Assumptions. There is always some doubt as to how well an exposure model or its mathematical expression approximates the true relationships between site-specific environmental conditions. Air modeling was conducted in this RA to estimate the concentrations of contaminants in air in a number of locations that were considered potential exposure points. An emission rate for wind erosion of the respirable fraction of contaminated soil was first estimated, followed by dispersion modeling. Windblown or fugitive dust emissions from Site 4 were estimated using the Cowherd et al. (1988) model. A discussion of the Cowherd model and assumptions is presented in Appendix B. Site-specific data were used when available, supplemented by regional data and empirical formulas. Assumptions were, in general, conservative--to give a reasonable but conservative estimate of the soil emission rate.

The dispersion modeling procedure described in Cowherd et al. (1985) was used to estimate annual average ambient concentrations attributable to respirable

particulate emissions from Site 4. This model is based on a series of Industrial Source Complex-Long Term (ISCLT) model outputs that were tabulated using averaged meteorological data for seven climatic regions in the United States. A complete discussion of the dispersion model and assumptions is presented in Appendix B. Assumptions for the estimated concentrations of contaminants in air were generally conservative.

7.6.2.3 Parameter Value Uncertainty. Numerous parameter values are included in the calculations of chemical fate and transport and human intake. Uncertainties may be associated with significant site data gaps or gaps in the available analytical data. As previously discussed, uncertainties always exists in attempting to predict future conditions and estimating future human intakes of site contaminants. One major source of uncertainty with all four exposure pathways is in the selection of exposure parameters (e.g., exposure frequency, exposure duration, averaging time, fraction ingested from contaminated source etc.). In addition to the above-mentioned exposure parameters, each pathway has pathway-specific assumptions that may contribute to uncertainty.

For the residential and light industrial land uses scenarios, the assumptions used are the EPA Region X "reasonable maximum exposure" (RME) values (USEPA, 1990b). These values are conservative, and potential future exposures are likely to be much less than the indicated Region X values. For the military land use scenario, more reasonable conservative exposure parameters were employed; therefore, the estimated risks are more likely to approach actual potential future risks.

Large uncertainties exist with the dermal absorption exposure pathway. To quantitate dermal exposure, chemical-specific oral and dermal absorption factors are required. However, because these data are not available for most explosives, except for 2,4,6-TNT, chemical-specific absorption factors could not be determined. Thus, per EPA Region X guidance (USEPA, 1991d), the oral and dermal absorption factors for 2,4,6-TNT were used as default values for all explosives except RDX (available information indicate that RDX is not dermally absorbed). However, structural and

chemical differences exist between 2,4,6-TNT and the other explosives, so there are large uncertainties in applying the TNT dermal and oral absorption factors to the other explosives.

The applicability of laboratory-derived absorption factors to conditions at UMDA (dry dust on skin) is also uncertain. Laboratory-derived absorption factors are obtained under artificial laboratory conditions (applied to shaved skin and taped in place) using dimethylsulfoxide (DMSO), corn oil, or other vehicles that significantly increase the dermal absorption of chemicals. Therefore, the use of laboratory-derived absorption factors for 2,4,6-TNT as indicative of site conditions is questionable. The assumption that laboratory-derived absorption factors for 2,4,6-TNT are applicable to site conditions results in significantly elevated risks for the dermal absorption pathway; actual potential future risks are likely to be significantly lower. Additional uncertainties in the dermal exposure pathway exist for the skin surface area available for contact (SA), the soil to skin adherence factor (AF), and the fraction of soil in contact with skin from the contaminated source (FC). Region X RMEs were used for these parameters. As previously discussed, these values are conservative, and potential future exposures are likely to be much less than those indicated by Region X RME values. The large number of conservative assumptions required to quantitate the dermal absorption exposure pathway likely leads to an overestimation of the potential future risks of the site.

Uncertainties also exist in the data as to whether the available soil and groundwater concentration measurements are representative of the true distribution of soil and groundwater contaminant concentrations. The 95 percent upper confidence limit on the arithmetic mean of the chemical concentration is generally used as the exposure point concentration, which is conservative (i.e., exposure point concentrations are not likely to be greater than the 95 percent upper confidence limit on the arithmetic mean). For two contaminants--1,3,5-TNB and 2,4-DNT--soil samples were not collected from the lagoons, but were collected from the berms outside the lagoons, providing an additional source of uncertainty. Because the concentrations of contaminants inside the lagoons appeared to be greater than in the berms, the

maximum detected concentrations in the berms were assumed to be the exposure point concentrations.

7.6.2.4 Magnification of Uncertainties. The uncertainties discussed above are carried throughout the RA process and affect the final risk estimates. Because these uncertainties generally represent conservative assumptions, and are frequently combined in multiplicative ways, the final risk estimates will be even more conservative due to fundamental rules of probability (i.e., overestimates of actual potential future risk) (Burmaster and Lehr, 1991). Therefore, when evaluating potential future risks (and remedial action criteria in Section 8.0), it must be remembered that the risk estimates were generally very conservative, and that the actual potential future risks at the site are likely lower than the calculated risk estimates.

8.0 REMEDIAL ACTION CRITERIA

Remedial action criteria (or cleanup action levels) are developed in this section for the surface soils of the Explosive Washout Lagoons area based on the land use scenarios, exposure pathways, and specific exposure assumptions presented previously in this RA. This includes the development of remedial action criteria for soil, which are based on the protection of groundwater from further contamination due to leaching of explosives from residual contaminants in site soils.

The action levels for contaminants of concern that are potential carcinogens are residual contaminant concentrations in site media that allow associated health risk levels to fall within target risk ranges. The target risks considered, which encompass the EPA target risk range of 10^{-4} to 10^{-6} (National Contingency Plan (NCP); 40 CFR, Subpart E, Section 300.430), are 10^{-4} , 10^{-5} , and 10^{-6} .

The action levels for noncarcinogenic contaminants of concern are residual contaminant concentrations in site media that result in hazard indices that do not exceed 1.0 (40 CFR, Subpart E, Section 300.430). The target hazard indices considered are 0.1, 1.0 and 10.

It is important to recognize that several contaminants of concern—specifically 2,4,6-TNT, 2,4-DNT, 2,6-DNT, and RDX—exhibit both carcinogenic and noncarcinogenic toxic effects. Within what is considered an acceptable "target value pair" (e.g., 10^{-4} risk level and hazard index of 1.0), the accepted action level for a given contaminant that may exhibit carcinogenic and noncarcinogenic effects should be the lesser of the carcinogenic and noncarcinogenic values.

The following approach for determining remedial action criteria for each environmental medium causing elevated risk at the Explosive Washout Lagoons is in accordance with approaches described in Rosenblatt and Small (1981), Small (1984), and EPA (1986b). The elements of this approach include:

- Identification of the reasonable exposure pathways and environmental media facilitating unacceptable exposures.

- For each pathway/environmental medium to which exposure results in estimated cancer risks exceeding 10^{-6} , and/or a noncancer hazard quotient of greater than 1.0, rearrangement of the appropriate exposure assessment equations (as presented in Section 5.0 and 7.0) so that the contaminant concentrations in the affected media are defined in terms of acceptable exposure levels (doses corresponding to the acceptable risk level for potential carcinogens and RfDs for noncarcinogens) and other variables used to estimate exposure.
- Determination of remedial action criteria by calculation of the contaminant concentrations in affected media that would result in acceptable exposure levels (doses corresponding to the acceptable risk level for potential carcinogens and RfDs for noncarcinogens) at exposure points.

Remedial action criteria determined for each medium and pathway by this procedure are referred to by Rosenblatt and Small (1981) as single pathway preliminary pollutant limit values (SPPPLV). If a particular medium has been determined to exhibit unacceptable risks via more than one exposure pathway, the cleanup goal for that medium must account for the possibility of multiple exposures by more than one pathway. SPPPLVs are used in Equation 8-1 (Rosenblatt and Small, 1981) to derive the cleanup goals, or preliminary pollutant limit values (PPLV), that account for possible multiple exposures to contaminants of concern in the same medium by different exposure pathways:

$$\text{PPLV} = \frac{1}{(1/\text{SPPPLV} (1)) + (1/\text{SPPPLV} (2)) + \dots + (1/\text{SPPPLV} (m))} \quad (\text{Eq 8-1})$$

where:

- m = total number of pathways considered in the multiple exposure calculation
- PPLV = preliminary pollutant limit values

SPPLV = single pathway preliminary pollutant limit values.

In situations where only one exposure pathway is causing unacceptable exposure for the medium being evaluated, the SPPLV for that pathway is the final cleanup goal. Because all four potential exposure pathways may potentially pose risks in excess of 10^{-6} , or are estimated to result in noncancer hazard quotients of greater than 1.0 for one or more of the three land use scenarios, the above method will be used.

Remedial action criteria determined by the above procedures for the target risks of 10^{-6} , 10^{-5} , and 10^{-4} represent the concentrations below which potential human exposures to residual contamination are estimated not to cause risks in excess of the applicable target risk. Considering that the exposure estimates presented in Section 5.0 are conservative, so too are the remedial action criteria conservative (i.e., low). It is also important to note that the criteria are target levels that do not consider potential technology limitations. Typically, if the remedial action criterion is below the capability of available technologies, the inherent limits of the best available technology become the operative remedial action level. Nine evaluation criteria--some of which are related to human health evaluation and risk--have been developed to address statutory requirements as well as additional technical and policy considerations that have proven to be important for selecting among remedial alternatives. These evaluation criteria are as follows (USEPA, 1989a):

- **Overall protection of human health and environment**
- **Compliance with ARARs (unless a waiver is applicable)**
- **Long-term effectiveness and permanence**
- **Reduction of toxicity, mobility, or volume through the use of treatment**
- **Short-term effectiveness**
- **Implementability**
- **Cost**
- **State acceptance**
- **Community acceptance.**

In addition, the tentative remedial action criteria presented in this section are not meant to be strictly used in establishing definite bounds for the cleanup of contaminated media. These goals are useful as guidelines for defining and evaluating remedial action alternatives and should be used only for this purpose, in conjunction with knowledge of the nature and extent of contamination, estimates of the reduction of risks posed by implementation of different remedial alternatives, and other key remedial action evaluation criteria. The selected remedial actions for contaminated media need not meet the cleanup goals specified herein as long as they are cost-effective remedial alternatives that effectively mitigate and minimize threats to and provide adequate protection of public health and welfare and the environment, as specified in the NCP (CFR 300.68(i)).

8.1 REMEDIAL ACTION CRITERIA FOR EXPOSURE BY SOIL INGESTION

Table 8-1 presents the action levels for several target risk and hazard index values calculated for the residential land use scenario by way of the soil ingestion exposure pathway. The remedial action criteria calculation performed included the same exposure assumptions as used for risk characterization under the residential land use scenario.

For the residential land use scenario, action levels are derived by a two-step process. First, age-group specific action levels are derived. These action levels are then simultaneously evaluated by a mathematical algorithm. The algorithm produces an overall action level that is protective of human health assuming a lifetime of exposure to the individual who spends a lifetime at the site and conceivably is the receptor for each of the age groups.

The first step is accomplished by rearranging the equations in Sections 5.0 and 7.0 that were used to derive intakes and risks and hazard indices, as described above. The rearrangement consists of simply solving for the contaminant concentration in the source media as a function of the values for the other equation variables, using the target risk and hazard index values identified above.

TABLE 8-1

Remedial Action Criteria (Action Levels) for the Explosive Wastebot Lagoons (Site 4)
Incidental Soil Ingestion
Residential Land Use Scenario

Analyte	Action Level (mg/kg) Corresponding to 1.0E-06 Risk Level						Total Carcinogenic Action Level (a)	
	0-3 YRS	3-6 YRS	6-9 YRS	9-12 YRS	12-15 YRS	15-18 YRS	Risk = 1E-06	Risk = 1E-04
ANALOG	—	—	—	—	—	—	—	—
136TNS	—	—	—	—	—	—	—	—
130NS	—	—	—	—	—	—	—	—
240TNT	215.50	70.53	403.78	711.04	1007.31	1204.52	22.72	2272
240TNT	9.51	3.12	21.78	31.37	44.44	53.15	1.00	100
240TNT	9.51	3.12	21.78	31.37	44.44	53.15	1.00	100
HMX	—	—	—	—	—	—	—	—
NS	—	—	—	—	—	—	—	—
PDX	58.77	19.32	134.57	183.82	274.72	328.59	8.59	82.0
								620

Analyte	Action Level (mg/kg) Corresponding to a Hazard Index of 1.0						Total Noncarcinogenic Action Level (b)	
	0-3 YRS	3-6 YRS	6-9 YRS	9-12 YRS	12-15 YRS	15-18 YRS	Hazard Index = 0.1	Hazard Index = 1
ANALOG	245.67	4.25	29.53	42.06	60.44	72.29	0.36	3.63
136TNS	491.35	8.50	59.35	86.32	120.86	144.56	9.73	7.25
130NS	245.67	4.25	29.53	42.06	60.44	72.29	3.63	36.25
240TNT	9228.92	170.00	1188.06	1706.49	2417.53	2891.56	14.50	145.00
240TNT	4913.46	85.00	592.53	853.25	1208.77	1445.78	7.25	72.50
HMX	245673.06	4280.00	29525.82	43982.34	60439.31	72288.96	362.50	3625.00
NS	2456.73	42.50	295.27	439.82	604.39	722.89	3.63	36.25
PDX	14740.35	255.00	1777.00	2559.74	3625.30	4337.34	21.78	217.50
								2175.0

(a) - Total carcinogenic action levels (mg/kg) are calculated by taking the reciprocal of the sum of the reciprocals of the action level for each age interval. This calculation has the effect of weighting each age interval, included in the summation, in proportion to the risk incurred within each interval.

(b) - Total noncarcinogenic action levels (mg/kg) are calculated by averaging the calculated action levels for 0-3 year olds and 3-9 year olds because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario.

... indicates that the relevant health effects criteria are unavailable.

The second step involves calculation of total action levels. For carcinogenic action levels, this involves taking the reciprocal of the sum of the reciprocals of the action levels for each age interval. This calculation has the effect of combining all the contaminant intakes received within each of the age periods that a potential receptor experiences, by weighing each age interval in proportion to the risk incurred during each interval. For example, if one substitutes the resulting total action level back into the risk and intake calculations for each age period, and then solves for risk and sums the results, the result would be the target risk. For noncarcinogenic action levels for the residential soil ingestion pathway, this involves averaging the calculated action levels for 0 to 3 year olds and 3 to 6 year olds. Because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario, this calculation has the effect of developing action levels protective of the most sensitive age group (0 to 6 year olds).

The results of the calculation are broken into age intervals only for the target values of risk equals 10^{-4} and hazard index equals 1.0. (Age interval calculations were also performed for all other target risk and hazard index values, but only the totals are included in Table 8-1.) It is apparent from the age breakdown that the most stringent action levels are necessary for the protection of young children (0 to 6 years old).

Table 8-2 presents the remedial action criteria for the various target risk and hazard index values calculated for the light industrial land use scenario based on the soil ingestion exposure pathway. The calculation used the same exposure assumptions as used for risk characterization for this land use scenario. The total carcinogenic and noncarcinogenic action levels are approximately 5 and 25 times greater than for the residential land use scenario, respectively, primarily because only exposure by adults is assumed for the light industrial land use scenario.

Table 8-3 presents the remedial action criteria for several target risk and hazard index values calculated for the most probable military land use scenario by way of the soil ingestion exposure pathway. The calculation uses the same exposure assumptions

TABLE 8-2

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Incidental Soil Ingestion
Light Industrial Land Use Scenario**

Analyte	Action Level (mg/kg) for Various Target Risk Levels		
	Risk = 1.0×10^{-6}	Risk = 1.0×10^{-5}	Risk = 1.0×10^{-4}
135TNS	—	—	—
130NS	—	—	—
245TNT	121.0	1210	12000
240NT	5.3	53	534
260NT	5.3	53	534
HMX	—	—	—
NS	—	—	—
RDX	33.0	330	3300

Analyte	Action Level (mg/kg) for Various Hazard Indices		
	Hazard Index = 0.1	Hazard Index = 1.0	Hazard Index = 10
135TNS	9.7	96.8	968
130NS	10.4	103.0	1030
245TNT	96.8	967.8	9678
240NT	367.1	3671.2	36712
260NT	103.0	1030.0	10300
HMX	9678.0	96780.3	967803
NS	96.8	967.8	9678
RDX	590.7	5906.8	59068

— indicates that the relevant health effects criteria are unavailable.

TABLE 8-3

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Incidental Soil Ingestion
Military Land Use Scenario**

Analyte	Action Level (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04
135TNS	—	—	—
135NS	—	—	—
246TNT	7300	73000	730000
24DNT	322	3221	32206
26DNT	322	3221	32206
HMX	—	—	—
NS	—	—	—
RDX	1801	18000	180001

Analyte	Action Level (mg/kg) for Various Target Hazard Indices		
	Hazard Index = 0.1	Hazard Index = 1.0	Hazard Index = 10
135TNS	44	436	4360
135NS	86	876	8760
246TNT	436	4360	43600
24DNT	1782	17820	178200
26DNT	876	8760	87600
HMX	43600	436000	NA
NS	436	4360	43600
RDX	2626	26260	262600

— indicates that the relevant health effects criteria are unavailable.

NA - Not applicable because the calculated action level is greater than one million parts per million (mg/kg).

as used for risk characterization under this land use scenario by way of the soil ingestion exposure pathway. The action levels are much greater than the other two land use scenarios, reflecting the shorter assumed time exposure parameters and only adult exposure for the military land use scenario.

8.2 REMEDIAL ACTION CRITERIA FOR EXPOSURE BY DUST INHALATION

Tables 7-6 through 7-8 indicate that current conditions at the Explosive Washout Lagoons do not pose particularly great risks or hazards from exposure by dust inhalation, as compared to exposure by soil ingestion or dermal absorption of soil, for any of the three land use scenarios. However, because soil action levels are additive across pathways, the dust inhalation pathway will contribute to the total remedial action criteria. Thus, because final remediation should account for all potential exposure, remedial action criteria are calculated for this exposure pathway and for all three land use scenarios, even though calculated risks were shown to be low.

Table 8-4 presents action levels for the various target risk and hazard index values evaluated for the residential land use scenario by way of the dust inhalation exposure pathway. The three columns at the left side of Table 8-4 show action levels for air based on the same exposure assumptions as used for risk characterization for the residential land use scenario. The other columns in Table 8-4 list action levels for the dust source (surface soil). The development of these values uses the relationship of dust concentration in air to surface soils concentration determined by the wind erosion and dispersion modeling described in Appendix B, the results of which are presented in Table 7-5. The action levels presented in Table 8-4 are quite high. In fact, based on all the surface soils data collected at Site 4, the only analyte that exceeded the target levels of 10^{-6} for risk and 1.0 for hazard index is 2,4,6-TNT (and only in two out of 16 samples).

Table 8-5 presents remedial action criteria for the various target risk and hazard index values evaluated for the light industrial land use scenario by way of the

TABLE 8-4

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Inhalation of Dust
Residential Land Use Scenario**

Analyte	Dust Action Levels for Air (pg/m ³)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04	Risk = 1.0E-06	Risk = 1.0E-05	Risk = 1.0E-04
135TNB	--	--	--	--	--	--
13DNB	--	--	--	--	--	--
246TNT	7.78E+04	7.78E+05	7.78E+06	3,968	39,683	396,825
24DNT	3.43E+03	3.43E+04	3.43E+05	175	1,751	17,507
26DNT	3.43E+03	3.43E+04	3.43E+05	175	1,751	17,507
HMX	--	--	--	--	--	--
NB	--	--	--	--	--	--
RDX	2.12E+04	2.12E+05	2.12E+06	1,082	10,823	108,225

Analyte	Dust Action Levels for Air (pg/m ³)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Hazard Indices		
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10
135TNB	1.17E+04	1.17E+05	1.17E+06	595	5,952	59,524
13DNB	2.33E+04	2.33E+05	2.33E+06	1,190	11,905	119,048
246TNT	1.17E+05	1.17E+06	1.17E+07	5,952	59,524	595,238
24DNT	4.67E+05	4.67E+06	4.67E+07	23,810	238,095	NA
26DNT	2.33E+05	2.33E+06	2.33E+07	11,905	119,048	NA
HMX	1.17E+07	1.17E+08	1.17E+09	595,238	NA	NA
NB	1.17E+05	1.17E+06	1.17E+07	5,952	59,524	595,238
RDX	7.00E+05	7.00E+06	7.00E+07	35,714	357,143	NA

HI - Hazard Index

NA - Not applicable because the calculated action level is greater than one million parts per million (mg/kg).

-- indicates that the relevant health effects criteria are unavailable.

TABLE 8-5

Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Inhalation of Dust
Light Industrial Land Use Scenario

Analyte	Dust Action Levels for Air (pg/m3)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04	Risk = 1.0E-06	Risk = 1.0E-05	Risk = 1.0E-04
135TNB	--	--	--	--	--	--
13DNB	--	--	--	--	--	--
246TNT	1.61E+06	1.61E+06	1.61E+07	8,230	82,296	822,962
24DNT	7.12E+03	7.12E+04	7.12E+05	363	3,631	36,307
26DNT	7.12E+03	7.12E+04	7.12E+05	363	3,631	36,307
HMX	--	--	--	--	--	--
NB	--	--	--	--	--	--
RDX	4.40E+04	4.40E+05	4.40E+06	2,244	22,444	224,444

Analyte	Dust Action Levels for Air (pg/m3)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Hazard Indices		
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10
135TNB	1.29E+04	1.29E+05	1.29E+06	658	6,584	65,837
13DNB	2.58E+04	2.58E+05	2.58E+06	1,317	13,167	131,674
246TNT	1.29E+05	1.29E+06	1.29E+07	6,584	65,837	658,369
24DNT	5.16E+05	5.16E+06	5.16E+07	26,335	263,348	NA
26DNT	2.58E+05	2.58E+06	2.58E+07	13,167	131,674	NA
HMX	1.29E+07	1.29E+08	1.29E+09	658,369	NA	NA
NB	1.29E+05	1.29E+06	1.29E+07	6,584	65,837	658,369
RDX	7.74E+05	7.74E+06	7.74E+07	39,502	395,022	NA

HI - Hazard Index

NA - Not applicable because the calculated action level is greater than one million parts per million (mg/kg).

-- indicates that the relevant health effects criteria are unavailable.

dust inhalation exposure pathway. The format of Table 8-5 is the same as for Table 8-4. The action level calculation uses the same exposure assumptions as used for risk characterization for the land use scenario. Concentrations of 2,4,6-TNT from only two surface soil samples exceeded the action levels based on target levels of 10^{-6} for risk and 1.0 for hazard index. No other analytes were detected at concentrations greater than the action levels.

Table 8-6 presents remedial action criteria for the military land use scenario by way of dust inhalation exposure. The action level calculation uses the same exposure assumptions as used for risk characterization under this land use scenario. The resulting action levels for all contaminants are greater than any detected concentrations in surface soils associated with the lagoons.

8.3 REMEDIAL ACTION CRITERIA FOR EXPOSURE BY DERMAL CONTACT WITH SOIL

Table 8-7 presents action levels for several target risk and hazard index values calculated for the residential land use scenario by way of the dermal contact with soil pathway. The remedial action criteria calculation performed includes the same exposure assumptions as used for risk characterization under the residential land use scenario. For the residential land use scenario, action levels are derived by a two-step process, as described in Section 8.1 for the soil ingestion exposure pathway. The results of the calculation are broken into age intervals only for the target values of risk equal to 10^{-6} and hazard index equal to one. (Age interval calculations were also performed for all other target risk and hazard index values, but only the totals are included in Table 8-7.) It is apparent from the age breakdown that the most stringent action levels are necessary for the protection of young children (0 to 6 years old).

Table 8-8 presents remedial action criteria for the various target risk and hazard index values calculated for the light industrial land use scenario based on the dermal contact with soil exposure pathway. The calculation uses the same exposure assumptions as used for risk characterization for this land use scenario. The total carcinogenic and noncarcinogen action levels are approximately 2 and 6 times greater,

TABLE 8-6

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Inhalation of Dust
Military Land Use Scenario**

Analyte	Dust Action Levels for Air (pg/m3)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04	Risk = 1.0E-06	Risk = 1.0E-05	Risk = 1.0E-04
135TNB	--	--	--	--	--	--
13DNB	--	--	--	--	--	--
246TNT	9.13E+06	9.13E+07	9.13E+08	465,561	NA	NA
24DNT	4.03E+05	4.03E+06	4.03E+07	20,539	205,395	NA
26DNT	4.03E+05	4.03E+06	4.03E+07	20,539	205,395	NA
HMX	--	--	--	--	--	--
NB	--	--	--	--	--	--
RDX	2.49E+06	2.49E+07	2.49E+08	126,971	NA	NA

Analyte	Dust Action Levels for Air (pg/m3)			Dust Source (Soil) Action Levels (mg/kg) for Various Target Hazard Indices		
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10
135TNB	5.48E+04	5.48E+05	5.48E+06	2,793	27,934	279,337
13DNB	1.09E+05	1.09E+06	1.10E+07	5,587	55,867	558,673
246TNT	5.48E+05	5.48E+06	5.48E+07	27,934	279,337	NA
24DNT	2.19E+06	2.19E+07	2.19E+08	111,735	NA	NA
26DNT	1.09E+06	1.10E+07	1.09E+08	55,867	558,673	NA
HMX	5.48E+07	5.48E+08	5.48E+09	NA	NA	NA
NB	5.48E+05	5.48E+06	5.48E+07	27,934	279,337	NA
RDX	3.29E+06	3.29E+07	3.29E+08	167,602	NA	NA

HI - Hazard Index

NA - Not applicable because the calculated action level is greater than one million parts per million (mg/kg).

-- Indicates that the relevant health effects criteria are unavailable.

TABLE 8-7

Remedial Action Criteria (Action Levels) for the Explosive Washout Lagoons (Site 4)
Dermal Contact With Soil
Residential Land Use Scenario

Analyte (c)	Action Level (mg/kg) Corresponding to 1.0E-06 Risk Level					Total Carcinogenic Action Level (a)	
	0-3 yrs	3-6 yrs	6-9 yrs	9-12 yrs	12-15 yrs	15-18 yrs	
135TNB	—	—	—	—	—	—	1E-06
13DNB	—	—	—	—	—	—	1E-06
246TNT	16.96	22.48	64.55	76.24	82.91	76.89	475
24DNT	0.70	0.90	2.85	3.32	3.66	3.37	21
26DNT	0.70	0.90	2.85	3.32	3.66	3.37	21
HMX	—	—	—	—	—	—	—
NB	—	—	—	—	—	—	—

8-14

Analyte (c)	Action Level (mg/kg) Corresponding to a Hazard Index of 1.0					Total Noncarcinogenic Action Level (b)		
	0-3 yrs	3-6 yrs	6-9 yrs	9-12 yrs	12-15 yrs	15-18 yrs	Hazard Index = 0.1	Hazard Index = 1
135TNB	16.20	1.21	1.35	3.87	4.81	4.89	0.13	1.28
13DNB	36.40	2.42	2.70	7.76	9.03	9.06	0.26	2.56
246TNT	181.98	12.12	13.48	38.73	46.15	46.74	1.28	12.81
24DNT	—	48.48	53.97	154.91	180.56	183.89	5.12	51.23
26DNT	—	24.24	26.06	77.46	90.20	91.96	2.56	25.61
HMX	18198.01	1212.12	1340.21	3872.76	4814.53	4874.36	128.97	1280.66
NB	181.98	12.12	13.48	38.73	46.15	46.74	1.28	12.81

(a) - Total carcinogenic action levels (mg/kg) are calculated by taking the reciprocal of the sum of the reciprocals of the action level for each age interval. This calculation has the effect of weighting each age interval, included in the summation, in proportion to the risk incurred within each interval.

(b) - Total noncarcinogenic action levels (mg/kg) are calculated by averaging the calculated action levels for 0-3 year olds and 3-6 year olds because chronic RfDs are used to assess exposure periods of approximately 7 years or longer, and young children are assumed to experience the highest intake in a residential scenario.

(c) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans. — indicates that the relevant health effects criteria are unavailable.

TABLE 8-8

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Dermal Contact With Soil
Light Industrial Land Use Scenario**

Analyte (a)	Action Level (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04
135TNB	--	--	--
13DNB	--	--	--
246TNT	9.0	89.6	896.1
24DNT	0.4	4.0	39.5
26DNT	0.4	4.0	39.5
HMX	--	--	--
NB	--	--	--

Analyte (a)	Action Level (mg/kg) for Various Hazard Indices		
	Hazard Index = 0.1	Hazard Index = 1	Hazard Index = 10
135TNB	0.7	7.2	71.7
13DNB	1.4	14.3	143.4
246TNT	7.2	71.7	716.9
24DNT	28.7	286.8	2867.6
26DNT	14.3	143.4	1433.8
HMX	716.9	7168.9	71689.1
NB	7.2	71.7	716.9

(a) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans.

'--' indicates that the relevant health effects criteria are unavailable.

respectively, than for the residential land use scenario, primarily because only exposure by adults is assumed under the light industrial land use scenario.

Table 8-9 presents remedial action criteria for several target risk and hazard index values calculated for the most probable military land use scenario by way of the dermal contact with soil exposure pathway. The calculation uses the same exposure assumptions as used for risk characterization under this land use scenario by way of the soil ingestion exposure pathway. The action levels for the military land use scenario are much greater than for the other two land use scenarios, reflecting the shorter assumed time exposure parameters and only adult exposure.

8.4 REMEDIAL ACTION CRITERIA IN SOIL BASED ON THE PROTECTION OF GROUNDWATER

Along with risks posed by direct exposure to contaminants of concern in soil—such as ingestion of soil, inhalation of dust, or dermal contact with soil—it is prudent, when developing remedial action criteria for soil, to account for the probable effect of residual soil contaminants on groundwater quality. The goal is that remediation levels in soil should be sufficient to protect groundwater from posing future unacceptable health risks, in the event that groundwater returns to potable quality and future leaching of the soils continues.

Section 8.4.1 summarizes the current methodology used to develop soil action levels for the protection of groundwater and associated results. A more detailed description of the methodology employed, including a discussion of specific uncertainties in the calculations and assumptions, is presented in Appendix C. Following a summary of the methodology currently used to estimate soil action levels, based on the protection of groundwater, it is useful to discuss some unique site features that influence the process of derivation of soil action levels based on the protection of groundwater. Section 8.4.2 summarizes the site-specific characteristics that invalidate the rigorous derivation of soil action levels based on the protection of groundwater.

TABLE 8-9

**Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Dermal Contact With Soil
Military Land Use Scenario**

Analyte (a)	Action Level (mg/kg) for Various Target Risk Levels		
	Risk = 1E-06	Risk = 1E-05	Risk = 1E-04
135TNB	--	--	--
13DNB	--	--	--
246TNT	540.7	5407.4	54074.1
24DNT	23.9	238.6	2385.6
26DNT	23.9	238.6	2385.6
HMX	--	--	--
NB	--	--	--

Analyte (a)	Action Level (mg/kg) for Various Hazard Indices		
	Hazard Index = 0.1	Hazard Index = 1	Hazard Index = 10
135TNB	3.2	32.4	324.4
13DNB	6.5	64.9	648.9
246TNT	32.4	324.4	3244.4
24DNT	129.8	1297.8	12977.8
26DNT	64.9	648.9	6488.9
HMX	3244.4	32444.4	324444.4
NB	32.4	324.4	3244.4

(c) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans.

'--' indicates that the relevant health effects criteria are unavailable.

8.4.1 Methodology for and Results of Remedial Action Criteria Calculations Based on Groundwater Protection

The approach taken to develop soil action levels for the protection of groundwater is limited to a single contaminant (2,4,6-TNT) under both the residential and light industrial land use scenarios, and is also based on some gross assumptions about conditions in the vicinity of Site 4. Action levels are developed only for 2,4,6-TNT, because measured partition coefficients are available for 2,4,6-TNT in soil that is similar to the soil at UMDA. Also, 2,4,6-TNT is, by far, the most pervasive soil contaminant at Site 4.

The methodology followed is in general agreement with the approach used in a Record of Decision for a site in Millcreek, Pennsylvania (USEPA, 1989a). The approach included determination of an acceptable concentration of TNT in groundwater used as drinking water at a potential receptor location assumed to be proximate to the lagoons; determination of the concentration of TNT in the leachate by assuming the mixing of leachate with groundwater flow and percolating precipitation; and use of the Freundlich isotherms measured in similar soils at other Army installations to estimate the TNT soil concentrations in equilibrium with the leachate (Pennington and Patrick, 1990). The specifics of this modeling approach are presented in Appendix C.

The results of the modeling (Appendix C) show that--for the protection of groundwater at a compliance point immediately adjacent to the lagoons and a 10^{-6} target risk level--the remedial action criteria are 0.51 mg/kg TNT for the residential land use scenario and 1.13 mg/kg TNT for the light industrial land use scenario. Comparison of the soil cleanup action level of TNT based on the protection of groundwater with the cleanup action level estimate for TNT in soil based on the soil ingestion pathway (see Tables 8-1 and 8-2) reveals far more conservative values for the protection of groundwater (i.e., a difference of greater than 100 times for the residential land use scenario and 30 times for the light industrial land use scenario.)

Inherent to the derivation of soil action levels based on the protection of groundwater by the methodology outlined above and described in Appendix C is the assumption that soil leaching is an important process for causing groundwater contamination. As the discussion in Section 8.4.2 reveals, the significance of soil leaching on groundwater contamination at the subject site may be minor or irrelevant--calling into question the usefulness of the above calculation of soil cleanup levels based on the protection of groundwater.

8.4.2 Observations Concerning the Calculation of Remedial Action Criteria Based on Groundwater Protection

The fundamental issue in attempting to quantitatively relate soil action levels to action levels based on the protection of groundwater is that the existing chemical data suggest that groundwater contamination at Site 4 has not resulted from the leaching of contaminants in soil.

Inherent to the task of "estimating soil action levels that are protective of groundwater" is the assumption that the leaching of contamination from soil will or has caused groundwater contamination. This inherent assumption may be invalid at Site 4. The principal observation in support of the suspicion that groundwater contamination has resulted from processes independent of soil leaching is that near-surface lagoon soils, and soils from surrounding berms, are highly contaminated with 2,4,6-TNT, while groundwater is not contaminated primarily by TNT. Instead, an extensive plume of RDX is the principal groundwater contamination signature. Therefore, it may be inappropriate to predict current groundwater contaminant concentrations by using soils data and assuming commonly used contaminant partitioning and transport modeling, because there is no way to validate models for a specific site.

It is known that TNT and RDX have some different chemical (e.g., octanol-water partition coefficient) and biodegradation properties (see Appendix A); however, we do not feel that these chemical property differences are sufficient to explain the discrepancies between soil and groundwater data. A more plausible explanation for

the apparent independence of contamination associated with soil and groundwater stems from the nature of historical operations at the Explosive Washout Lagoons. Three facts are significant concerning operations at the site:

- 85 million gallons of explosives-contaminated wastewater were directed into the lagoons over a span of 10 years and infiltrated through the soil.
- The composition of particular explosives processed (and wastes generated) changed with time.
- Surface sludges were periodically removed from the lagoons for disposal, implying that the contaminants detected in surface soil now are not necessarily representative of wastes generated throughout the active history of the site.

Based on these observations, it seems probable that the RDX groundwater plume was produced by an influx of RDX-contaminated wastewater, and that the plume is not necessarily closely related chemically to the soil currently present in the lagoons. This is not to say that the typical processes commonly used for determining action levels for the protection of groundwater (such as leaching from soil by rainwater, equilibrium partitioning between soil and leachate, mixing and advection of contaminants in groundwater) do not occur, but that they may not be significant processes at Site 4.

In addition, there are conflicts regarding contaminant groundwater flow direction, and thus contaminant transport direction, at Site 4. Groundwater elevations measured in monitoring wells produce a potentiometric surface that suggests groundwater flow direction to the northwest (Roy F. Weston, 1989). However, the RDX contaminant plume in groundwater suggests that the dominant flow direction is southerly and perhaps southeasterly. This observed contradiction brings inherent uncertainty into the determination of groundwater flow direction and velocity. Flow direction and velocity are necessary modeling parameters to determine remedial action criteria for soil based on the protection of groundwater.

Two other issues affect the development of soil action levels based on the protection of groundwater. Both issues, as discussed below, affect typical assumptions used in this type of analysis:

- Equilibrium partitioning based on the organic carbon content of soils is the common way of estimating corresponding soils concentrations from groundwater concentrations (and vice versa) and represents the most prevalent partitioning data available. However, equilibrium partitioning between TNT in soil and groundwater has been shown to not strongly be a function of organic carbon in soil based on batch adsorption/desorption experiments on TNT-contaminated soils (Pennington and Patrick, 1990). Therefore, it seems inappropriate by analogy to 2,4,6-TNT to use this approach for other explosives contaminants, even though the necessary data are available.
- A standard assumption necessary in this type of analysis is that groundwater initially is "clean," so that the future effect of leaching contaminated soil on groundwater quality can be estimated by modeling. This assumption seems to be particularly difficult to justify at Site 4, considering the highly contaminated groundwater and extensive distribution of contaminants. In other words, even if surface soil was remediated to the minimum level achievable, the benefits to future groundwater quality from minimizing the leaching of residual soil contaminants are likely to be insignificant compared to any separate groundwater remediation that is likely necessary at the site.

8.5 REMEDIAL ACTION CRITERIA FOR MULTIPLE PATHWAY EXPOSURE

Because remedial action criteria (SPPLVs) were developed for more than one pathway, these SPPLVs are used in Equation 8-1 (Rosenblatt and Small, 1981) to derive the cleanup goals, or PPLVs, that account for possible multiple exposures to contaminants of concern by different exposure pathways. However, because of the

inherent problems of developing soil action levels based on the protection of groundwater (see Section 8.4.2), PPLVs are based only on the soil exposure pathways. Tables 8-10 through 8-12 present the PPLVs for several target risk and hazard index values for the residential, light industrial, and military land use scenarios.

The PPLVs presented in Tables 8-10 through 8-12 are levels at which each contaminant will not exceed the target risk levels or hazard index values. However, because the remedial action criteria are based on conservative assumptions (see Section 7.6 for a discussion of uncertainties), the criteria presented in Tables 8-10 through 8-12 are conservative (i.e., low)—that is, actual health risks are likely to be less than estimated for each remedial action criterion. In addition, as discussed in Section 7.6, large uncertainties are associated with the dermal absorption exposure pathway; these results should only be used qualitatively.

TABLE 8-10

**Remedial Action Criteria for Multiple Pathway Exposures (PPLVs)
for the Explosive Warrent Lagoons (Site 4)
Residential Land Use Scenario**

Analyte	Remedial Action Criteria (mg/kg) at Various Target Risk Levels									
	Soil Ingestion					Dermal Contact With Soil				
	1.00E-04	1.00E-05	1.00E-06	1.00E-07	1.00E-08	1.00E-04	1.00E-05	1.00E-06	1.00E-07	PPLV
135TMB	—	—	—	—	—	—	—	—	—	—
130N8	—	—	—	—	—	—	—	—	—	—
240TNT	2272	227	23	—	—	—	—	—	—	—
240NT	100	10	1.0	—	—	475	48	4.8	4.0	4.0
260NT	100	10	1.0	—	—	21	2.1	0.21	1.7	0.17
H4IX	—	—	—	—	—	21	2.1	0.21	1.7	0.17
N8	—	—	—	—	—	—	—	—	—	—
RDX	600	62	0.2	—	—	—	—	—	—	—
						(4)	(4)	(4)	62	6.2

Analyte	Remedial Action Criteria (mg/kg) at Various Target Hazard Indices									
	Soil Ingestion					Dermal Contact With Soil				
	HI = 0.1	HI = 1.0	HI = 10	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	HI = 1.0	HI = 10
135TMB	0.36	3.6	36	5062	50620	0.1	1.3	13	0.10	0.90
130N8	0.73	7.3	73	1191	11900	0.3	2.6	26	0.10	1.0
240TNT	3.6	36	363	5062	50624	1.3	13	130	0.90	9.0
240NT	14.5	145	1450	23010	23006	5.1	51	510	3.77	37.7
260NT	7.3	73	725	11906	119048	2.6	26	260	1.91	19.1
H4IX	363	3635	36250	506328	NA	126	1261	12610	95	9458
N8	3.6	36	363	5062	50624	1.3	13	130	0.90	9.0
RDX	22	218	2175	35714	357143	(4)	(4)	(4)	22	217
									22	2174

(a) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans.

TABLE 8-11

**Remedial Action Criteria for Multiple Pathway Exposures (PPLVs)
for the Explosive Washout Lagoons (Site 4)
Light Industrial Land Use Scenario**

Analyte	Remedial Action Criteria (mg/kg) at Various Target Risk Levels									
	Soil Ingestion					Dermal Contact With Soil				
	1.00E-04	1.00E-03	1.00E-02	1.00E-01	1.00E-00	1.00E-04	1.00E-03	1.00E-02	1.00E-01	1.00E-00
135TNS	—	—	—	—	—	—	—	—	—	—
135NBS	—	—	—	—	—	—	—	—	—	—
240TNT	12100	1210	121	—	—	—	—	—	—	—
240NT	530	53	5.3	823000	82300	808	80	8.0	84	8.4
260NT	530	53	5.3	30300	3030	40	4.0	0.40	37	3.7
HAUX	—	—	—	30300	3030	40	4.0	0.40	37	3.7
NB	—	—	—	—	—	—	—	—	—	—
RDX	3300	330	33	224400	22440	(a)	(a)	(a)	3282	328

Analyte	Remedial Action Criteria (mg/kg) at Various Target Hazard Indices									
	Soil Ingestion					Dermal Contact With Soil				
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	HI = 10
135TNS	0.7	07	008	058	0594	05040	0.72	7.2	72	07
135NBS	10	104	1038	1317	13167	131670	1.4	14	143	133
240TNT	07	008	0078	0594	05937	059370	7.2	72	717	067
240NT	307	3071	30710	20335	203348	NA	20.7	207	2070	2072
260NT	104	1038	10380	13167	131674	NA	14.4	144	1440	1340
HAUX	0078	00780	007803	006300	NA	NA	717	7160	71000	00007
NB	07	008	0078	0594	05937	059370	7.2	72	717	067
RDX	501	5007	50008	30502	305022	NA	(a)	(a)	(a)	57227

(a) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans.

TABLE 8-12

**Remedial Action Criteria for Multiple Pathway Exposures (PPLVs)
for the Explosive Washout Lagoons (Site 4)
Military Land Use Scenario**

Analyte	Remedial Action Criteria (mg/kg) at Various Target Risk Levels									
	Soil Ingestion			Dust Inhalation			Dermal Contact With Soil			PPLV
	1.00E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-05	1.00E-06	
135TNS	--	--	--	--	--	--	--	--	--	--
135NBS	--	--	--	--	--	--	--	--	--	--
246TNT	730000	73000	NA	NA	465591	54074	54074	5407	541	603
240TNT	32200	3220	2063000	206300	20630	2366	2366	236	24	22
260TNT	32200	3220	2063000	206300	20630	2366	2366	236	24	22
HMX	--	--	--	--	--	--	--	--	--	--
NB	--	--	--	--	--	--	--	--	--	--
RDX	180100	18010	NA	NA	120671	(a)	(a)	(a)	(a)	1900

Analyte	Remedial Action Criteria (mg/kg) at Various Target Hazard Indices									
	Soil Ingestion			Dust Inhalation			Dermal Contact With Soil			PPLV
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	
135TNS	44	436	4360	2793	27934	279346	3.2	32	324	301
135NBS	86	876	8760	5567	55667	556676	6.5	65	649	604
246TNT	436	4360	43600	27934	279337	NA	32	324	3244	3014
240TNT	1762	17620	176200	111735	NA	NA	130	1298	12980	12005
260TNT	876	8760	87600	55667	556673	NA	65	649	6490	6036
HMX	43600	436000	NA	NA	NA	NA	3244	32444	324444	30203
NB	436	4360	43600	27934	279337	NA	32	324	3244	2979
RDX	2628	26280	262800	167602	NA	NA	(a)	(a)	(a)	25674
										256743

(a) - Remedial action criteria are not determined for RDX for this exposure pathway because of insufficient evidence of dermal absorption in humans.

9.0 SUMMARY AND CONCLUSIONS

This RA was performed to assess the potential future health risks and hazards posed by exposure to explosives-contaminated surface soils associated with the UMDA Explosive Washout Lagoons, and to evaluate safe residual explosives concentrations (action levels) in these soils if remediation is determined to be a requirement. Based on the available data and assessments presented herein, conclusions with respect to the Explosive Washout Lagoons are offered below.

9.1 CONTAMINATION ASSESSMENT

9.1.1 Soil

- **Contamination from explosives is widespread in soil near the lagoons.**
- **Explosives have been detected at all sample locations in the vicinity of the lagoons. Higher concentrations exist in surface soil samples from the lagoons than in surface soil samples from berms near the lagoons; however, berm soil concentrations are still elevated.**
- **Contaminant concentrations in soils generally decrease with depth; however, concentrations tend to increase at depths of 40 to 50 feet, suggesting an influence from groundwater contamination on the deeper soils.**
- **RDX and HMX are more widely distributed with respect to depth than are the other explosives.**

9.1.2 Groundwater

- **Explosives contamination is widespread in groundwater, with contaminants present at a distance of over 650 yards from the lagoons (well 4-3).**
- **RDX is widely distributed (detected in 28 out of 34 monitoring wells), while the other explosives generally are detected only at locations close**

to the lagoons and/or in several wells at low concentrations. The implication from the RDX distribution is that it represents the effect of an influence from historical RDX-contaminated wastewater discharge, not simply leaching from soils. Differential biodegradation of RDX compared to the other explosives may also have an effect on the distribution of RDX.

- The full areal and vertical extent of the RDX plume has not yet been determined.
- Contamination distribution suggests the southerly migration of contaminants, while predominant groundwater flow direction based on water level measurements by Weston may be northwesterly.

9.2 CONTAMINANTS OF CONCERN

- The contaminants of concern selected for soil were 1,3,5-TNB; 1,3-DNB; 2,4,6-TNT; 2,4-DNT; HMX; NB; and RDX.
- The contaminants of concern selected for groundwater were 1,3,5-TNB; 1,3-DNB; 2,4,6-TNT; 2,4-DNT; 2,6-DNT; HMX; NB; RDX; and tetryl.

9.3 EXPOSURE ASSESSMENT

- Three future land use scenarios were considered:
 - 1) Residential
 - 2) Light industrial
 - 3) Military (most probable).
- Four exposure pathways were considered:
 - 1) Soil ingestion
 - 2) Dust inhalation
 - 3) Dermal contact with soil
 - 4) Groundwater ingestion.

9.4 RISK CHARACTERIZATION

- Total risks for the soil ingestion pathway varied from approximately 1.8×10^{-3} for residential land use to 5.5×10^{-6} for military land use, with 3.3×10^{-4} for industrial land use. Total hazard indices were 1,120 (residential), 40 (industrial), and 9 (military).
- Total risks for inhalation of dust were approximately $1.0\text{E-}05$ (residential), $4.9\text{E-}06$ (industrial), and $8.7\text{E-}08$ (military). Total hazard indices varied from 0.66 (residential) to 0.14 (military), with 0.6 for the industrial land use scenario.
- Total risks for dermal contact with soil were approximately 8.2×10^{-3} (residential), 4.4×10^{-3} (industrial), and 7.2×10^{-5} (military). Total hazard indices varied from 3,067 (residential) to 121 (military), with 546 for the industrial land use scenario. As discussed in Section 7.6, large uncertainties are associated with the dermal absorption exposure pathway.
- Total risks and hazards posed by the soil ingestion, dust inhalation, and dermal contact with soil exposure pathways were dominated by TNT exposure.
- The total risk and hazard values for groundwater ingestion were similar for the residential and industrial land use scenarios, assuming a receptor location near the lagoons, with risks of 4.1×10^{-3} and 1.3×10^{-3} for residential and industrial land use, respectively; and hazard indices of approximately 65 and 37, respectively. Total risks and hazards from groundwater ingestion were not calculated for the military land use scenario, because it was assumed that drinking water sources would be the same as currently, where shallow groundwater is not used for drinking water.

The total risk and hazard index values are summarized for each exposure pathway and each land use scenario in Table 9-1.

9.5 REMEDIAL ACTION CRITERIA

- The same land use scenarios, exposure pathways, and specific assumptions were used to estimate remedial action criteria as were used to calculate risks and hazard indices from site-specific chemical data.
- Remedial action criteria were developed only for explosives contaminants for which toxicological data were available, not degradation products that may exist in residual soil subsequent to remediation.
- The cleanup levels based on exposure by soil ingestion, dust inhalation, and dermal contact with soil are presented in Table 9-2. However, as discussed in Section 7.6, large uncertainties are associated with the dermal absorption exposure pathway.
- Cleanup levels based on the protection of groundwater were estimated by:
 - Determining an acceptable level for TNT at an assumed receptor location proximate to the lagoons.
 - Mixing the concentration with groundwater and percolation water to estimate leachate concentration.
 - Using the Freundlich isotherms measured in similar soils at other Army depot activities to estimate the TNT soil concentrations in equilibrium with the leachate.
- Using this approach and assuming a target risk of 10^{-6} , the remedial action criteria for TNT in soil (to be protective of groundwater) is 0.51 mg/kg for residential land use and 1.13 mg/kg for light industrial land use.

TABLE 9-1

**Summary of Results of Risk Characterization
All Exposure Pathways and All Land Use Scenarios
Explosive Washout Lagoons (Site 4), UMDA**

Land Use Scenario	Total Risk				Total Hazard Index			
	<u>Soil Ingestion</u>	<u>Dust Inhalation</u>	<u>Dermal Contact With Soil</u>	<u>Groundwater Ingestion</u>	<u>Soil Ingestion</u>	<u>Dust Inhalation</u>	<u>Dermal Contact With Soil</u>	<u>Groundwater Ingestion</u>
Residential	1.77E-03	1.02E-05	8.23E-03	4.15E-03	1120	0.66	3067	63.1
Light Industrial	3.33E-04	4.90E-06	4.36E-03	1.27E-03	40.5	0.6	546	36.3
Military	5.52E-06	8.66E-08	7.23E-05	(a)	9	0.14	121	(a)

(a) Exposure by groundwater ingestion was not considered for the military land use scenario because it is not expected to be different from the current use where no shallow drinking water wells are installed.

TABLE 9-2

**Summary of Remedial Action Criteria for Multiple Pathway Exposures (PPLVs)
for the Explosives Washout Lagoons (Site 4)
for All Three Land Use Scenarios**

Analyte	PPLVs (mg/kg) at Various Target Risk Levels								
	Residential Land Use Scenario			Industrial Land Use Scenario			Military Land Use Scenario		
	1.00E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-05	1.00E-06
136TNS	—	—	—	—	—	—	—	—	—
13DNS	—	—	—	—	—	—	—	—	—
246TNT	388	40	4.0	837	84	8.4	80313	8031	803
24DNT	17	1.7	0.17	37	3.7	0.37	2231	223	22
28DNT	17	1.7	0.17	37	3.7	0.37	2231	223	22
HMX	—	—	—	—	—	—	—	—	—
NB	—	—	—	—	—	—	—	—	—
RDX	820	82	8.2	3250	325	33	188028	18803	1880

Analyte	PPLVs (mg/kg) at Various Target Hazard Indices								
	Residential Land Use Scenario			Industrial Land Use Scenario			Military Land Use Scenario		
	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10	HI = 0.1	HI = 1.0	HI = 10
136TNS	0.10	0.98	9.8	0.67	6.7	67	3.0	30	301
13DNS	0.19	1.9	19	1.3	13	133	6.0	60	604
246TNT	0.86	8.6	86	6.7	67	667	30	301	3014
24DNT	3.8	38	380	26.7	267	2670	121	1208	12080
28DNT	1.9	19	190	13.4	134	1340	60	604	6040
HMX	86	846	8458	667	6668	66687	3020	30203	302030
NB	1.0	10	96	6.7	67	667	30	298	2979
RDX	22	217	2174	572	5723	57227	2587	25874	258743

- Given the existing relatively high level of groundwater contamination at Site 4, the assumption that groundwater will be "clean" in the future--thus requiring that soil cleanup levels be protective of groundwater as a drinking water source--may be unrealistic. That is, regardless of the stringency of the soil remedial action criteria, the groundwater may remain contaminated to a level that will preclude its use as a drinking water source, despite potential direct efforts (e.g., pump and treatment) to return it to drinking water quality. Therefore, soil cleanup levels based on the protection of groundwater may be less desirable than soil cleanup levels based on direct contact with soil.
- The protection of groundwater scenario has a higher degree of uncertainty, as compared to the scenarios involving direct contact with soil, because of uncertainty in fundamental parameters, such as groundwater flow direction, groundwater flow velocity, thickness of aquifers, and the assumption of chemical equilibrium between leachate and soil. The results of this model should be used only qualitatively.

10.0 REFERENCES

- Ahrenholz, S.H., and R.M. Channing, 1980. NIOSH Health Hazard Evaluation Determination Report, HE 79.
- Agency for Toxic Substances and Disease Registry (ATSDR), 1989. Toxicological Profile for 2,4- and 2,6-Dinitrotoluene, U.S. Public Health Service, Atlanta, Georgia.
- American Conference of Governmental Industrial Hygienists (ACGIH), 1977. Documentation of the Threshold Limit Values for Substances in Workroom Air, Cincinnati, Ohio.
- Ana-Lab Corp., 1988. Groundwater Monitoring Report, August 1988, prepared for Umatilla Army Depot Activity, Hermiston, Oregon, November 1988.
- Battelle Pacific Northwest Laboratories (Battelle), April 1982. Environmental Contamination Survey and Assessment of Umatilla Army Depot Activity (UMDA), Report No. DRXTH-FS-CR-82127, prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Bentley, R.E. et al., 1984. Determination of the Toxicity to Aquatic Organisms of HMX and Related Wastewater Constituents: Part 3 - Toxicity of HMX, TAX, and SEX to Aquatic Organisms, Final Report, Contract DAMD17-80-C-0011, Springborn, Bionomics, Inc.
- Beritic, T., 1956. "Two Cases of M-dinitrobenzene Poisoning With Unequal Clinical Response," British Journal of Industrial Medicine, Vol. 13, No. 114.
- Brower, M.E., 1992. Personal communication with Charles O. Shore, Dames & Moore, March 1992.
- Burmaster, D.E., and J.H. Lehr, 1991. "It's Time to Make Risk Assessment a Science," Groundwater Monitoring Review, Vol. 11, No. 3.
- Century Environmental Services (CES), 1986a. Groundwater Monitoring Report, March 1986, Umatilla Army Depot Activity, prepared for Umatilla Army Depot Activity (UMDA), Hermiston, Oregon, June 1986.
- Century Environmental Services (CES), 1986b. Groundwater Monitoring Report, August 1986, Umatilla Army Depot Activity, prepared for UMDA, Hermiston, Oregon, October 1986.

- Century West Engineering Corp. (CWEC), 1987a. Groundwater Monitoring Report, February 1987, Umatilla Army Depot Activity, prepared for UMDA, Hermiston, Oregon, April 1987.
- Century West Engineering Corp. (CWEC), 1987b. Groundwater Monitoring Report, August 1987, Umatilla Army Depot Activity, prepared for UMDA, Hermiston, Oregon, October 1987.
- Clay, D.R., 1991. "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions," Memorandum dated April 22, 1991, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
- Clayton, G.D., and F.E. Clayton, eds., 1981. Patty's Industrial Hygiene and Toxicology, John Wiley & Sons, Inc.
- Cody, T.E., S. Witherup, L. Hastings, K. Stemmer, and R.T. Christian, 1981. "1,3-Dinitrobenzene, Toxic Effect In Vivo and In Vitro," Journal of Toxicology and Environmental Health, Vol. 7, No. 5, pp. 829-847.
- Couch, D.B., P.I. Allen, and D.J. Abernathy, 1981. "The Mutagenicity of Dinitrotoluene in *Salmonella typhimurium*," Mutagenic Research, Vol. 90, p. 373.
- Cowherd, C., G.E. Muleski, P.J. Englehart, and D.A. Gillette, 1985. Rapid Assessment of Exposure to Particulate Emissions From Surface Contamination Sites, EPA 600/8-85/002, Office of Health and Environmental Assessment, Washington, D.C.
- Cowherd, C., G.E. Muleski, and J.S. Kinsey, 1988. Control of Open Fugitive Dust Sources, EPA 450/3-88/088, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.
- Ellis, H.V., J.H. Hagensen, J.R. Hodgson, J.L. Minor, C.B. Hong, E.R. Ellils, J.D. Girvin, D.O. Helton, B.L. Herndon, and C.C. Lee, 1979. Mammalian Toxicity of Munitions Compounds: Phase III--Effects of Lifetime Exposure. Part I. 2,4-DNT. Final Report No. 7. Contract No. DAMD17-74-C-4073, Midwest Research Institute, Kansas City, Missouri.
- Ellis, H.V. et al., 1980. Chronic Mammalian Toxicological Evaluation of RDX, Midwest Research Institute, Kansas City, Missouri.
- Ellis, H.V. et al., 1985. "Subchronic and Chronic Toxicity Studies of 2,4-Dinitrotoluene, Part I, Beagle Dogs," Journal of the American College of Toxicology, Vol. 4, No. 4, pp. 233-242.

- Ermakov, E.V., V.S. Aizenshatadt, and B.B. Ventsenosteu, 1969. "Chronic Trinitrotoluene Poisoning (Clinical Picture and Pathogenesis of Neuro-Vegetative Disturbances)," Soviet Medicine, Vol. 32, pp. 119-122.
- Everett et al., 1985. HMX: 13-Week Toxicity Study in Rats by Dietary Administration, Contract No. DAMD17-80-C-0053, AD A171601, Inveresk Research International, Final Reports, IRI, Ltd., Musselburgh, Scotland.
- Fairhall, L., 1969. Industrial Toxicology, Hafner Publishing Co.
- Fati, S., and E. Daniele, 1965. "Histological Changes in Experimental Chronic Tetryl Poisoning," Folia Med., Vol. 48, No. 4, pp. 269-276.
- Fogleman, R.W., J.R. Elsea, O.E. Paynter, and W. Kundzins, 1955. "Toxicity of Trinitrobenzene-Aniline Complex, a Rodent Repellant," Agricultural Food Chemistry, Vol. 3, No. 11, pp. 936-939.
- Gordon, L., and W.R. Hartley, 1989. Health Advisory on 2,4,6-Trinitrotoluene, Office of Drinking Water, U.S. Environmental Protection Agency, January 1989.
- Hammill, P.V., E. Steinberger, R.J. Levine, L.J. Rodriguez-Rigar, S. Lemechow, and J.S. Arumin, 1982. "Epidemiologic Assessment of Male Reproductive Hazard from Occupational Exposure to TDA and DNT," Journal of Occupational Medicine, Vol. 24, p. 985.
- Hart E.R., 1976. Two-Year Feeding Study in Rats. Final Report, Contract No. N00014-73-C-0162, Task No. NR 202-043, Litton Bionetics Inc., Kensington, Maryland.
- Haythorn, S.R., 1920. "Experimental Trinitrotoluene Poisoning," Journal of Industrial Hygiene, Vol. 2, pp. 298-318.
- Lane, R.W., G.S. Simon, R.W. Dougherty, J.L. Egle, and J.F. Borzelleca, 1985. "Reproductive Toxicity and Lack of Dominant Lethal Effects of 2,4-dinitrotoluene in the Male Rat," Drug Chemistry and Toxicology, Vol. 8, pp. 265-280.
- Lee, C.C., C.B. Hong, H.V. Ellis, J.C. Dacre and J.P. Glennon, 1985. "Subchronic and Chronic Toxicity Studies of 2,4-Dinitrotoluene, Part II, CD Rats," J. Am. Coll. Toxicol., Vol. 4, pp. 243-256.
- Lee, C.C., H.V. Ellis, J.J. Kowalski, J.R. Hodgson, and S.W. Hwang, 1978. Mammalian Toxicity of Munitions Compounds. Phase II: Effects of Multiple Doses. Part II: 2,4-DNT, Midwest Research Institute, Kansas City, Missouri.

- Lee, C.C., et al., 1976. Mammalian Toxicity of Munition Compounds. Phase II: Effects of Multiple Doses. Part III. 2,6-Dinitrotoluene. Progress Report No. 4, Midwest Research Institute Project No. 3900-B, Contract No. DMAD-17-74-C-4073. (cited in ATSDR, 1989)
- Lee, C.C., 1975. Mammalian Toxicity of Munitions Compounds: Phase I: Acute Oral Toxicity. Primary Skin and Eye Irritation. Dermal Sensitization, and Disposition and Metabolism. Report No. 1, ADBO11150L, Midwest Research Institute, Kansas City, Missouri.
- Leonard, T.B., O. Lyght, and J.A. Popp, 1983. "Dinitrotoluene Structure-Dependent Initiation of Hepatocytes in Vivo," Carcinogenesis, Vol. 4, pp. 1059-1061.
- Levine, B.S., E. Furedi, D.F. Gordon, P.M. Lish, and J.J. Barkley, 1984. "Subchronic Toxicity of Trinitrotoluene in Fischer 344 Rats," Toxicology, Vol. 32, pp. 253-265.
- Lish, P.M., B.S. Levine, E.M. Furedi, E.M. Sagartz, and V.S. Rac, 1984. Determination of the Chronic Mammalian Toxicological Effects of RDX: Twenty-Four Month Chronic Toxicity/Carcinogenicity Study of RDX in the B6C3F₁ Hybrid Mouse. AD A 160774, Phase VI, Vol. 1, IIT Research Institute, Contract No. DAMD17-79-C-9161, prepared for USAMRDC.
- McLellan, W.L., W.R. Hartley, and M.E. Brower, 1988. Health Advisory for HMX, prepared for the Office of Drinking Water, U.S. Environmental Protection Agency.
- McNamara, B.P., H.P. Averill, E.J. Owens, J.F. Callahan, D.G. Fairchild, H.P. Ciuchta, R.H. Rengstorff, and R.K. Biskup, 1974. Edgewood Arsenal Technical Report. The Toxicology of Cyclotrimethylenetrinitramine (RDX) and Cyclotetramethyl tetranitramine (HMX) Solutions in Dimethylsulfoxide (DMSO), Cyclohexanone, and Acetone. U.S. Department of the Army, Aberdeen Proving Ground, Maryland.
- Neal, P.A., W.F. Oettingen, and R.K. Snyder, 1944. "Absorption of TNT Through the Intact Skin of Human Subjects," Public Health, Bulletin XI, 285.55.
- National Institute of Occupational Safety and Health/Occupational Safety and Health Administration (NIOSH/OSHA), 1985. Product Guide to Chemical Hazards. U.S. Department of Health and Human Services.
- Parke, D., 1961. "Studies in Detoxification V. The Metabolism of m-Dinitro (¹⁴C) Benzene in the Rabbit," Biochemistry Journal, Vol. 78, p. 262.

- Pennington, J.C., and W.H. Patrick, Jr., 1990. "Adsorption and Desorption of 2,4,6-Trinitrotoluene by Soils," Journal of Environmental Quality, Vol. 19, pp. 559-567.
- Popp, J.A., and T.B. Leonard, 1985. "The Hepatocarcinogenicity of Dinitrotoluenes," Toxicity of Nitroaromatic Compounds, D.E. Rickert, ed., Hemisphere Publishing, New York, pp. 53-60.
- Popp, J.A., and T.B. Leonard, 1983. "The Hepatocarcinogenicity of Dinitrotoluenes. Hepatocarcinogenicity of 2,6-DNT," Proceedings. American Association for Cancer Research, Vol. 24 (Abst. 361).
- Registry of Toxic Effects of Chemical Substances (RTECS), 1981. Tatken and Lewis eds., NIOSH, U.S. Department of Health and Human Services.
- Rickert, D.E., B.E. Butterworth, and J.A. Popp, 1984. "Dinitrotoluene: Acute Toxicity, Oncogenicity, Genotoxicity, and Metabolism," CRC Critical Reviews in Toxicology, Vol. 13, No. 3.
- Rosenblatt, D.H., and M.J. Small, 1981. Preliminary Pollutant Limit Values for Alabama Army Ammunition Plant, Technical Report 8105, AD/A104203, USABRDL, Fort Detrick, Maryland.
- Roy F. Weston, Inc., 1989. Umatilla Army Depot Activity Remedial Investigation, Draft Final Report No. CETHA-IR-CR-89038, prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Roy F. Weston, Inc., 1987. RAISS-Volunteer Army Ammunition Plant RI/FS. Remedial Investigation (RI) Report, USATHAMA Contract No. DAAA15-85-D-0015.
- Schneider, N.R., S.L. Bradley, and M.E. Anderson, 1977. "Toxicology of Cyclotrimethylenetrinitramine: Distribution and Metabolism in the Rat and the Miniature Swine," Toxicology and Applied Pharmacology, Vol. 39, pp. 531-541.
- Schut, H.A., T.R. Loeb, G.D. Stoner, and L.A. Grimes, 1983. "Distribution, Elimination, and Test for Carcinogenicity of 2,6-DNT After Interperitoneal and Oral Administration to Strain A Mice," Journal of Toxicology and Environmental Health, Vol. 12, p. 659.
- Schut, H.A.J., T.R. Loeb, and G.D. Stoner, 1982. "Distribution, Elimination and Test for Carcinogenicity of 2,4-DNT in Strain A Mice," Toxicology and Applied Pharmacology, Vol. 64, p. 213.

- Simmers, J.W., 1991. Telephone conversation between J.W. Simmers, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, and N.W. Gabel, Dames & Moore, February 11, 1991.
- Small, M.J., 1988. Residual Explosives Criteria for Treatment of Area P Soil, Louisiana Army Ammunition Plant, USABRDL, Fort Detrick, Maryland.
- Small, M.J., 1984. The Preliminary Pollutant Limit Value Approach: Procedures and Data Base, USABRDL, Fort Detrick, Maryland.
- Soares, E.R., and L.F. Lock, 1980. "Lack of an Indication of Mutagenic Effects of Dinitrotoluenes and Diaminotoluenes in Mice," Environmental Mutagenics, Vol. 2, pp. 111-124.
- Soboleva, L.P., 1969. "State of the Myocardin During Chronic Trinitrotoluene Poisoning (Clinical Picture and Pathogenesis of Neuro-Vegetative Disturbances)," Soviet Medicine, Vol. 32, pp. 119-122.
- Trabalka, J.R., and C.T. Garten, Jr., 1982. Development of Predictive Models for Xenobiotic Bioaccumulation in Terrestrial Ecosystems, Publication No. 2037, ORNL-5869, NTIS DE83 003171, Oak Ridge National Laboratory.
- U.S. Army Research and Development Command (USARDC), 1978. Preliminary Problem Definition Study of 48 Munitions-Related Chemicals, Vol. 1, Final Report, Contract No. DAMD 17-77-C-7057, Alexandria, Virginia.
- U.S. Environmental Protection Agency (USEPA), 1991a. Integrated Risk Information System (IRIS), Environmental Criteria and Assessment Office, Cincinnati, Ohio.
- U.S. Environmental Protection Agency (USEPA), 1991b. Interoffice memorandum from Pei-Fung Hurst, Chemical Mixtures Assessment Branch, USEPA Environmental Criteria and Assessment Office, to Harry Craig, USEPA Region X, June 25, 1991.
- U.S. Environmental Protection Agency (USEPA) 1991c. Risk Assessment Guidance for Superfund. Volume 1: Human Health Evaluation Manual. Supplemental Guidance. Standard Default Exposure Factors, Interim Final, OSWER Directive 9285.6-03.
- U.S. Environmental Protection Agency (USEPA), 1991d. Technical Review Comments on the Draft Interim Risk Assessment for the Explosives Washout Lagoons, Umatilla Depot Activity, USEPA Region X, September 1991.

- U.S. Environmental Protection Agency (USEPA), 1991e. Supplemental Risk Assessment Guidance for Superfund, Health and Environmental Assessment Section, USEPA Region X, August 16, 1991.
- U.S. Environmental Protection Agency (USEPA), 1990a. Health Effects Assessment Summary Tables (HEAST), 4th Quarter, 1990.
- U.S. Environmental Protection Agency (USEPA), 1990b. Statement of Work, RI/FS Risk Assessment Deliverables, USEPA Region X.
- U.S. Environmental Protection Agency (USEPA), 1990c. Health and Environmental Effects Document for Trinitrophenylmethylnitramine, ECAO-CIN-G091, Office of Health and Environmental Assessment, Cincinnati, Ohio.
- U.S. Environmental Protection Agency (USEPA), 1989a. Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples, EPA/540/2-89/057, Office of Emergency and Remedial Response, prepared by Booz-Allen and Hamilton, Inc., Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1989b. Exposure Factors Handbook, EPA/600/8-89/043, Office of Health and Environmental Assessment, USEPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1989c. Health and Environmental Effects Document for 1,3,5-Trinitrobenzene, Office of Health and Environmental Assessment, USEPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1989d. Health and Environmental Effects Document for RDX Cyclonite, Office of Health and Environmental Assessment, USEPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1989e. Memorandum on Interim Final Guidance for Soil Ingestion Rates, OSWER Directive 9850.4, Office of Solid Waste and Emergency Response, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1989f. Region X Technical Memorandum No. 1A, UMDA RI/FS Workplan Guidance.
- U.S. Environmental Protection Agency (USEPA), 1989g. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final, EPA 540/1-89/002, Office of Emergency Remedial Response.

- U.S. Environmental Protection Agency (USEPA), 1988a. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, EPA 540/G-89/004, Office of Emergency and Remedial Response, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1988b. Superfund Exposure Assessment Manual, EPA/540/1-88/001, Office of Emergency Remedial Response.
- U.S. Environmental Protection Agency (USEPA), 1986a. Health and Environmental Effects Profile for Dinitrotoluene, Office of Health and Environmental Assessment, USEPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1986b. Superfund Public Health Evaluation Manual, USEPA 540/1-86/060, Office of Emergency and Remedial Response, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), September 1981. Installation Assessment. Umatilla Army Depot Activity. Oregon, TS-PIC, 0066, Environmental Monitoring Systems Laboratory.
- U.S. Environmental Protection Agency (USEPA), 1980a. Ambient Water Quality Criteria for Dinitrotoluene, EPA 440/5-80-045, Office of Water Regulations and Standards, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1980b. "Water Quality Criteria Documents; Availability," Federal Register 45(231): 79318-79379.
- Voegtlin C., C.W. Hooper, and J.M. Johnson, 1921. "Trinitrotoluene Poisoning: Its Nature, Diagnosis and Prevention," Journal of Industrial Hygiene, Vol. 3, pp. 239-254 and 280-292.
- Whong, W., N. Speciner, and G. Edwards, 1980. "Mutagenic Activity of Tetryl, A Nitroaromatic Explosive, In Three Microbial Test Systems," Toxicology Letters, Vol. 5, pp. 11-17.
- Whong, W., and G.S. Edwards, 1984. "Genototoxic Activity of Nitroaromatic Explosives and Related Compounds in *Salmonella typhimurium*," Mutagenic Research, Vol. 136, pp. 206-215.
- Woodruff, R.C., J.M. Mason, R. Valencia, and S. Zimmering, 1985. "Chemical Mutagenesis Test in *Drosophila* V. Results of 53 Coded Compounds Tested for the National Toxicology Program," Environmental Mutagenics, Vol. 7, pp. 677-702.

Woollen, B.H., M.G. Hall, R. Craig, and G.T. Steel, 1985. "Dinitrotoluene: An Assessment of Occupational Absorption During the Manufacture of Blasting Explosives," International Archives of Occupational and Environmental Health, Vol. 55, pp. 319-330.

APPENDIX A

Environmental Fate of Explosives Contaminants and Their Degradation Products

APPENDIX A
Environmental Fate of Explosives Contaminants
and Their Degradation Products

A.1 INTRODUCTION

The explosives for which environmental fate and transport information has been evaluated are listed (with their acronyms) in Table A-1. Also included in Table A-1 are the principal biodegradation products of 2,4,6-TNT, the most extensively studied explosive. The information is organized for analysis of fate and transport processes that affect persistence in environmental media. The processes considered are chemical-specific rather than site-specific--i.e., they are related to the physical and chemical properties of the explosives (Table A-2). The resulting analysis can then be applied to the specific features of existing sites of contamination. The effect of these processes on the bioavailability of explosives is also considered.

Assessing the fate and transport of any chemical that may ultimately be released to the environment requires an evaluation of processes that affect its structural transformations and its partitioning between environmental media. These processes include photolysis, oxidation, hydrolysis, volatilization, sorption, bioaccumulation, and biodegradation. The evaluation of these processes is usually systematized by placing them in a format that requires a discrete analysis of a chemical's potential for change within each process. In this way, the principal processes that constitute the pathways by which the chemical is environmentally dissipated can be identified. The methodology involved in this type of analysis and its application to specific chemicals are discussed in Callahan *et al.* (1979).

A.2 ENVIRONMENTAL PROCESSES

A.2.1 Photolysis

The major photoproduct observed from the effect of sunlight on TNT in river water is TNB (Burlinson *et al.*, 1979). This compound is stable with respect to further photodegradation. The photochemistry of TNT--and to a lesser extent RDX and

TABLE A-1

Listing of Explosives, TNT Metabolites, and Their Acronyms^a

<u>Compound</u>	<u>Acronym</u>
2,4,6-Trinitrotoluene	TNT
2,4-Dinitrotoluene	2,4-DNT
2,6-Dinitrotoluene	2,6-DNT
1,3,5-Trinitrobenzene	TNB
1,3-Dinitrobenzene	DNB
Nitrobenzene	NB
Hexahydro-1,3,5-trinitro-1,3,5-triazine	RDX
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine	HMX
N,2,4,6-Tetranitro-N-methylaniline	Tetryl
Nitrocellulose	--
2-Amino-4,6-dinitrotoluene	2-A
4-Amino-2,6-dinitrotoluene	4-A
2,4-Diamino-6-nitrotoluene	2,4-DA
2,6-Diamino-4-nitrotoluene	2,6-DA
2,2',6,6'-Tetranitro-4,4'-azoxytoluene	4,4'-AZ
4,4',6,6'-Tetranitro-2,2'-azoxytoluene	2,2'-AZ
2',4,6,6'-Tetranitro-2,4'-azoxytoluene	2,4'-AZ

^aThe acronyms are consistent with their usage in Burrows *et al.* (1989) and Walsh (1990).

TABLE A-2

Physical and Chemical Properties of the Explosives*

	<u>TNT</u>	<u>2,4-DNT</u>	<u>2,6-DNT</u>	<u>TNB</u>
CAS Registry No.	118-96-7	121-14-2	606-20-2	99-35-4
Empirical Formula	$\text{C}_7\text{H}_5\text{N}_3\text{O}_6$	$\text{C}_7\text{H}_3\text{N}_3\text{O}_6$	$\text{C}_7\text{H}_3\text{N}_3\text{O}_6$	$\text{C}_7\text{H}_3\text{N}_3\text{O}_6$
Molecular Weight	227.15	182.15	182.15	213.12
Density (g/cm ³)	1.65	1.521	1.538	1.63
Melting Point (°C)	80.75	72	66	122
Vapor Pressure (mm Hg, 25°C)	5.51×10^{-4}	2.17×10^{-4}	5.67×10^{-4}	3.03×10^{-4}
Aqueous Solubility (mg/L, 25°C)	150	280	206	385
Henry's Constant (atm.m ³ /mole, 25°C)	1.10×10^{-4}	1.86×10^{-7}	4.86×10^{-7}	2.21×10^{-9}
Log K _{ow}	2.00	1.98	1.89	1.18
BCF (fish)	8.95	10.6	9.82	2.65

TABLE A-2 (cont'd)

	DNB	RDX	HMX	Tetryl
CAS Registry No.	99-65-0	121-82-4	2691-41-0	479-45-8
Empirical Formula	$\text{C}_4\text{H}_5\text{N}_3\text{O}_6$	$\text{C}_3\text{H}_5\text{N}_3\text{O}_6$	$\text{C}_4\text{H}_5\text{N}_3\text{O}_6$	$\text{C}_7\text{H}_5\text{N}_3\text{O}_6$
Molecular Weight	168.12	222.15	296.20	287.17
Density (g/cm ³)	1.575	1.83	1.90(β form)	1.73
Melting Point (°C)	90	205	286	129.5
Vapor Pressure (mm Hg, 25°C)	1.31×10^{-4}	4.03×10^{-3}	3.33×10^{-16}	5.69×10^{-9}
Aqueous Solubility (mg/L, 25°C)	533	60	5	80
Henry's Constant (atm.m ³ /mole, 25°C)	5.44×10^{-4}	1.96×10^{-11}	2.60×10^{-15}	2.69×10^{-11}
Log K _{ow}	1.49	0.87	0.26	1.65
BCF (fish)	4.70	1.50	0.49	6.31

Burrows et al, 1989.

HMX--has been studied more extensively in the laboratory. When TNT is irradiated in distilled water, the major, primary photoproduct--2,4,6-trinitrobenzaldehyde--is converted to several azo and azoxy compounds. Under these conditions, the TNB is a minor product. The detailed results of these studies are discussed in Burrows *et al.* (1989).

Similar studies of 2,4-DNT have shown that photolysis follows a similar course--reduction of the nitro groups and oxidation of the methyl group (Burlinson *et al.*, 1979). Photolysis of 2,6-DNT resulted in unstable mixtures.

Rates of photolysis have been observed to be enhanced in natural waters. This enhancement is attributed to the action of humic acids as photosensitizers (Burrows *et al.*, 1989). Rate enhancement of 10- to 100-fold has been observed with TNT, while the photolyses of other nitroaromatics have shown rate enhancements of 2- to 26-fold.

Aqueous solutions of both RDX and HMX are photolyzed slowly by sunlight to produce nitrate and formaldehyde. Completion of the reaction occurred within 7 to 10 days (Spanggord *et al.*, 1983). Photolysis of tetryl in sunlight proceeds more slowly than the photolysis of nitramines, requiring 20 days for completion (Kayser *et al.*, 1984). The major products were N-methylpicramide, nitrate, and nitrite.

A.2.2 Oxidation/Reduction

There is no experimental evidence to indicate that oxidation under ambient environmental conditions can degrade explosives (Burrows *et al.*, 1989). Reduction of nitro groups, however, may be possible in anaerobic aquifers, if sufficient organic matter is present to maintain multivalent metal cations in their lower oxidation states. These metal species (e.g., Fe^{+2}) are capable of reducing organic pollutants abiotically. In general, as water proceeds from the vadose zone to the saturated zone, soil organic matter reacts with oxidizing species such as dissolved oxygen, ferric ion, and sulfate to produce an environment that becomes progressively less oxidizing and less acidic. Thus, chemical contaminants of the soil can be subjected to first oxidizing and then reducing conditions as they are leached downward to groundwater (Freeze and Cherry, 1979).

A.2.3 Hydrolysis

The only explosive for which hydrolysis has been demonstrated is tetryl. Kayser *et al.* (1984) have reported a half-life (extrapolated) for this reaction of 302 ± 76 days at 20° C and pH 6.8. The products of hydrolysis are 2,4,6-trinitrophenol (i.e., picric acid) and methylnitramine. The conditions for this reaction are environmentally relevant, but the significance of the transformation has not been validated by the detection of picric acid in samples from tetryl-contaminated surface water or groundwater.

Hydrolysis may also be an important degradative process for nitrocellulose. The nitrate ester bonds are susceptible to hydrolysis. However, the environmental relevance of this process is uncertain.

A.2.4 Volatilization

Volatilization is considered to have an insignificant role in decreasing the concentration of explosives in environmental media (Burrows *et al.*, 1989). Vapor pressures are low and the Henry's Constants indicate little tendency for volatilization from water (Table A-2). Although volatilization may be insignificant as a loss mechanism, it could have an important role in extending contamination at low levels throughout the terrestrial environment. Simmers (1991) has suggested that the TNT detected in aerial parts of plants grown on contaminated soil is transported from the soil to the plant surface by volatilization and condensation.

The transport of some agricultural pesticides in soil via alternating steps of volatilization and condensation has been identified as a mechanism for extending the areas that they have contaminated (USEPA, 1987a). This phenomenon is similar to the passage of organic analytes through a gas-chromatography column. Transport via this mechanism should occur most easily from soils that are heavily contaminated or have little adsorptive capacity for the explosives (e.g., low-organic sandy soils). The generality of this transport mechanism for organic chemicals in soil has not been studied sufficiently to compare its effectiveness with other transport processes.

A.2.5 Adsorption

The adsorption of TNT to 15 soils has been studied by Pennington and Patrick (1990). Of these soils, all but two were collected at 13 different explosives facilities. The two reference soils were a clayey silt and a clay (both montmorillonitic). The average linear adsorption coefficient, K_d , for all soils was 4.0. The range for K_d was 2.3 to 11, the highest representing the clay soil. Pennington and Patrick (1990) observed that the organic content of the soils did not exert as much effect on adsorption of TNT as did the mineral content. The three mineral characteristics that could be correlated with adsorption were oxalate-extractable iron, clay content, and cation exchange capacity. Both adsorption and desorption occurred within 2 hours. The data from the adsorption experiments were fitted best to the Langmuir isotherm model, which indicates that adsorption depends on the availability of adsorption sites rather than on partitioning.

The adsorption of TNT on sediments has been studied by Spanggord *et al.* (1980). In these experiments, equilibration of TNT between water and sediment required about 240 hours. The average absorption partition coefficient was 53 ± 20 . A similar study for 2,4-DNT produced a K_d equal to 8.7; the range of four determinations was 3.9 to 12. For RDX, the value of K_d ranged from 1.4 to 5.5. The sediment used for these determinations had an organic content of 3.3 percent. Spanggord *et al.* (1980) concluded that adsorption to sediment was not an important environmental process for these explosives in surface water.

A.2.6 Bioaccumulation

Two experimental studies on the bioaccumulation of TNT in plants have been conducted (Palazzo and Leggett, 1986; Simmers *et al.*, 1989). In the earlier study, yellow nutsedge was grown in hydroponic cultures containing TNT concentrations of 5, 10, and 20 mg/L. Growth was affected at all concentrations, and root weights were reduced about 95 percent. After harvesting at 42 days, TNT and its metabolites, 4-A and 2-A, were detected throughout the plants. The TNT appeared to accumulate in roots, rhizomes, and tubers but not in leaves. Most of the absorbed TNT was

converted to 4-A and 2-A. Bioaccumulation in roots, which ranged from 22 to 35, increased with concentration in the hydroponic media. However, direct adsorption to the exterior surface of the roots, rather than bioaccumulation, could not be eliminated as an explanation for this phenomenon.

Simmers (1991) has observed that the bioaccumulation of TNT from soil by plants does not appear to be significant. Eight different plants were grown in TNT-contaminated soil from a military installation (Simmers *et al.*, 1989). The higher concentrations of TNT inhibited plant growth in soils that were not amended with other organic material. Simmers (1991) has expressed the opinion that detections of TNT in the aerial parts of plants grown on contaminated soil are due to volatilization of TNT from soil, followed by condensation of TNT on the plant surfaces.

Aquatic bioconcentration factors (BCF) can be calculated for explosives from empirical relationships between solubility and experimentally determined BCFs. The values for BCF, calculated by Burrows *et al.* (1989) using these empirical relationships, are provided in Table A-2. These values indicate only a slight tendency for the explosives to accumulate in aquatic life.

If terrestrial organisms come into contact with soil or sediment to which the explosives are adsorbed, bioaccumulation (via ingestion) is expected to be minor or negligible. Trabalka and Garten (1982) have reported that chemicals with $\log K_{ow}$ values of less than 3.5--or solubilities greater than 10 mg/L--do not accumulate in mammals or birds. These cutoff values for $\log K_{ow}$ and solubility were based on a frequency analysis of 123 paired observations for 68 chemicals and 90 paired observations for 47 chemicals, respectively. The values for $\log K_{ow}$ of the explosives indicate that they would not accumulate in animal receptors. This indication is also consistent for the explosives solubilities, with the exception of HMX. In Table A-2, the solubility of HMX is given as 5 mg/L. However, if detoxification occurs in terrestrial animals via biotransformation (e.g., reduction of nitro groups), none of the explosives should be expected to accumulate.

A.2.7 Biodegradation

Explosives have been observed to degrade under such various conditions as liquid culture, soil culture, soil-water slurries, activated sludge, and composting. The latter two have been conducted both in the laboratory and as pilot-scale field demonstrations. Most studies have focussed on the biodegradation of TNT.

A.2.7.1 TNT. A summary of representative investigations is presented in Table A-3. A more extensive summary of investigations is provided by Walsh (1990) and Woodward (1990). With the exception of partial mineralization by white rot fungus in liquid culture (Fernando *et al.*, 1990), it is apparent from Table A-3 that the same aromatic amine metabolites are produced under essentially all conditions. In composts and sludge, these aromatic amines become associated with the high-molecular-weight material of humus and microbial biomass. In these investigations, the concentration levels of aromatic amines peak at 2 to 3 weeks and thereafter decrease due to humification at about the same rate as their precursor explosives, as discussed below.

Extraction of the composted humus or the microbial floc with polar organic solvents does not remove the aromatic amines from this insoluble high-molecular-weight material (Kaplan and Kaplan, 1982; Doyle *et al.*, 1986; Williams *et al.*, 1988). Moreover, chemical fractionation of this material indicates that the TNT metabolites associated with it are covalently bonded. In this content, the nature of the bonding of other aromatic amines with humus may have relevance. For example, Berry and Boyd (1985) found that para-nitroaniline reacted faster than other substituted anilines with humus constituents. The resulting macromolecules appear to have the amino group incorporated covalently into the ring structures of the humus. Similarly, Saxena and Bartha (1983) have reported that the incorporation of halogen-substituted anilines into humus occurs by covalent bonding.

As a consequence of these reactions--and others that could occur within the microorganisms--TNT metabolites become a structural part of humic materials. The degradation of humic materials in soil depends primarily on the presence of

TABLE A-3

Biodegradation of TNT--A Summary of Representative Investigations

Reference	Metabolic Products*	Conditions	Persistence
Pennington and Patrick (1990)	4-A 2-A 2,6-DA	Anaerobic soil-water slurry produced the monoamino compounds; aerobic conditions produced all three. TNT-contaminated soil was from Joliet Army Ammunition Plant.	Biotic reduction exceeded abiotic reduction. Reduction appeared to be faster under reduced conditions.
Fernando et al. (1990)	Polar metabolites	Soil or liquid cultures of white rot fungus at TNT concentrations of 10,000 and 100 ppm, respectively.	Approximately 19 percent converted to CO ₂ in 90 days. Eighty-five percent was degraded.
Kaplan and Kaplan (1982)	4-A 24 days 2-A 2,4-DA 91 days 2,6-DA 4,4'AZ 2,4'AZ Insoluble macro molecules No significant volatiles or CO ₂	Compost of TNT, manure, alfalfa, grass, hardwood leaves, and garden soil at 55°C and 60% moisture.	Total metabolites decreased from 86.6 percent (24 days) to 61.5 percent (91 days). Percentage of incorporation into humic substances increased from 5.7 (24 days) to 22.1 (91 days).
Hoffsommer et al. (1978)	4-A 2-A 2,4-DA 2,6-DA	Aerated ditch containing activated sludge and supplemental nutrients to which TNT was added.	Percentage of amine metabolites decreased from 34 (3 days) to 3 (30 days). The largest percentage of metabolized TNT was associated with the microbial floc.
Isbister et al. (1982)	2-A 4-A 2,6-DA 2,2'AZ Insoluble macromolecules--major	Laboratory-scale composting of TNT.	Reduction of ¹⁴ C-TNT correlated with increase of radiolabel in humic substances.

TABLE A-3 (cont'd)

Reference	Metabolic Products*	Conditions	Persistence
Spanggord et al. (1980)	4-A 2-A 2,4-DA 2,6-DA 4,4'AZ	Selected surface waters that received TNT wastes.	--
Doyle et al., (1986) (Atlantic Research Corp.)	2-A Initial production followed by disappearance. 4-A Insoluble macromolecules	Laboratory and onsite pilot-scale composting of TNT, RDX, HMX, and tetryl in contaminated sediment from Louisiana AAP.	Half-life for TNT was 1.0 and 1.6 weeks.
Isbister et al. (1982) (Atlantic Research Corp.)	2-A trace amounts 4-A	Laboratory and green house-scale composting of TNT added to Lakeland sand.	Half-life for TNT was 3 weeks in the laboratory. In the green house study, the concentration was below detection after 3 weeks.
Williams et al. (1988) (R.F. Weston, Inc.)	2-A Increasing during the initial 4-A 4 weeks, decreasing 2,4-DA thereafter. 2,6-DA	Onsite pilot-scale composting of TNT, RDX, HMX, and tetryl in contaminated sediment from Louisiana AAP.	TNT decreased from 17 gram/kg to 74 mg/kg in 153 days at 55°C.
Palazzo and Leggett (1986)	4-A Detected in the plants but 2-A not in the culture medium.	Hydroponic culture of yellow nutsedge.	Not determined.

Metabolic Products:

Acronym	Compound
2A	2-amino-4,6-dinitrotoluene
4A	4-amino-2,6-dinitrotoluene
2,4-DA	2,4-diamino-6-nitrotoluene
2,6-DA	2,6-diamino-4-nitrotoluene
4,4'AZ	2,2',6,6'-tetranitro-4,4'-azoxytoluene
2,2'AZ	4,4',6,6'-tetranitro-2,2'-azoxytoluene
2,4AZ	2',4,6,6'-tetranitro-2,4'-azoxytoluene

ligninolytic enzymes, released by microorganisms to degrade lignin to smaller, more easily absorbed fragments (USEPA, 1987b). The chemical bonds whose breakdown are catalyzed by these enzymes are esters, ketals, and ethers. Thus, although this process could slowly release TNT metabolites to soil, the fragments of humus into which they would remain incorporated should be absorbed and degraded by the extant microbial population.

In contaminated soil, surface water, and groundwater (as opposed to compost), it can be assumed that TNT metabolites will also be incorporated into microbial biomass. However, the potential for release and transport of the TNT metabolites in these media may be greater than it would be in compost, because the total mass of organic material into which it could be incorporated is less. Indeed, TNT metabolites have been detected in several surface waters (Spanggord *et al.*, 1980) and in groundwater (USATHAMA, 1990). Further degradation or adsorption and incorporation into humic materials can occur in these two media (Berry and Boyd, 1985), though aromatic amines are considered to be persistent in anaerobic sediments or groundwater (USEPA, 1987b). Also, Simmers (1991) has noted that heavily contaminated soils lack TNT-degrading microorganisms.

The biodegradation of DNT has not been as well studied as TNT. In laboratory studies, it has been demonstrated that 2,4-DNT can be completely mineralized within 1 week (Spanggord *et al.*, 1980; Isbister *et al.*, 1980). The mixed microbial cultures were obtained from natural water bodies in the vicinity of explosives manufacturing activities. Some aromatic amine metabolites were detected during these experiments, but the metabolites did not accumulate. Under the conditions of these experiments, 2,6-DNT was not degraded.

In other investigations on the biodegradation of 2,4-DNT, mineralization to carbon dioxide and water was not so readily accomplished (McCormick *et al.*, 1978; Lia *et al.*, 1984; Mori *et al.*, 1984). Lia *et al.* (1984) reported no degradation of 2,4-DNT after 14 days of incubation in aerobic fermenters. Under anaerobic conditions, reduction of one of the nitro groups to 2-A and 4-A was observed. Reduction

presumably proceeded via nitroso intermediates. The aromatic amines could no longer be detected after 14 days and were, thus, either metabolized or incorporated into the microbial biomass. In the experiments of Mori *et al.* (1984), the reduction of 2,4-DNT was observed under aerobic conditions, and the intermediates appeared to be hydroxylamines rather than nitroso compounds.

The reported experiments indicate that microbial populations acclimated to explosives compounds may be capable of degrading 2,4-DNT completely. However, its position isomer, 2,6-DNT, appears to be resistant to microbial action under those conditions. Unacclimated microorganisms reduce 2,4-DNT to aromatic amines similar to those produced from TNT. The decrease in concentration of these aromatic amines to below the detection limit (during the experiment) could mean that they are incorporated into the biomass as are the amines produced from TNT.

A.2.7.2 TNB, DNB, and NB. TNB appears to be very persistent in soils and groundwater, while DNB is not. Walsh (1990) reports that TNB is routinely detected in groundwater samples that contain TNT. In samples from present or former explosives facilities, the level of TNB in groundwater often exceeds that of TNT, 2-A and 4-A; while the level of DNB can be near the level of detection, microbial mineralization of DNB has been observed in experiments conducted with water taken from the Tennessee River downstream from the Volunteer Army Ammunition Plant (Mitchell and Dennis, 1982). Aquatic microorganisms from an unacclimated location, however, were without this degradative capability. In water from the Tennessee River, TNB was very slowly converted to 3,5-dinitroaniline.

The foregoing observations do not indicate whether the aromatic ring of DNB is being broken down. An acclimated microbial population is apparently necessary for the degradation of DNB, but this degradation may stop with the production of 3-nitroaniline. In a model ecosystem containing algae, snails, water fleas, mosquito larvae, and fish, Lu and Metcalf (1975) reported that NB was persistent. This observation, however, was also based on a lack of degradation of the aromatic ring.

A.2.7.3 RDX and HMX. Anaerobic biodegradation of the nitramine explosives, RDX and HMX, has been observed only in liquid cultures and in soil columns, supplemented with glucose (McCormick *et al.*, 1984; Greene *et al.*, 1985). Aerobic biodegradation has been reported only during composting (Isbister *et al.*, 1982; Doyle *et al.*, 1986; Williams *et al.*, 1988). These experimental results may indicate a need for significant nutrient augmentation, because RDX also appears to be persistent in groundwater where such augmentation would be lacking (Cornhusker, Umatilla). Spangford *et al.* (1980) have reported that RDX is also persistent in aerobic surface waters. In the experiments of McCormick *et al.* (1984) and Greene *et al.* (1985), HMX was less easily degraded than RDX.

In soil or water environments where sufficient supplemental nutrients are present, RDX and HMX may be degraded via sequential reduction of the nitro groups to nitroso groups (McCormick *et al.*, 1984; Greene *et al.*, 1985). Cleavage of the ring structure and mineralization appear to occur during composting (Isbister *et al.*, 1982), though the incorporation of intermediates into humic materials may also be possible.

A.2.7.4 Tetryl. The only information available on biodegradation of tetryl is the decrease in its concentration during composting. Doyle *et al.* (1986) found that the decrease in tetryl concentration was unaffected by variations in composting conditions. In their investigation of two composts, carbon dioxide accounted for 5.0 and 3.2 percent of the radiolabeled tetryl, while the unextractable residue accounted for 84.2 and 92.6 percent, respectively. Because the structure of tetryl is similar to that of TNT, these data suggest that some of the nitro groups of tetryl are being reduced to amino groups, and the resulting aromatic amines then become incorporated into high-molecular-weight material.

A.3 ENVIRONMENTAL BIOAVAILABILITY

The bioavailability of explosives and their metabolites in environmental media can be lessened by adsorption or incorporation into naturally occurring macromolecules. Adsorption to sediment, suspended particulates, aquatic macromolecules, and soil substances is the principal process controlling the

bioavailability of extant organic chemicals in the environment (Hamelink and Spacie, 1977; Hamelink, 1980; Landrum *et al.*, 1984; Bartha *et al.*, 1982). Aquatic organisms, both pelagic and benthic, are exposed to organic pollutants almost entirely via direct contact with contaminated water rather than via its ingestion. Moreover, an organic chemical must be uncomplexed and dissolved in water for it to be adsorbed into an aquatic organism. The reason for this limitation is that the adsorption of organic pollutants to aquatic or soil particulates prevents transport of the pollutants across cell membranes and consequently prevents entry into the body of the organism. Soil invertebrates and plants also require an organic xenobiotic to be dissolved in the soil water for its direct absorption (Bartha *et al.*, 1982).

Although the adsorption of some explosives and metabolites can decrease their concentration (and hence their bioavailability) in aquatic systems and soil water, the incorporation of the amine metabolites into polymeric structures of humic materials or microbial cell walls does much more. It does, in fact, change the chemical identity of the metabolites. Regeneration of the aromatic amines may occur under some limited circumstances (Bartha, 1983), but their degradation should normally occur as part of the humic materials. Humus is degraded by the action of extracellular ligninolytic enzymes (USEPA, 1987b; Haider and Martin, 1988). The smaller molecules from this degradation are then available to the biota for absorption and use.

A.4 SUMMARY OF FATE IN ENVIRONMENTAL MEDIA

In this section, the fate of the selected explosives is summarized from the perspective of the three environmental media--air, water, and soil. This summary is also presented in a tabular format in Table A-4.

A.4.1 Air

Atmospheric processes are not relevant to the environmental fate of explosives except in the situation of wind-erosion of soil contaminated with explosives, which is not addressed herein. During manufacture and disposal, the explosives are released only as liquid or solid wastes. Then, as part of the aquatic or soil environment, their transport to the atmosphere is not considered significant.

TABLE A-4

Summary of Environmental Fate of Selected Explosives

Explosive	Photolysis	Oxidation/ Reduction	Hydrolysis	Volatilization	Adsorption	Bioaccumulation	Biodegradation	Principal Environmental Fate
TNT	In shallow surface water, photolysis may be the principal process for degradation. The major product is TNB, which is itself stable to further photodegradation.	Relevance is uncertain.	Not relevant.	Altering volatilization and concentration on soil particles may spread low levels of contamination in some soil systems.	Adsorption of TNT is slight and appears to be correlated with the mineral content of soil rather than the organic content. Leaching and transport of suspended particles may occur.	Bioaccumulation in plants is questionable and does not appear to occur in animals.	If sufficient nutrients are present, the microbia can become acclimated to produce amines and azoxy metabolites.	Under composting conditions, biodegradation produces amine metabolites that become incorporated into humus. In shallow surface water, however, photolysis is the principal fate. High concentrations of TNT in soils lacking in abundant nutrients may inhibit the development of an acclimated microbia. Leaching from these soils may occur.
2,4-DNT 2,6-DNT	In shallow surface water, photolysis may be important. Products stable to further photodegradation are not produced.	Relevance is uncertain.	Not relevant.	Probably not important.	Adsorption to soil and sediment may be very minor. Leaching may occur.	Probably not important.	2,4-DNT but not 2,6-DNT is reported to be mineralized by the microbia from a munitions site. Other investigations detected only the amine metabolites.	The environmental fate of 2,4-DNT and 2,6-DNT should be very similar to the fate of TNT.
TNB DNB NB	TNB appears to be stable to photodegradation. The stability of DNB and NB is uncertain.	Relevance is uncertain.	Not relevant.	Significance is uncertain.	Adsorption of TNB may be similar to adsorption of TNT. Leaching of all three may be important.	Probably not important.	TNB appears to be persistent but DNB degrades in the presence of an acclimated microbia. Both DNB and NB are probably reduced to amines.	TNB appears to be persistent in soil and groundwater. DNB and NB are degraded microbiologically but their mineralization is uncertain.
RDX HMX	In shallow surface water, RDX and HMX will be degraded within 7 to 10 days.	Relevance is uncertain.	Not relevant.	Probably not important.	Adsorption is slight; leaching could be important.	Probably not important.	For biodegradation to occur there appears to be a need for significant nutrient augmentation.	RDX may be persistent in soil and groundwater; the persistence of HMX is uncertain. In shallow surface water photolysis will degrade both explosives.
Tetryl	In shallow surface water, tetryl will be degraded to N-methylpicramide within 20 days.	Relevance is uncertain.	The hydrolytic half-life is about 10 months. The products are picric acid and methylnitramine.	Probably not important.	Significance is uncertain.	Probably not important.	Degradation and incorporation into humus occurs during composting.	Although partial degradation may occur via photolysis or hydrolysis the fate of its degradation products is uncertain.
Nitrocellulose	Not relevant.	Probably not important.	Significance is uncertain.	Not relevant.	As a polymer, it should be adsorbed to all soil particles.	Not relevant.	Degradation occurs during composting and should occur wherever sufficient soil nutrients are present.	The principal fate is biodegradation.

A.4.2 Water

In shallow surface water, photolysis is probably the most effective process for the degradation of TNT, 2,4-DNT, 2,6-DNT, RDX, HMX, and tetryl. Degradation of the explosives occurs within 1 to 3 weeks, but some products of the degradation appear stable to further photolysis under these conditions. From TNT, the stable photo product is TNB. From tetryl, n-methylpicramide is produced and appears (from the conducted studies) to be more stable than its precursor. The degradative products of the other photolabile explosives would then be expected to undergo further photodegradation.

Inasmuch as photolysis is an effective degradative process only for dissolved substances in the upper 7 to 8 inches of natural surface waters (Zepp and Cline, 1977), explosives in deeper water or in the sediment may exhibit persistence. Biodegradation, under these conditions, requires not only an acclimated biota but also nutrient augmentation. If sufficient nutrients are present, amine and azoxy metabolites can be produced from the nitroaromatics, though TNB again appears to be persistent. Biodegradation of the nitramines and tetryl is uncertain in surface water and sediment.

A.4.3 Soil

Under composting conditions, the nitroaromatic explosives degrade to various aromatic amines that become incorporated unto the macromolecular structures of humic materials and biotic cell walls. In contaminated soil, effective biodegradation of the nitroaromatics--as well as the other explosives--also requires organic nutrient augmentation. In soil, however, release and transport of the aromatic amine metabolites may accompany biodegradation of the explosives, because the total mass of organic material into which they could be incorporated in soil is less than it would be in a compost pile. Very high concentrations of TNT in soils lacking abundant nutrients may inhibit the development of an acclimated microbiota. The leaching and transport of explosives as suspended particulates may lead to contamination of groundwater and nearby surface water.

TNB and RDX appear to be the most persistent explosives materials in soil and groundwater. The observed persistence of TNT in soils and groundwater, however, may be associated with the inhibition of degradation that its very high concentrations in soils seem to effect. The fate of HMX and tetryl in soil systems is uncertain. Nitrocellulose should be subject to biodegradation.

A.5 REFERENCES

- Bartha, R. 1983. "Covalent Attachment of Pesticide Residues to Soil Humus," Abstracts, Division of Environmental Chemistry, American Chemical Society, National Meeting, Washington, D.C., September 1983.
- Bartha, R., I.-S. You, and A. Saxena, 1982. "Humus-Bound Residues of Phenylamide Herbicides: Their Nature, Persistence, and Monitoring," Pesticide Chemistry, Vol. 3, J. Miyamoto and P.C. Kearney, eds., Pergamon Press, New York.
- Berry, D.F., and S.A. Boyd, 1985. "Reaction Rates of Phenolic Humus Constituents and Anilines During Cross-Coupling," Soil Biology and Biochemistry, 17: 631-636.
- Burlinson, N.E., M.E. Sitzmann, D.J. Glover, and L.A. Kaplan, 1979. Photochemistry of TNT and Related Nitroaromatics. Part III, Technical Report 78-198, NTIS AD-B045845, Naval Surface Weapons Center, Silver Spring, Maryland (as cited in Burrows et al., 1989).
- Burrows, E.P., D.H. Rosenblatt, W.R. Mitchell, and D.L. Parmer, 1989. Organic Explosives and Related Compounds: Environmental and Health Considerations, Technical Report 8901, U.S. Army Biomedical Research and Development Laboratory, Fort Detrick, Maryland.
- Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, et al., 1979. Water-Related Environmental Fate of 129 Priority Pollutants, EPA-440/4-79-029ab, Office of Water Planning and Standards, USEPA.

- Doyle, R.C., J.D. Isbister, G.L. Anspach, and J.F. Kitchens, 1986. Composting Explosives/Organics Contaminated Soil, Contract No. DAAK11-84-C-0057, Report No. AMXTH-TE-CR-86077, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Fernando, T., J.A. Bumpus, and S.D. Aust, 1990. "Biodegradation of TNT (2,4-trinitrotoluene) by *Phanerochaete chrysosporium*," Appl. Environ. Microbiol. 56: 1,666-1,671.
- Freeze, R.A., and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Englewood Cliffs, New Jersey.
- Greene, B., D.L. Kaplan, and A.M. Kaplan, 1985. Degradation of Pink Water Compounds in Soil-TNT, RDX, HMX, TR-85/046, ADA157954, U.S. Army Natick Research and Development Laboratory (as cited in Walsh, 1990).
- Haider, K.M., and J.P. Martin, 1988. "Mineralization of ^{14}C -labelled Humic Acids and of Humic-Acid Bound ^{14}C -xenobiotics by *Phanerochaete chrysosporium*," Soil Biology and Biochemistry, 20: 425-429.
- Hamelink, J., 1980. "Bioavailability of Chemicals in Aquatic Environments," Biotransformation and Fate of Chemicals in the Environment, A.W. Maki, K.L. Dickson, and J. Cairns, Jr., eds., American Society of Microbiology, Washington, D.C.
- Hamelink, J.L., and A. Spacie, 1977. "Fish and Chemicals: The Process of Accumulation," Annual Reviews of Pharmacology and Toxicology, 17: 167-177.
- Hoffsommer, J.C., et al., 1978. Biodegradability of TNT: A Three-Year Pilot Study, Naval Surface Weapons Center, Silver Spring, Maryland (as cited in Walsh, 1990).
- Isbister, J.D., R.C. Doyle, and J.F. Kitchens, 1980. Engineering and Development Support of General Decontamination Techniques. Task 6. Adapted/Mutant Biological Treatment. Phase I. Literature Review (as cited in Walsh, 1990).

- Isbister, J.D., R.C. Doyle, and J.F. Kitchens, 1982. Engineering and Development Support of General Decontamination Technology. Task 11. Composting of Explosives, Contract No. DAAK11-80-C-0027, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Kaplan, D.L., and A.M. Kaplan, 1982. "Thermophilic Biotransformations of 2,4,6-Trinitrotoluene Under Simulated Composting Conditions," Applied Environmental Microbiology, 44: 757-760.
- Kayser, E.G., N.E. Burlinson, and D.H. Rosenblatt, 1984. Kinetics of Hydrolysis and Products of Hydrolysis and Photolysis of Tetryl, Technical Report 84-78, NTIS AD-A153144, Naval Surface Weapons Center, Silver Spring, Maryland.
- Landrum, P.F., S.R. Nihart, B.J. Eadie, and W.S. Gardner, 1984. "Reverse-Phase Separation Method for Determining Pollutant Binding to Aldrich Humic Acid and Dissolved Organic Carbon of Natural Waters," Environmental Science and Technology, 18: 187-192.
- Lia, D.-S., K. Thomson, and A.C. Anderson, 1984. "Identification of Nitroso Compounds From Biotransformation of 2,4-dinitrotoluene," Applied Environmental Microbiology, 47: 1,295-1,298 (as cited in Walsh, 1990).
- Lu, P.Y., and R. Metcalf, 1975. "Environmental Fate and Biodegradability of Benzene Derivatives as Studied in a Model Aquatic Ecosystem," Environmental Health Perspectives, 19: 269-273.
- Lyman, W.J., W.F. Rheel, and D.H. Rosenblatt, eds., 1982. Handbook of Chemical Property Estimation Methods, McGraw-Hill Book Company, New York.
- McCormick, N.G., J.H. Cornell, and A.M. Kaplan, 1978. "Identification of Biotransformation Products From 2,4-dinitrotoluene," Applied Environmental Microbiology, 35: 945-948 (as cited in Walsh, 1990).

- McCormick, N.G., J.H. Cornell, and A.M. Kaplan, 1984. The Fate of Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and Related Compounds in Anaerobic Denitrifying Continuous Culture Systems Using Simulated Wastewater, TR-85/008, ADA149462, U.S. Army Natick Research and Development Laboratory (as cited in Walsh, 1990).
- Mitchell, W.R., and W.H. Dennis, 1982. "Biodegradation of 1,3-dinitrobenzene," Journal of Environmental Science and Health, A17: 837-853 (as cited in Walsh, 1990).
- Mori, M., T. Miyahara, Y. Hasegawa, Y. Kuao, and H. Kozuka, 1984. "Metabolism of Dinitrotoluene Isomers by *Escherichia coli* Isolated From Human Intestine," Chemical Pharmacology Bulletin, 32: 4,070-4,075 (as cited in Walsh, 1990).
- Palazzo, A.J., and D.C. Leggett, 1986. "Effect and Disposition of TNT in a Terrestrial Plant," Journal of Environmental Quality, 15: 49-52.
- Pennington, J.C., and W.H. Patrick, Jr., 1990. "Adsorption and Desorption of 2,4,6-Trinitrotoluene by Soils," Journal of Environmental Quality, 19: 559-567.
- Saxena, A., and R. Bartha, 1983. "Binding of 3,4-Dichloroaniline by Humic Acid and Soil: Mechanism and Exchangeability," Soil Science, 136: 111-116.
- Simmers, J.W., 1991. Telephone conversation between J.W. Simmers, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, and N.W. Gabel, Dames & Moore (February 11, 1991).
- Simmers, J.W., C.R. Lee, and J.G. Skogerboe, 1989. "Plant Uptake From TNT Contaminated Soils," Proceedings for the 14th Annual Army Environmental R&D Symposium, Report No. CETHA-TE-TR-98055, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Spanggord, R.J., et al., 1983. Environmental Fate Studies of HMX, NTIS AD-A138550, U.S. Army Medical Research and Development Command (as cited in Burrows et al., 1989).

- Spangord, R.J., T. Mill, T. Chou, W. Mabey, J. Smith, and S. Lee, 1980. Environmental Fate Studies on Certain Munition Wastewater Constituents. ADA099256, SRI International, Menlo Park, California.
- Trabalka, J.R., and C.T. Garten, Jr., 1982. Development of Predictive Models for Xenobiotic Bioaccumulation in Terrestrial Ecosystems. Publication No. 2037, ORNL-5869, NTIS DE83 003171, Oak Ridge National Laboratory.
- Walsh, M.E., 1990. Environmental Transformation Products of Nitroaromatics and Nitramines. Special Report 90-2, CETHA-TE-CR-89205, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory/U.S. Army Toxic and Hazardous Materials Agency.
- Williams, R.T., P.S. Ziegenfuss, and P.J. Marks, 1988. Field Demonstration Composting of Explosives-Contaminated Sediments at the Louisiana Army Ammunition Plant (LAAP). Contract No. DAAK11-85-D-007, Report No. AMXTH-IR-TE-88242, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Williams, R.T., P.S. Ziegenfuss, and P.J. Marks, 1981. Field Demonstration--Composting of Propellants-Contaminated Sediments at the Badger Army Ammunition Plant (BAAP). Contract DAAK11-85-D-007, Report No. CETHA-TE-CR-89061, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Woodward, R.E., 1990. Evaluation of Composting Implementation: A Literature Review. Contract No. DAAL03-86-D-001, Report No. TCN 89363, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), 1990. Remedial Investigation/Feasibility Study of the Savanna Army Depot Activity, Savanna, Illinois. Contract No. DAAA15-88-D-0008, prepared by Dames & Moore, Bethesda, Maryland.

- U.S. Environmental Protection Agency (USEPA), 1987a. Development of Predictive Chemical Assessment Methodologies for Absorption/Mobility of Chemicals in Soils, EPA Contract No. 68-02-4254, Task 26, Office of Toxic Substances, USEPA, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA), 1987b. Expert Systems Questionnaire. Survey Concerning Biodegradation, EPA Contract No. 68-02-4254, Office of Toxic Substances, USEPA, Washington, D.C.
- Zepp, R.G., and D.M. Cline, 1977. "Rates of Direct Photolysis in Aquatic Environment," Environmental Science and Technology, 11: 359-366.

APPENDIX B

Assessment of the Concentrations of Site-Related Airborne Chemicals at Points of Potential Exposure

APPENDIX B

Assessment of the Concentrations of Site-Related Airborne Chemicals at Points of Potential Exposure

This appendix describes the methodology undertaken to assess the inhalation exposure concentrations for soil contaminants of concern induced by wind erosion from the Explosive Washout Lagoons (Site 4). An emission rate for wind erosion of the respirable size fraction of contaminated soil is first estimated; then dispersion models are used to estimate concentrations of contaminants in air in a number of locations that are considered to be potential exposure points.

B.1 WIND EROSION EMISSIONS MODEL

Airborne particulate matter with an aerodynamic diameter less than or equal to 10 μm , referred to as PM_{10} , is respirable and when contaminated can contribute to inhalation exposure (Cowherd *et al.*, 1988). The first step in estimating an emission rate from wind erosion is classification of the soil surface material. The soil surface is classified as having either a "limited reservoir" or an "unlimited reservoir" of erodible surface particles.

Soil sampling was performed to assess the soil characteristics at Site 4. Based on field observations, soil classifications, and sieve analyses performed on samples in the vicinity of the lagoons, the aggregate size mode was estimated at 0.25 millimeter. The aggregate size mode is between the opening size of the sieve with the largest catch and the opening size of the next largest sieve (Cowherd *et al.*, 1988). Because more than 60 percent of the soil passes the 1-millimeter sieve, an "unlimited reservoir" exists at the site.

A simplified version of the wind erosion equation was used to estimate windblown or fugitive dust emissions from Site 4 (Cowherd *et al.*, 1988). The modified equation is of the form:

$$E = kaIKCL'V'$$

where:

- E** = **PM₁₀ wind erosion losses of tilled fields, tons/acre/yr**
- k** = **estimated fraction of total suspended particles (TSP) that is PM₁₀**
- a** = **portion of total wind erosion losses that would be measured as suspended particulates**
- I** = **soil erodibility, tons/acre/yr**
- K** = **surface roughness factor, dimensionless**
- C** = **climatic factor, dimensionless**
- L'** = **unsheltered field width factor, dimensionless**
- V'** = **vegetative cover factor, dimensionless.**

As an aid in understanding the mechanics of this equation, "T" can be thought of as the basic erodibility of a flat, very large, bare field in a climate highly conducive to wind erosion and K, C, L', and V' as reduction factors for a rough surface, a climate less conducive to wind erosion, smaller sized fields, and vegetative cover, respectively. The overall approach and much of the data are adapted from the wind erosion equation, which was developed as the result of nearly 40 years of research by the U.S. Department of Agriculture.

I, K, L', and V' are obtained from empirical studies and are presented as graphs in Cowherd et al. (1988). "T" is based on the soil particle size, "K" is based on the height and spacing of any ridges (i.e. a representation of the surface roughness), "L'" is an adjusted field width for any obstruction in the prevailing wind direction, and "V'" considers any reduction in erosion due to the presence of vegetative cover. The climatic factor (C) for a specific site is computed using the following expression:

$$C = 0.345 \frac{W^3}{PE^2}$$

where:

W = mean annual wind velocity corrected to a standard height of 30 feet, miles/hour

PE = Thornthwaite's precipitation-evaporation index
= $0.83 \times (\text{sum of 12 monthly ratios of precipitation to actual evapotranspiration (AET)})$

The mean annual wind speed was estimated using a wind rose* for UMDA (Roy F. Weston, 1989). The height of the sensor (4 meters) was obtained via personal communication with UMDA personnel. Monthly precipitation data was obtained from the UMDA Installation Assessment (USATHAMA, 1979).

Because there are no field measurements of actual evapotranspiration (AET), empirical formulas can be used to estimate AET. Thornthwaite's method was used to estimate the potential evapotranspiration (PET). The following is the empirical formula as described by Dunne and Leopold (1978):

$$E_{\pi} = 1.6 \left[\frac{10T_i}{I} \right]^{\frac{1}{4}}$$

where:

E_{π} = unadjusted PET (cm/month)

T_i = mean monthly air temperature (°C)

I = annual heat index (°C), where

$$I = \sum_{i=1}^{12} \left[\frac{T_i}{5} \right]^{1.5}$$

*Source: UMDA airfield site map.

$$a = 0.49 + 0.0179 (I) - 0.0000771 (I^2) + 0.000000675 (I^3)$$

i = subscript representing month i

The unadjusted PET value (E_{Ti}) is then adjusted for the number of days per month and latitude, which effects the length of the day, to obtain the adjusted PET. The E_{Ti} value is multiplied by the appropriate factor to adjust for the month and latitude (USEPA, 1988). Average monthly temperatures were obtained from the UMDA Installation Assessment (USATHAMA, 1979). Based on PET, AET can then be computed using Dunne and Leopold (1978):

$$AET = PET f(AW/AWC)$$

where:

f() = functional relationship

AW = available soil moisture (cm)

AWC = available water capacity of the soil (cm)

The available soil (AW) moisture is estimated as the rooting depth of vegetation times the difference between the available soil moisture and the wilting point. The available water capacity (AWC) of the soil is estimated as the rooting depth of vegetation times the difference between the field capacity and the wilting point. When the soil is sufficiently moist, AET will be equal to PET (i.e., $f(AW/AWC) = 1$). If evapotranspiration continues without frequent input of moisture from precipitation or irrigation, the available water in the soil will begin to reduce AET below PET. For bare soils, the only mechanism for transporting moisture upward is the diffusion of vapor through air pores. After the surface dries out, this process becomes very slow. It is suggested by Dunne and Leopold (1978) that after 1.0 centimeter of water has evaporated from barren soils the evaporation essentially stops. Given the lack of site-specific soil moisture data from the lagoon areas, the dry and hot climate condition, and the lack of significant precipitation (approximately 10 inches per year), PET was computed and only adjusted if it exceeded the average

monthly precipitation, in which case it was set equal to the average monthly precipitation. This is a conservative estimate (i.e., a high estimate of AET, because the assumption that evapotranspiration is equal to precipitation is equivalent to assuming desert conditions).

The following are the estimated and computed parameters used in the wind erosion equation:

Source size	= 30 m x 30 m
I	= 160 tons/acre/yr
K	= 1.0
W	= 4.0 m/sec or 8.94 mph
W (adj to 30 ft.)	= 10.29 mph
PE	= 21
C	= 0.70
L'	= 0.70
V'	= 1.0

The estimated annual soil emission rate (E) for Site 4 is 6.3 mg/sec. The two adjacent lagoons were considered as one 30 x 30 meter source (Figure 3-1, in main text). The base of the lagoons is relatively smooth and devoid of any vegetation. Given that some basic assumptions had to be made in estimating the emission rate using the above described procedures, another method--Cowherd *et al.*, (1985)--was also applied for comparative purposes. The soil emission rate computed using this alternate procedure (Cowherd, *et al.*, 1985) is 3.3 mg/sec. This helps to confirm that the 6.3 mg/sec is a reasonable and probably conservative estimate of the soil emission rate.

B.2 DISPERSION MODELS

The dispersion modeling procedure described in Cowherd *et al.* (1985) was used to estimate annual average ambient concentrations attributable to respirable particulate emissions from Site 4.

The model is based on a series of Industrial Source Complex-Long Term (ISCLT) model outputs that were tabulated using averaged meteorological data for seven climatic regions in the United States. ISCLT is a refined model in EPA's UNAMAP family of models and incorporates features particularly well-suited for wind erosion applications. Because the ISCLT model is the basis for the dispersion modeling procedure used in this appendix (i.e., Cowherd *et al.*, 1985), some general discussion of ISC and references are supplied below.

Three critiques of the ISC model have been published (Bowers and Anderson, 1981; Bowers *et al.*, 1982; Schulman and Hanna, 1986). Emissions from both wind erosion and mechanical resuspension were modeled in these critiques for each of two area source sizes--a 10- by 10-meter square and a 100- by 100-meter square. The choice of source sizes was based on examination of a data base of contamination sites with "actual soil contamination." During development of the methodology, sources larger (175 m², 250 m²) and smaller (55 m²) than 100 m² were also considered; however, the resultant concentration estimates from the 10- and 100-m² sources were found to be reasonable approximations to the concentrations for the other source sizes. More specifically, for a constant emission rate, the maximum difference in concentration estimates was < 20 percent at 1 kilometer from the source center, regardless of source size; differences decreased rapidly beyond this point.

The Cowherd *et al.* (1985) model contains 192 receptor points at which concentration estimates may be obtained. These estimates are made using the tabulated unscaled concentration for each receptor point for the particular region of interest. The points are arranged in a polar coordinate system at distances from 200 to 7,000 meters from the center of the contaminated site. The maximum distance of 7 kilometers corresponds to the 4-mile radius used in the Hazard Ranking System (HRS) as an indicator of the "population which may be harmed should hazardous substances be released to the air" (Federal Register, 1982). The receptors are grouped into "fine" and "course" grids and are arranged as follows:

- Fine Grid: 32 receptors at four distances (200, 300, 400, and 500 meters) along eight directions (N, NE,...NW radials)
- Course Grid: 160 receptors at 10 distances (750 to 7,000 meters) along 16 directions (N, NNE,...NNW radials).

Once the annual concentration estimates are plotted, isopleths of concentrations can be drawn. These isopleths indicate the spatial variation of concentration and are used to develop estimates of population exposure. The procedure uses the entire concentration field obtained by scaling the tabulated results to construct isopleths. The equation used is as follows:

$$d = [X_T - X_0] / [X_1 - X_0]$$

where:

- d = relative distance from receptor 0 to receptor 1, where concentration equals X_T
- X_T = target concentration (i.e., concentration to which the isopleth corresponds)
- X_0 = (lower) concentration value at receptor 0
- X_1 = (higher) concentration value at receptor 1 and $X_0 \leq X_T \leq X_1$.

One possible modification to the orientation of estimated concentration involves "rotation" of the initial concentration field so that the axis or radial of maximum concentration is oriented parallel to the prevailing wind direction. Such rotation should be applied only in cases in which erosion is the dominant resuspension mechanism and only if the results of a site survey suggest that this procedure is warranted. Based on the wind rose available for UMDA, the results were rotated so that the maximum concentrations were toward the northeast (the direction of the prevailing wind).

As discussed previously, the differences between the dispersion modeling procedure results presented in Cowherd et al. (1985) based on the ISC model and those obtained by the ISCLT model are greater at closer distances (<1,000 meters) to the source, depending on the source size. It can also be surmised that the estimation of concentrations at closer distances to the source becomes less accurate. Another dispersion model was used to estimate respirable particulate concentration within 200 meters from the center of the contaminated site. This was done to assess the relationship of concentrations along the same radial direction at closer distances (<200 meters) to the site, compared to the concentrations at greater distances (>200 meters) using the Cowherd model; and to estimate concentrations at receptor locations near the site. The model used was EPA's recommended virtual upwind point source dispersion equation:

$$x = \frac{16(2Q)}{2\pi L(2\pi)^{0.5}\sigma_z u}$$

where:

- x = concentration (g/m³) at distance (m) downwind
- Q = source strength or emission rate (g/sec)
- L_v = L + L' (m)
- L = distance from the source center to the receptor (m)
- L' = distance from the source center to the virtual upwind point source (given by 2.51 times of the cross wind of the source) (m)
- u = mean wind speed (m/sec)
- σ_z = standard deviation of the vertical plume concentration (m)

(This parameter is obtained from compiled graphs based on the downwind distance where a concentration estimate is desired, and an assumed atmospheric stability class.)

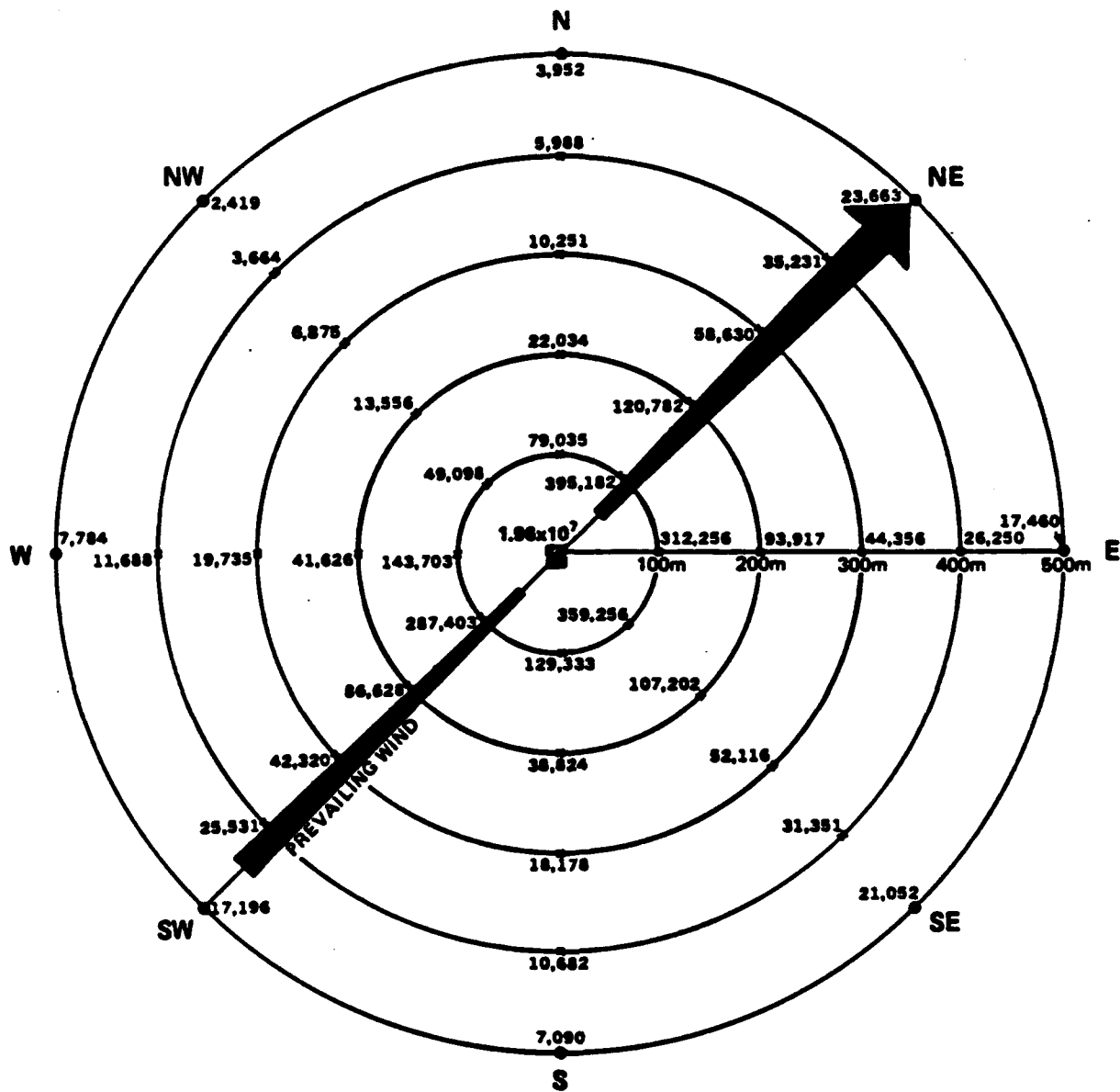
The following are the estimated parameters used in the virtual upwind equation for an assumed receptor location proximate to the site and assuming Class D as the atmospheric stability class:

$$\begin{aligned} Q &= 6.275 \times 10^3 \text{ g/sec} \\ L &= 15 \text{ m} \\ L' &= 75.3 \text{ m} \\ L_v &= 90.3 \text{ m} \\ u &= 4 \text{ m/sec} \\ \sigma_z &= 1.8 \text{ m} \end{aligned}$$

This model was found to over-predict concentration by an average of only 8 percent and contains appropriate parameters for estimating dispersion from small area sources (Baker and MacKay, 1985). This slight over-prediction—which is desirable with respect to health and air quality standards—can probably be attributed to the assumption of a uniform height of the plume (box).

It was concluded that there is no difference in the relationship of concentrations along the same radial direction at distances closer than 200 meters (concentrations computed using the virtual upwind equation) or greater than 200 meters (concentrations computed as per Cowherd *et al.*, 1985). Therefore, the unscaled concentrations presented in the Cowherd model were plotted and extrapolated to include the distances closer to (100 meters) the center of the contaminated site. For onsite concentrations, EPA recommended use of the virtual upwind point source equation.

Figure B-1 presents windblown respirable dust concentrations from the Explosive Washout Lagoons, which when multiplied by the concentration in parts per million (ppm) of a particular contaminant of interest will yield the concentration of that contaminant in picograms per cubic meter. The estimated contaminant concentrations in air are presented in the main text (Table 7-5, Section 7.0).



0 200 Meters
SCALE

FIGURE B-1
DISPERSED MODELED DUST CONCENTRATIONS (in pg/m^3)
FROM EXPLOSIVE WASHOUT LAGOONS

B.3 DISCUSSION OF EMISSION MODEL PARAMETERS

The following is a discussion of the parameters selected for use in the emission and dispersion models:

- Fraction of TSP (k): Based on USDA research, approximately half of the total suspended particulate (TSP) is PM_{10} and, therefore, this value is set equal to 0.5.
- Portion of total wind erosion measured as suspended particulate (a): Again, based on USDA research this is estimated to be 0.025, or 2.5 percent.
- Soil erodibility (I): This is based on the percent of soil particles greater than 0.84 millimeter. Based on seive analyses of nearby soils, approximately 5 percent of the soil particles at the lagoon site are greater than 0.84 millimeter. From Figure 7-1 in Cowherd *et al.* (1988), the estimated soil erodibility is approximately 160 tons/acre/yr.
- Surface roughness factor (K): Because the actual surface of the bottom of the lagoons is relatively smooth, the conservative estimate of K equal to 1.0 is assumed.
- Climatic factor (C): The climatic factor is based on the mean annual speed and the precipitation-evaporation index as described previously. Because--for this site--monthly AET was essentially set equal to monthly precipitation, a lower estimate of PE is computed and hence a conservative value of C is obtained (i.e., greater wind erosion is estimated).
- Unsheltered field width factor (L'): The existing dikes (or berms) around the Explosive Washout Lagoons provide some shelter against the wind. The dike height is approximately 6 feet (1.83 millimeter). The width of the contaminated site perpendicular to the prevailing wind is 30 millimeter. Therefore, as per the wind erosion equation, the sheltered

width is $[30 - 10(1.83)] = 11.7$ millimeter. From Figure 7-5 in Cowherd *et al.* (1988), the calculated sheltered width (L') is approximately 0.70.

- Vegetative cover factor (V'): Because the lagoon areas are virtually devoid of any vegetation, this factor is conservatively assumed to be 1.0.

B.4 REFERENCES

Baker, L.W., and K.P. MacKay, 1985. Screening Models for Estimating Toxic Air Pollution Near a Hazardous Waste Landfill.

Bowers, J.F., A.J. Anderson, and W.R. Hargraves, 1982. Tests of the Industrial Source Complex (ISC) Dispersion Model at the Armco, Middletown, Ohio Steel Mill. EPA-450/4-82-006, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Bowers, J.F., and A.J. Anderson, 1981. An Evaluation Study for the Industrial Source Complex (ISC) Dispersion Model. EPA-450/4-81-002, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cowherd, C., G.E. Muleski, and J.S. Kinsey, 1988. Control of Open Fugitive Dust Sources. EPA-540/3-88-008, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

Cowherd, C., G.E. Muleski, P.J. Englehart, and D.A. Gillette, 1985. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA/600/8-85/002, Office of Health and Environmental Assessment, Washington, D.C.

Dunne, T., and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman and Co., New York, New York.

Federal Register. 1982. "National Oil and Hazardous Substance Contingency Plan" 47 FR 31219, July 16, 1982.

- Roy F. Weston, Inc., 1989. Umatilla Army Depot Activity Remedial Investigation, Draft Final Report No. CETHA-IR-CR-89038, prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- Schulman, L.L., and S.R. Hanna, 1986. "Evaluation of Downwash Modifications to the Industrial Source Complex Model," J. Air Poll. Control Assoc. 36 (3), 25-264.
- U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), 1979. Installation Assessment of Umatilla Army Depot Activity, Report No. 142, Aberdeen Proving Ground, Maryland.
- U.S. Environmental Protection Agency (USEPA), 1988. Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites, Office of Solid Waste and Emergency Response, USEPA, Washington, D.C.

APPENDIX C

Methodology for Developing Remedial Action Criteria for Soil Based on the Protection of Groundwater

APPENDIX C

Methodology for Developing Remedial Action Criteria for Soil Based on the Protection of Groundwater

The methodology discussed in this appendix follows EPA guidance (USEPA, 1989). This guidance is a compendium of examples of methods used to develop remedial action criteria for soil based on the protection of groundwater from hazardous waste sites for which there are Records of Decision. The example used in this appendix is from a Record of Decision for a site in Millcreek, Pennsylvania (USEPA, 1989).

C.1 MODELING APPROACH AND RESULTS

The first step was to determine the remedial action criteria in groundwater for the contaminants of concern based on several target values for risk and hazard index. The results of these calculations for the residential and light industrial land use scenarios and the same exposure assumptions as used in the risk characterization section of the main text are presented in Tables C-1 and C-2, respectively. Because the compliance point for assumed drinking water wells is specified in the National Contingency Plan (40 CFR, Subpart E, Section 300.430) as the boundary of the site, the action levels presented in Tables C-1 and C-2 for an assumed target risk or hazard index value can be considered as the concentration of groundwater at the source area (C_0). In other words, no contaminant transport modeling is necessary to estimate the concentration at the compliance point because the compliance point and the source concentration are coincident.

After the source concentration is determined, the percolation rate and lateral groundwater flow (LGWF) are calculated to estimate the leachate concentration immediately beneath the source.

$$\text{percolation rate} = \text{percolation} \times \text{area}$$

where:

$$\text{percolation} = \text{amount of precipitation per year (m/year)}$$

TABLE C-1
Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Groundwater Ingestion
Residential Land Use Scenario

<u>Analyte</u>	<u>Carcinogenic Action Levels (mg/l)</u>		
	<u>Risk = 1E-06</u>	<u>Risk = 1E-05</u>	<u>Risk = 1E-04</u>
135TNB	—	—	—
13DNB	—	—	—
246TNT	1.17E-03	1.17E-02	1.17E-01
24DNT	8.18E-06	8.18E-04	8.18E-03
26DNT	8.18E-06	8.18E-04	8.18E-03
HMX	—	—	—
NB	—	—	—
RDX	3.18E-04	3.18E-03	3.18E-02
Tetryl	—	—	—

<u>Analyte</u>	<u>Noncarcinogenic Action Levels (mg/l)</u>		
	<u>Hazard Index = 0.1</u>	<u>Hazard Index = 1.0</u>	<u>Hazard Index = 1</u>
135TNB	1.78E-04	1.78E-03	1.78E-02
13DNB	3.60E-04	3.60E-03	3.60E-02
246TNT	1.78E-03	1.78E-02	1.78E-01
24DNT	—	—	—
26DNT	—	—	—
HMX	1.78E-01	1.78E+00	1.78E+01
NB	1.78E-03	1.78E-02	1.78E-01
RDX	1.06E-02	1.06E-01	1.06E+00
Tetryl	—	—	—

— indicates that the relevant health effects criteria are unavailable.

TABLE C-2
Remedial Action Criteria (Action Levels)
for the Explosive Washout Lagoons (Site 4)
Groundwater Ingestion
Light Industrial Land Use Scenario

<u>Analyte</u>	<u>Carcinogenic Action Level (mg/l)</u>		
	<u>Risk = 1E-06</u>	<u>Risk = 1E-05</u>	<u>Risk = 1E-04</u>
135TNB	—	—	—
13DNB	—	—	—
246TNT	3.06E-03	3.06E-02	3.06E-01
24DNT	1.01E-04	1.01E-03	1.01E-02
26DNT	1.01E-04	1.01E-03	1.01E-02
HMX	—	—	—
NB	—	—	—
RDX	9.94E-04	9.94E-03	9.94E-02
Tetryl	—	—	—

<u>Analyte</u>	<u>Noncarcinogenic Action Level (mg/l)</u>		
	<u>Hazard Index = 0.1</u>	<u>Hazard Index = 1.0</u>	<u>Hazard Index = 1</u>
135TNB	2.92E-04	2.92E-03	2.92E-02
13DNB	5.63E-04	5.63E-03	5.63E-02
246TNT	2.92E-03	2.92E-02	2.92E-01
24DNT	—	—	—
26DNT	—	—	—
HMX	2.92E-01	2.92E+00	2.92E+01
NB	2.92E-03	2.92E-02	2.92E-01
RDX	1.75E-02	1.75E-01	1.75E+00
Tetryl	—	—	—

— indicates that the relevant health effects criteria are unavailable.

$$\text{area} = \text{total area of contaminated soil (m}^2\text{)}$$

At Site 4, percolation rate is computed as:

$$\begin{aligned} &0.229 \text{ (m/yr)} \times 900 \text{ (m}^2\text{)} \\ &205.74 \text{ m}^3\text{/yr} = 205,740 \text{ l/yr} \end{aligned}$$

The source of the yearly precipitation value (9 in./yr) is Roy F. Weston, Inc. (1989), and the area of contamination is estimated from Figure 3-1.

The LGWF is the total flow of groundwater passing beneath the site per year. It is calculated by the following equation:

$$\text{LGWF} = \text{saturated thickness (m)} \times \text{groundwater velocity (m/yr)} \times \text{lateral source length (m)}$$

At Site 4, LGWF is calculated as:

$$\begin{aligned} &40 \text{ ft (0.3048 m/1 ft)} \times (600 \text{ m/35 yr}) \times 30 \text{ m} \\ &6,270.2 \text{ m}^3\text{/yr} = 6,270,171 \text{ l/yr} \end{aligned}$$

The saturated thickness is reported in Roy F. Weston, Inc. (1989); the groundwater velocity is a rough approximation, assuming that contamination has travelled at least 600 meters (the approximate distance from the lagoons to monitoring wells 4-3 and 4-5) since the beginning of operations at Site 4 (assuming that operations began in 1955); and the lateral source length is dimension of the source.

The total flow in the saturated zone underlying the contaminated area is the sum of the LGWF and the percolation rate.

$$\begin{aligned} \text{Total flow} &= 6,270,171 \text{ l/yr} + 205,740 \text{ l/yr} \\ &= 6,475,911 \text{ l/yr} \end{aligned}$$

The annual mass of contaminant leaching from the unsaturated zone, in mg/yr, is then the product of C_0 and total flow. The contaminant concentration in the unsaturated pore space, or the leachate concentration (C_l), is the annual mass divided by the percolation rate.

For Site 4, assuming a 10^{-6} target risk and a residential land use (Table C-1):

$$C_0 = 1.2 \times 10^{-3} \text{ mg/l}$$

$$\text{annual mass of leachate} = 1.2 \times 10^{-3} \text{ mg/l} \times 6,475,911 \text{ l/yr} = 7,771 \text{ mg/yr}$$

$$C_1 = 7,771 \text{ (mg/yr)} / 205,740 \text{ (l/yr)} = 3.78 \times 10^{-2} \text{ mg/l}$$

To produce a TNT concentration of $1.2 \times 10^{-3} \text{ mg/l}$ in the saturated zone underlying the contaminated area at Site 4, the leachate concentration immediately beneath the site would be expected to be $3.78 \times 10^{-2} \text{ mg/l}$.

The final step in this process is to predict, based on equilibrium chemical thermodynamics, what soil concentration would be in equilibrium with the leachate concentration (C_1). The Freundlich equation used is:

$$C_s = K_d \times (C_1)^{1/n}$$

where:

C_s = dry weight concentration of the organic compound of interest in soil (mg/kg)

C_1 = equilibrium leachate concentration (mg/l)

n = an experimentally derived exponential adjustment factor to the adsorption isotherm

K_d = soil:water partition coefficient (l/kg).

Pennington and Patrick (1990) experimentally determined a number of adsorption isotherms for TNT from a variety of soil samples from Army Ammunition Plants with TNT contamination. These experimental soil adsorption data were fit to a Freundlich model and K_d and n were determined for each of the experimental soils. Although a UMDA soil was not selected as an experimental soil sample, based on sieve analyses from UMDA soils, knowledge of UMDA geology, observation of the chemical and physical characteristics table of samples used by Pennington and Patrick (1990), and knowledge of geology of the Savanna Army Depot Activity, the Savanna

sample was chosen as an analog. The K_d and n values derived for this soil sample in Pennington and Patrick (1990) are 5.3 and 1.4, respectively. Substituting all values into the Freundlich equation:

$$\begin{aligned} C_s &= 5.3 \text{ l/kg } (3.78 \times 10^{-2} \text{ mg/l})^{1/1.4} \\ &= 0.51 \text{ mg/kg TNT} \end{aligned}$$

Using the 10^{-6} target risk level for TNT and the light industrial land use scenario for C_0 from Table C-2 (3.65×10^{-3} mg/l), and the same calculations shown above, produces a equilibrium soil concentration of 1.13 mg/kg. Therefore, the remedial action criteria for TNT in soil based on the protection of groundwater are 0.51 mg/kg for the residential land use scenario and 1.13 mg/kg for the light industrial land use scenario (assuming a target risk of 10^{-6}). For 10^{-5} or 10^{-4} target risk levels, these remedial action criteria can simply be multiplied by factors of 10 and 100, respectively. Other contaminants of concern besides TNT were not evaluated, because only total organic carbon partition coefficients were available and not Freundlich K_d 's. Pennington and Patrick (1990) showed that the organic carbon content of soils was poorly correlated with adsorption of TNT. Therefore, the use of an organic carbon adsorption relationship appeared to be inappropriate for other explosives analytes by analogy with TNT. Furthermore, total organic carbon analyses have not been performed in soils from Site 4, and an estimate would probably contain a high degree of uncertainty because the organic carbon content would be expected to be very low.

C.2 UNCERTAINTIES IN MODEL

Besides the major concerns addressed in the main text concerning the general validity of developing soil action levels based on the protection of groundwater for the Explosive Washout Lagoons, particular uncertainties exist in the model described above, even if it is assumed that it is completely valid.

- The input groundwater concentrations (C_0) were derived directly from the remedial action criteria for groundwater at given target levels assuming that the compliance point and the source point were

coincident. In fact, this may be slightly conservative and C_0 should be greater to account for dispersion, degradation, and dilution between the compliance point and the source point.

- The percolation rate is based on the average annual precipitation and an estimate of the contaminated area--both of which have some associated uncertainty. In addition, this calculation assumes that all precipitation infiltrates to groundwater, while in fact some precipitation is lost to evapotranspiration (as discussed in Appendix B). This assumption is conservative, because if percolation is in fact less, the leachate concentration and resulting soil action level would be greater.
- The LGWF term is highly uncertain. Groundwater velocity is an extremely rough estimate based on estimated contaminant transport distance over an undetermined time. Even if the contaminant transport distance and the time of contamination were correct, there is no certainty that the conditions that produced the current contaminant distribution are representative of what is occurring today and in the future. The saturated thickness is also uncertain, based on the current depth of contamination, though a more realistic value than that presented by Roy F. Weston, Inc. (1989) cannot as yet be determined. Additionally, some error is introduced by the estimate of the dimensions of the contaminated area.
- The assumption of total and immediate mixing of leachate with groundwater and percolated precipitation--though a gross simplification of a complex process--is conservative.
- The analogy of Savanna soils to UMDA soils introduces some level of uncertainty, but it is probably small relative to the other uncertainties discussed above.

C3 REFERENCES

- Pennington, J.C., and W.H. Patrick, Jr., 1990. "Adsorption and Desorption of 2,4,6-Trinitrotoluene by Soils," Journal of Environmental Quality, Vol. 19, pp. 559-567.
- Roy F. Weston, Inc., 1989. Umatilla Army Depot Activity Remedial Investigation. Draft Final Report No. CETHA-IR-CR-89038, prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland.
- U.S. Environmental Protection Agency (USEPA), 1989. Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples. EPA/540/2-89/057, Office of Emergency and Remedial Response, prepared by Booz-Allen and Hamilton, Inc., Washington, D.C.