

US EPA ARCHIVE DOCUMENT



Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System

Volume I: Modeling System and Science

Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System

Volume I: Modeling System and Science

prepared by

U.S. Environmental Protection Agency

Office of Research and Development
National Exposure Research Laboratory
Athens, GA
and
Research Triangle Park, NC

Office of Solid Waste
Washington, D.C.

This document is the first volume of a five-volume set. This volume describes the conceptual design, scientific rationale, and supporting data that are the foundation for the 3MRA modeling system. Volume II describes the data developed and used to run the 3MRA modeling system. Volume III describes the approach to quality assurance, including verification and validation activities ranging from extensive peer reviews to multimedia model comparisons. Volume IV describes the methodology used to evaluate sensitivity of model parameters and characterize different types of uncertainty in the 3MRA modeling system. Volume V describes the technology design and includes a user's guide.

Table of Contents

Section	Page
List of Figures	viii
List of Tables	x
1.0 Introduction	1-1
1.1 Background	1-1
1.2 Overall Design Goals of the 3MRA Modeling System	1-4
1.3 Overview of the 3MRA Modeling System	1-9
1.4 Overview of the 3MRA Science Module Architecture	1-12
1.5 Overview of Results Generated by the 3MRA Modeling System	1-15
1.6 Organization of This Document	1-19
1.7 References	1-21
2.0 Modeling Approach	2-1
2.1 Overview and Conceptual Approach	2-1
2.2 Spatial and Temporal Scale	2-6
2.2.1 Model Spatial Scale	2-6
2.2.2 Model Temporal Scale	2-8
2.3 Design of the 3MRA Modeling System Multipathway Modules	2-11
2.3.1 Chemicals in the 3MRA Modeling System Database	2-11
2.3.2 Sources (WMUs)	2-15
2.3.3 Transport Media, Fate Processes, and Intermedia Contaminant Fluxes	2-19
2.3.4 Food Chain/Food Web Components	2-21
2.3.5 Human Exposure and Risk	2-24
2.3.6 Ecological Receptors, Exposure Pathways, and Risk Measures	2-28
2.4 References	2-32
3.0 Spatial Aspects of Environmental Settings and Receptors	3-1
3.1 Overview of Spatial Layout for Environmental Settings and Receptors	3-1
3.1.1 Settings and Areas of Interests	3-1
3.1.2 Site Layout and Spatial Data Layers	3-1
3.2 Watersheds and Waterbodies	3-5
3.2.1 Definitions for Watershed and Waterbody Layout	3-7
3.2.2 Assumptions for Waterbodies and Regional Watersheds	3-8
3.2.3 Assumptions for Local Watersheds	3-8
3.2.4 Watershed Soils	3-9
3.3 Human Receptors, Farms, and Wells	3-9
3.3.1 Resident and Home Gardener Locations	3-10
3.3.2 Farm Locations	3-11
3.3.3 Well Locations (Private Wells Only)	3-11
3.3.4 Recreational Fisher Locations	3-11

Table of Contents (continued)

Section	Page
3.4	Habitats and Ecological Receptor Placement 3-12
3.4.1	Habitat Delineation 3-12
3.4.2	Assignment of Receptors to Habitats 3-16
3.5	Summary 3-17
3.6	References 3-17
4.0	Wastewater Source Modules 4-1
4.1	Purpose and Scope 4-1
4.2	Conceptual Approach 4-2
4.2.1	Description of Waste Management Units 4-3
4.2.2	Calculate Constituent Concentrations within the Unit 4-6
4.2.3	Calculate Solids Concentrations within the Unit 4-10
4.2.4	Calculate Volatile Emission Rates 4-12
4.2.5	Estimate Resuspension, Sedimentation, and Burial Velocities 4-13
4.2.6	Estimate Constituent Release in Leachate (Surface Impoundments only) 4-19
4.2.7	Adjust for Temperature Effects 4-23
4.3	Module Discussion 4-25
4.3.1	Strengths and Advantages 4-25
4.3.2	Uncertainty and Limitations 4-26
4.4	References 4-27
5.0	Land-based Source Modules 5-1
5.1	Purpose and Scope 5-1
5.2	Conceptual Approach 5-5
5.2.1	Description of WMUs 5-5
5.2.2	The Generic Soil Column Model 5-9
5.2.3	Local Watershed Model 5-15
5.2.4	Particulate Emissions Model 5-22
5.3	Module Discussion 5-24
5.3.1	Strengths and Advantages 5-24
5.3.2	Uncertainty and Limitations 5-26
5.4	References 5-28
6.0	Air Module 6-1
6.1	Purpose and Scope 6-1
6.2	Conceptual Approach 6-2
6.2.1	Characterize Source-specific Parameters 6-5
6.2.2	Calculate Receptor Locations (polar-grid or site-specific) 6-6
6.2.3	Calculate Receptor-specific Concentration and Deposition Rates 6-6
6.2.4	Calculate Constituent-specific Annual Average Concentrations and Deposition Rates 6-8

Table of Contents (continued)

Section	Page
6.3	Module Discussion 6-8
6.3.1	Strengths and Advantages 6-8
6.3.2	Uncertainty and Limitations 6-9
6.4	References 6-9
7.0	Watershed Module 7-1
7.1	Purpose and Scope 7-1
7.2	Conceptual Approach 7-2
7.2.1	Calculate Soil Contaminant Concentrations and Surface Water Loadings 7-3
7.2.2	Calculate Hydrological and Soil Erosion Inputs 7-5
7.3	Module Discussion 7-6
7.3.1	Strengths and Advantages 7-6
7.3.2	Uncertainty and Limitations 7-7
7.4	References 7-8
8.0	Surface Water Module 8-1
8.1	Purpose and Scope 8-1
8.2	Conceptual Approach 8-2
8.2.1	Construct Waterbody Network 8-2
8.2.2	Route Hydraulic Flow Through the Waterbody Network 8-4
8.2.3	Construct and Solve the Mass Balance Equations Describing Contaminant Fate and Transport throughout the Waterbody Network 8-6
8.3	Module Discussion 8-7
8.3.1	Strengths and Advantages 8-7
8.3.2	Uncertainty and Limitations 8-7
8.4	References 8-8
9.0	Vadose Zone and Aquifer Modules 9-1
9.1	Purpose and Scope 9-1
9.2	Conceptual Approach 9-2
9.2.1	Vadose Zone Module 9-3
9.2.2	Aquifer Module 9-5
9.2.3	Chemical Reaction Modeling 9-9
9.3	Module Discussion 9-11
9.3.1	Strengths and Advantages 9-11
9.3.2	Uncertainty and Limitations 9-12
9.4	References 9-14
10.0	Farm Food Chain Module 10-1
10.1	Purpose and Scope 10-1
10.2	Conceptual Approach 10-4

Table of Contents (continued)

Section	Page
10.2.1 Calculate Contaminant Concentrations in Plants due to Contaminants in Air	10-5
10.2.2 Calculate Contaminant Concentrations in Plants due to Contaminants in Soil	10-8
10.2.3 Calculate Total Contaminant Concentrations in Plants	10-9
10.2.4 Calculate Contaminant Concentrations in Beef and Milk	10-9
10.3 Module Discussion	10-11
10.3.1 Strengths and Advantages	10-11
10.3.2 Uncertainty and Limitations	10-12
10.4 References	10-13
11.0 Terrestrial Food Web Module	11-1
11.1 Purpose and Scope	11-1
11.2 Conceptual Approach	11-3
11.2.1 Calculate Contaminant Concentrations in Soil	11-5
11.2.2 Calculate Total Contaminant Concentrations in Plants	11-7
11.2.3 Calculate Contaminant Concentrations Soil Invertebrates	11-7
11.2.4 Calculate Contaminant Concentrations in Vertebrate Prey Categories	11-8
11.3 Module Discussion	11-9
11.3.1 Strengths and Advantages	11-9
11.3.2 Uncertainty and Limitations	11-10
11.4 References	11-12
12.0 Aquatic Food Web Module	12-1
12.1 Purpose and Scope	12-1
12.2 Conceptual Approach	12-3
12.2.1 Select Food Web Appropriate for Each Waterbody	12-3
12.2.2 Construct Dietary Matrix for Food Web	12-6
12.2.3 Calculate Contaminant Concentrations in Food Web	12-7
12.2.4 Report Contaminant Concentrations for Fish	12-14
12.3 Module Discussion	12-15
12.3.1 Strengths and Advantages	12-15
12.3.2 Uncertainty and Limitations	12-16
12.4 References	12-17
13.0 Human Exposure Module	13-1
13.1 Purpose and Scope	13-1
13.2 Conceptual Approach	13-4
13.2.1 Calculate Ambient Air Concentrations for Inhalation Exposures	13-5
13.2.2 Calculate Shower Air Concentrations for Inhalation Exposures	13-5
13.2.3 Calculate Dose from Inhalation of Carcinogens	13-6
13.2.4 Calculate Dose from Ingestion of Contaminants in Media or Food ..	13-7

Table of Contents (continued)

Section	Page
13.2.5 Calculate Dose from Ingestion of Contaminants in Breast Milk	13-9
13.3 Module Discussion	13-10
13.3.1 Strengths and Advantages	13-10
13.3.2 Uncertainty and Limitations	13-11
13.4 References	13-12
14.0 Human Risk Module	14-1
14.1 Purpose and Scope	14-1
14.2 Conceptual Approach	14-3
14.2.1 Calculate Risk Measures	14-3
14.2.2 Process Results for Decision Making	14-7
14.3 Module Discussion	14-9
14.3.1 Strengths and Advantages	14-9
14.3.2 Uncertainty and Limitations	14-10
14.4 References	14-11
15.0 Ecological Exposure Module	15-1
15.1 Purpose and Scope	15-1
15.2 Conceptual Approach	15-2
15.2.1 Criteria for the Ecological Exposure Module	15-3
15.2.2 Construct a Dietary Matrix	15-12
15.2.3 Calculate Applied Dose for Receptors in Terrestrial Habitats	15-15
15.2.4 Calculate Applied Dose for Receptors in Margin Habitats	15-18
15.3 Module Discussion	15-19
15.3.1 Strengths and Advantages	15-19
15.3.2 Uncertainty and Limitations	15-20
15.4 References	15-22
16.0 Ecological Risk Module	16-1
16.1 Purpose and Scope	16-1
16.2 Conceptual Approach	16-5
16.2.1 Development of EBs and CSCLs	16-5
16.2.2 Calculate Hazard Quotients	16-12
16.2.3 Process HQ Results for Decision Making	16-15
16.3 Module Discussion	16-18
16.3.1 Strengths and Advantages	16-18
16.3.2 Uncertainty and Limitations	16-19
16.4 References	16-21

List of Figures

Figure	Page	
1-1	3MRA modeling system design	1-11
1-2	Linkages among the source, fate, transport, exposure, and risk modules for the 3MRA modeling system.	1-13
1-3	Conceptual layout of typical 3MRA modeling system site	1-14
1-4	Probability that percent protection is less than P for a given waste concentration and target risk level	1-16
1-5	Percent of receptors protected for different waste concentrations and risk levels . . .	1-17
1-6	Protective Summary Output figure for human risk	1-18
1-7	Protective Summary Output figure for ecological HQ	1-18
1-8	Document organization	1-20
2-1	Conceptual framework for human receptors	2-2
2-2	Conceptual framework for ecological receptors	2-2
2-3	Conceptual framework of the 3MRA modeling system	2-3
2-4	Current area of interest and concentric distance rings for human risk	2-6
2-5	Example of watershed delineation for a typical site	2-6
2-6	Example of human receptor placement for a typical site	2-8
2-7	Example of representative ecological habitats delineated for typical site	2-8
2-8	Illustration of concurrent time aggregation of risks.	2-10
3-1	Site-based spatial overlays for 3MRA modeling system spatial framework (GIS analysis)	3-2
3-2	Example of transfer of polygons to 100 × 100 m template grid	3-4
3-3	GIS data coverages for waterbody and watershed delineation	3-5
3-4	Regional watershed subbasin delineation	3-6
3-5	Local watershed delineation	3-8
3-6	Example site layout for human receptors	3-10
3-7	Preprocessed habitat codes	3-14
4-1	Information flow for the Wastewater Source Module in the 3MRA modeling system .	4-2
4-2	Conceptual model schematic for Wastewater Source Modules	4-4
4-3	Surface impoundment cross-section showing sediment and soil layers modeled by the Surface Impoundment Module infiltration rate algorithms	4-20
5-1	Information flow for the Land-based Source Modules in the 3MRA modeling system	5-1
5-2	Interaction of the models that form the Land-based Source Modules	5-4
5-3	Illustration of landfill (shown with six cells and three waste layers)	5-5
5-4	Illustration of a waste pile in local watershed	5-7
5-5	Illustration of LAU in local watershed	5-8
5-6	Conceptual diagram of the Generic Soil Column Model (GSCM)	5-10
5-7	Daily water balance model.	5-15
5-8	Runoff/erosion conceptual model	5-19
6-1	Information flow for the Air Module in the 3MRA modeling system	6-1
6-2	Conceptual diagram of dispersion and deposition	6-3
7-1	Information flow for the Watershed Module in the 3MRA modeling system	7-1
7-2	Illustration of watersheds within an AOI	7-2

List of Figures (continued)

Figure	Page
8-1	Information flow for the Surface Water Module in the 3MRA modeling system 8-1
9-1	Information flow for the Vadose Zone and Aquifer Modules in the 3MRA modeling system 9-1
9-2	Conceptual diagram of Vadose Zone and Aquifer Module 9-3
10-1	Information flow for the Farm Food Chain Module in the 3MRA modeling system . 10-1
10-2	Release, exposure, and uptake mechanisms of contaminants in plants. 10-4
11-1	Information flow for the Terrestrial Food Web Module in the 3MRA modeling system 11-1
11-2	Hypothetical forest habitat with four home ranges shown 11-4
12-1	Information flow for the Aquatic Food Web Module in the 3MRA modeling system 12-1
12-2	Example of simplified food web for freshwater lake (Gobas et al., 1993) 12-4
12-3	Relationship between essential metal concentration and organism health (adapted from Chapman et al., 1996) 12-13
13-1	Information flow for the Human Exposure Module in the 3MRA modeling system . 13-1
14-1	Information flow for the Human Risk Module in the 3MRA modeling system. 14-1
15-1	Information flow for the Ecological Exposure Module in the 3MRA modeling system 15-1
15-2	Simple terrestrial food web showing example receptors 15-7
15-3	Simple margin food web showing both aquatic and terrestrial components 15-8
16-1	Information flow for the Ecological Risk Module in the 3MRA modeling system . . 16-1

List of Tables

Table	Page
2-1	Constituents in the 3MRA Database 2-12
2-2	Methodology and Data Sources for 3MRA Chemical Properties 2-14
2-3	WMU Types and Source Term Characteristics 2-16
2-4	WMU Types and Release Mechanisms Modeled 2-16
2-5	Human Exposure Pathways by Receptor Type 2-27
2-6	Ecological Exposure Routes Evaluated by Receptor Type 2-31
3-1	Ecological Risk Assessment Representative Habitats for Terrestrial Receptors 3-13
5-1	Summary of Mechanisms of Release of Particulate Emissions for Each WMU 5-22
11-1	Terrestrial Plant and Prey Categories in the Terrestrial Food Web 11-2
11-2	Example Exposure Concentrations for Contaminant γ Calculated by the Terrestrial Food Web Module 11-5
12-1	Matrix of Biota in Food Webs for Freshwater Systems in 3MRA 12-6
13-1	Default Pathways Considered by Receptor Type 13-3
14-1	Example HQ Counts for Hypothetical Sites 14-8
14-2	Example Cumulative Frequency at Hypothetical Site 14-9
15-1	Representative Habitats for 3MRA 15-4
15-2	Representative Habitats for Receptor Species 15-10
15-3	Categories of Dietary Items for Ecological Exposure Assessment 15-13
15-4	Example of Dietary Preferences for Raccoon 15-14
15-5	Example Dietary Preferences for Short-Tailed Weasel 15-16
15-6	Example Exposure Concentrations to Contaminant γ for Short-Tailed Weasel 15-17
16-1	Assessment Endpoints and Measures of Effects for the 3MRA Modeling System 16-3
16-2	Example HQ Counts for Mammals at Hypothetical Site 16-16
16-3	Example Cumulative Frequency HQ Histogram for Mammals at Hypothetical Site 16-16