Air Toxics Hot Spots Program Risk Assessment Guidelines

Technical Support Document for Exposure Assessment and Stochastic Analysis

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Table of Contents

Table of Contents i

Chapter 1: Introduction

1. Introduction 1-1

1.1 Multipathway Nature of Exposure Assessment 1-3

1.2 The Point Estimate Approach 1-5
1.2.1 Need for Exposure Variates for Specific Age Groupings 1-6

1.3 The Stochastic Approach ("Likelihood of Risks" Approach) 1-8

1.4 Tiered Approach to Risk Assessment 1-10
1.4.1 Tier 1 1-11
1.4.2 Tier 2 1-13
1.4.3 Tier 3 1-14
1.4.4 Tier 4 1-14

1.5 Exposure Assessment Pathways 1-15

1.6 Individual Risk versus Population Risk, and Duration of Exposure to Facility Emissions 1-15

1.7 SB352 1-16

1.8 Summary 1-17

1.9 References 1-18

Chapter 2: Air Dispersion Modeling

2.1 Air Dispersion Modeling in Risk Assessment: Overview 2-1

2.2 Emission Inventories 2-4
2.2.1 Air Toxics "Hot Spots" Emissions 2-4
2.2.1.1 Substances Emitted 2-4
2.2.1.2 Emission Estimates Used in Risk Assessment 2-5
2.2.1.3 Emission Release Parameters 2-6
2.2.1.4 Operation Schedule 2-6
2.2.1.5 Emission Controls 2-6
2.2.2 Landfill Emissions 2-7

2.3 Source Characterization 2-7
2.3.1 Source Type 2-7
2.3.1.1 Point Sources 2-7
2.3.1.2 Line Sources 2-7
2.3.1.3 Area Sources 2-8
2.3.1.4 Volume Sources 2-8

2.3.2 Quantity of Sources 2-8

2.4 Terrain Type 2-9
2.4.1 Terrain Type – Land Use 2-9
2.4.1.1 Land Use Procedure 2-10
2.4.1.2 Population Density Procedure 2-10
2.4.2 Terrain Type – Topography 2-12
2.4.2.1 Simple Terrain (also referred as "Rolling Terrain") 2-12
2.4.2.2 Intermediate Terrain 2-12
2.4.2.3 Complex Terrain 2-12

2.5 Level of Detail: Screening vs. Refined Analysis 2-13

2.6 Population Exposure 2-13
2.6.1 Zone of Impact 2-13
2.6.2 Population Estimates for Screening Risk Assessments 2-14
2.6.3 Population Estimates for Refined Risk Assessments 2-15
2.6.3.1 Census Tracts 2-15
2.6.3.2 Subcensus Tract 2-16
2.6.4 Sensitive Receptor Locations 2-17

2.7 Receptor Siting 2-17
2.7.1 Receptor Points 2-17
2.7.1.1 Receptor Height 2-18
2.7.2 Centroid Locations 2-18
2.7.3 Spatial Averaging of Modeling Results 2-19
2.7.4 Spatial Averaging Method 2-21
2.7.4.1 Residential Receptors 2-22
2.7.4.2 Worker Receptors 2-23
2.7.4.3 Pastures or Water Bodies 2-23

2.8 Meteorological Data 2-24
2.8.1 Modeling to Obtain Annual Average Concentrations for Various Health Impacts 2-25
2.8.2 Modeling One-Hour Concentrations used Simple and Refined Acute Calculations 2-33
2.8.3 Meteorological Data Formats 2-34
2.8.4 Treatment of Calms 2-34
2.8.5 Treatment of Missing Data 2-35
2.8.6 Representativeness of Meteorological Data 2-36
2.8.6.1 Spatial Dependence 2-36
2.8.6.2 Temporal Dependence 2-37
2.8.6.3 Further Considerations 2-37
2.8.7 Alternative Meteorological Data Sources 2-38
2.8.7.1 Recommendations 2-38
2.8.8 Quality Assurance and Control 2-38

2.9 Model Selection 2-39
2.9.1 Recommended Models 2-40
2.9.2 Alternative Models 2-40

2.10 Screening Air Dispersion Models 2-40
2.10.1 AERSCREEN 2-41
2.10.2 Valley Screening 2-42
2.10.3 CTSCREEN 2-42

2.11 Refined Air Dispersion Models 2-43
2.11.1 AERMOD 2-44
2.11.1.1 Regulatory Options 2-44
2.11.1.2 Special Cases 2-44
2.11.2 CTDMPLUS 2-47

2.12 Modeling Special Cases 2-47
2.12.1 Building Downwash 2-47
2.12.2 Deposition 2-47
2.12.3 Short Duration Emissions 2-49
2.12.4 Fumigation 2-49
2.12.5 Raincap on Stack 2-50
2.12.6 Landfill Sites 2-51

2.13 Specialized Models 2-51
2.13.1 Buoyant Line and Point Source Dispersion Model (BLP) 2-51
2.13.1.1 Regulatory Applications 2-52
2.13.2 Offshore and Coastal Dispersion Model (OCD) 2-52
2.13.2.1 Regulatory Applications 2-52
2.13.3 Shoreline Dispersion Model (SDM) 2-52

2.14 Interaction with the District 2-53
2.14.1 Submittal of Modeling Protocol 2-53

2.15 Report Preparation 2-55
2.15.1 Information on the Facility and Its Surroundings..... 2-55
2.15.2 Source and Emission Inventory Information..... 2-56
2.15.3 Exposed Population and Receptor Location..... 2-57
2.15.4 Meteorological Data..... 2-58
2.15.5 Model Selection and Modeling Rationale..... 2-58
2.15.6 Air Dispersion Modeling Results..... 2-59

2.16 References 2-60

Chapter 3: Daily Breathing Rates

3.1 Introduction 3-1

3.2 Breathing Rate Recommendations..... 3-1
3.2.1 Breathing Rates for Use in Chronic Exposure Risk Assessment 3-2
3.2.2 Eight-hour breathing rate point estimates 3-4
3.2.3 Short-term (1-Hour) ventilation rate point estimates 3-6

3.3 Estimation of Daily Breathing Rates 3-7
3.3.1 Inhalation Dose and Cancer Risk 3-7
3.3.2 Methods for Estimating Daily Breathing Rates..... 3-9

3.4 Available Daily Breathing Rate Estimates 3-11
3.4.1Traditional Breathing Rate Estimates..... 3-11
3.4.2 Daily Breathing Rate Estimates Based on Time-Activity-Ventilation (TAV) Data 3-12
3.4.2.1 Marty et al. (2002) 3-12
3.4.2.2. Allen et al. (2008) 3-15
3.4.3 Daily Breathing Rate Estimates Based on Energy Expenditure 3-16
3.4.3.1 Layton (1993) 3-16
3.4.3.2 Arcus-Arth and Blaisdell (2007) 3-18
3.4.3.3 US EPA (2009) Metabolic Equivalent-Derived Daily Breathing Rate Estimates..... 3-23
3.4.4 Daily Breathing Rate Estimates from Doubly Labeled Water Measurements..... 3-25
3.4.4.1 Brochu et al. (2006a,b) 3-26
3.4.4.2 Stifelman (2007) 3-29
3.4.4.3 Limits of Sustainable Breathing Rates Derived from PALs 3-30
3.4.5 Compilations of Breathing Rate Data 3-32

3.5 OEHHA-Derived Breathing Rate Distributions for the Required Age Groupings Using Existing Data 3-33
3.5.1 OEHHA-derived breathing rates based on CSFII energy intake data 3-33
3.5.2 OEHHA-derived breathing rates based on the IOM DLW Database 3-36
3.5.3 OEHHA Age Group Breathing Rate Distributions Derived From U.S. EPA (2009) MET Approach 3-42
3.5.4 OEHHA-Derived Third Trimester Breathing Rates 3-45
3.5.5 Summary of Long-Term Breathing Rates 3-46

3.6 8-Hour Breathing Rates 3-48

3.7 Short-term (1-Hour) Ventilation Rates 3-55

3.8 References 3-57

Chapter 4: Soil Ingestion Rates

4.1 Introduction 4-1

4.2 Soil Ingestion Recommendations 4-3
4.2.1 Incidental Soil Ingestion 4-3

4.3 Algorithm for Dose from Soil Ingestion 4-4
4.3.1 Inadvertent Soil Ingestion by Adults and Children 4-4
4.3.3 Inadvertent Soil Ingestion by Offsite Workers 4-7

4.4 Soil Intake – Key Children Studies 4-7
4.4.1 Davis and Co-workers Studies 4-7
4.4.1.1 Davis et al. (1990) 4-7
4.4.1.2 Davis and Mirick (2006) 4-8
4.4.2 Binder and Co-workers Study 4-10
4.3.2.1 Binder et al. (1986) 4-10
4.4.3. Calabrese and Co-workers Studies 4-11
a. Amherst, Massachusetts Studies 4-11
4.4.3.1 Calabrese et al. (1989) 4-12
4.4.3.2 Calabrese and Stanek (1992) 4-13
4.4.3.3 Stanek and Calabrese (1995a) 4-14
4.4.3.4 Stanek and Calabrese (1995b) 4-16
b. Anaconda, Montana Studies 4-17
4.4.3.5 Calabrese et al. (1997) 4-17
4.4.3.6 Calabrese et al. (1996) 4-19
4.4.3.7 Stanek et al. (1999) 4-20
4.4.3.8 Stanek and Calabrese (2000) 4-20
4.4.4 Clausing and Co-workers Studies 4-20
4.4.4.1 Clausing et al. (1987) 4-21

4.4.4.2 Van Wïjnen et al. (1990) 4-22
4.4.5 Other Relevant Studies and Analyses 4-23
4.4.5.1 Thompson and Burmaster (1991) 4-23
4.4.5.2 Sedman and Mahmood (1994) 4-24
4.4.5.3 Calabrese and Stanek (1995) 4-25
4.4.5.4 Stanek et al. (2001) 4-25
4.4.5.5 Zartarian et al. (2005) 4-26
4.4.5.6 Hogan et al. (1998) 4-26
4.4.6 U.S. EPA (2008) 4-27

4.5 Soil Ingestion – Adult Studies 4-28
4.5.1 Hawley (1985) 4-28
4.5.2 Calabrese et al (1990) 4-29
4.5.3 Stanek and Calabrese (1995b) 4-29
4.5.4 Stanek et al. (1997) 4-29
4.5.5 Davis and Mirick (2006) 4-30
4.5.6 Summary of Adult Soil Ingestion Estimates 4-30

4.5 Pica 4-28
4.5.1 General Pica 4-28
4.5.2 Soil Pica 4-29
4.5.3 Soil Pica Behavior In Children 4-29
4.5.3.1 Calabrese et al. (1991); Calabrese and Stanek (1992) 4-29
4.5.3.2 Wong (1988) as reviewed by Calabrese and Stanek (1993) 4-30
4.5.3.3 ATSDR (2001) 4-31
4.5.3.4 Zartarian et al. (2005) 4-31
4.5.3.5 U.S. EPA (1984) 4-31
4.5.3.6 U.S. EPA (2008) 4-31
4.5.3.7 Summary of Pica Behavior Studies in Children 4-321
4.5.4 Soil Pica Behavior In Adults 4-32

4.6 Hand to Mouth Transfer 4-33
4.6.1 Hand-to-Mouth Transfer Behavior in Children 4-33
4.6.2 Probabilistic Models of Hand-to-Mouth Transfer 4-33
4.6.3 Relevant Hand-to-Mouth Transfer Studies (Summary) 4-34
4.6.3.1 Dubé et al. (2004) 4-34
4.6.3.2 Beyer et al. (2003) 4-34
4.6.3.3 CPSC (2003) 4-35
4.6.3.4 Zartarian et al. (2000) 4-35
4.6.3.5 Zartarian et al. (2005) 4-35
4.6.3.6 OEHHA (2008) 4-35
4.6.3.7 Xue et al. (2007) 4-36
4.6.4 Extrapolation of Soil Ingestion from Hand-to-Mouth Contacts 4-37

4.7 Recommendations 4-38
4.7.1 Incidental Soil Ingestion by Children 4-38

4.8 References 4-41

Chapter 5: Breast Milk Intake Rates

5.1 Terminology and Nomenclature 5-1

5.2 Recommendations 5-2
5.2.1 Default Point Estimate for Daily Breast Milk Intake During the First Year 5-2
5.2.2 Stochastic Approach to Breast milk intake Among Individuals during the First Year of Life 5-3
5.2.3 Consideration of Variable Age of Breastfeeding Mothers 5-3
5.2.4 Analysis for Population-wide Impacts from Breast Milk Exposure 5-4

5.3 Conceptual Framework for Variable Breast milk intake Rates 5-4
5.3.1 Transfer Coefficients for Chemicals from Mother into Milk 5-7

5.4 Available Breast milk intake Rate Estimates 5-9
5.4.1 U.S. EPA Exposure Factors Handbook (1997)and Child Specific Exposure Factors Handbook (2008) 5-9
5.4.2 OEHHA Hot Spots Exposure and Stochastic Guidelines (OEHHA, 2000) 5-11
5.4.3 Arcus-Arth et al. (2005) 5-12

5.5 Representativeness of Breast milk Intake Estimates 5-14

5.6 Conclusion 5-14

Appendix 5A 5-16

5A.1 Breast Milk Lipid 5-16
5A.1.1 Breast Milk Lipid Content 5-16
5A.1.2 Breast Milk Lipid Intake Rates – Point Estimates 5-17
5A.1.3 Breast Milk Lipid Intake Rates – Distributions 5-18

5A.2 Prevalence of Breastfeeding 5-21
5A.2.1 The Ross Mothers Survey 5-21
5A.2.2 The National Immunization Survey 5-22
5A.2.3 California Newborn Screening Program (MCAH, 2007) 5-23
5A.2.4 Hammer et al. (1999) 5-24
5A.2.5 Taylor (2006) 5-24
5A.2.6 Summary of Prevalence Data 5-24
5A.2.7 Trends in Breastfeeding at Early-postpartum, 6 month, and 12 Month Ages 5-27
5A.2.8 Age at Weaning 5-29

5A.3 Subpopulations of Special Concern 5-32
5A.3.1 Infants Breastfed for an Extended Period of Time 5-32
5A.3.2 Infants of Older Mothers 5-34
5A.3.2.1 Breastfeeding Practices of Older Mothers 5-34
5A.3.2.2 Prevalence of Older Women Giving Birth in California 5-35
5A.3.3 High-end Consumers 5-37

5.7 References 5-38

Chapter 6: Dermal Exposure Assessment 6-1

6.1 Introduction 6-1

6.2 Recommended Dermal Exposure Values 6-2

6.3 Dermal Uptake from Contaminated Soil Contact 6-6

6.4. Derivation of Key Dermal Exposure Variates 6-11
6.4.1 Chemical-specific Factors 6-11
6.4.2 Body Surface Area / Body Weight Distributional Variate 6-12
6.4.3 Skin Surface Area Exposed 6-14
6.4.3.1 Fractional Body Part Surface Area 6-14
6.4.3.2 California Climate Regions and Skin Exposure 6-18
6.4.4 Soil Adherence Factors 6-18
6.4.5 Duration and Frequency of Exposure to Contaminated Soil 6-22
6.4.5.1 Exposure Duration 6-22
6.4.5.2 Exposure Frequency 6-23

6.5 Point Estimates and Stochastic Approach for Dermal Dose Assessment 6-28

6.6 Dermal Uptake Equations by Other Agencies 6-32
6.6.1 U.S. EPA Exposure Estimates 6-32
6.6.2 Cal/EPA Department of Pesticide Regulation Guidance for the Preparation of Human Pesticide Exposure Assessment Documents 6-33
6.6.3 CalTOX 6-33

6.7 References 6-35

Chapter 7: Home Produced Food Exposure Assessment 7-1

7.1 Introduction 7-1

7.2. Home Produced Food Exposure Recommendations 7-1
7.2.1 Point Estimates 7-2
7.2.2 Stochastic Approach 7-3

7.3 Home Grown Food Intake Dose 7-6
7.3.1 Point Estimate (Deterministic) Algorithm 7-6
7.3.2 Stochastic Algorithm 7-8

7.4 Food Consumption Variates for the Hot Spots Exposure Model 7-8
7.4.1 Derivation of Consumption Rates 7-8
7.4.1.1 Data 7-8
7.4.1.2 The NHANES Data 7-10
7.4.1.3 Methodology for the derivation of food consumption rates 7-11
7.4.1.4 Categorization of Produce 7-11
7.4.1.5 Categorization of Meat, Eggs, and Dairy 7-12
7.4.1.6 Estimating and Analyzing Consumption Rate Distributions 7-12
7.4.1.7 Produce, Meat, Dairy and Egg Consumption Distributions 7-14

7.5 Calculating Contaminant Concentrations in Food 7-20
7.5.1 Algorithms used to Estimate Concentration in Vegetation (Food and Feed)7-20
7.5.1.1 GRAF 7-21
7.5.1.2 Deposition onto Crops 7-21
7.5.1.3 Translocation from the Roots 7-23
7.5.2 Algorithms used to Estimate Dose to the Food Animal 7-25
7.5.2.1 Dose via Inhalation 7-25
7.5.2.2 Dose via Water Ingestion 7-26
7.5.2.3 Dose from Feed Ingestion, Pasturing, Grazing 7-26
7.5.2.4 Transfer Coefficients from Feed to Animal Products 7-27

7.6 Default Values for Calculation of Contaminant Concentration in Animal Products 7-29
7.6.1 Body Weight Defaults 7-29
7.6.2 Breathing Rate Defaults 7-30
7.6.3 Feed Consumption Defaults 7-30
7.6.3.1 Bovine Feed Ingestion 7-30
7.6.3.2 Swine Feed Ingestion 7-32
7.6.3.3 Chicken Feed Ingestion 7-32
7.6.3.4 Feed Ingestion by Chickens Raised for Meat 7-33
7.6.3.5 Laying Hen Feed Ingestion 7-33
7.6.4 Water Consumption Defaults 7-33
7.6.4.1 Bovine Water Consumption 7-33
7.6.4.2 Swine Water Consumption Rates 7-34
7.6.4.3 Water Consumption Rates by Chickens 7-34
7.6.5 Soil Ingestion Defaults 7-34

7.7 Fraction of Food Intake that is Home-Produced 7-35

7.8 References 7-37

Chapter 8: Water Intake 8-1

8.1 Introduction 8-1

8.2 Recommendations 8-1
8.2.1 Point Estimate Approach 8-1
8.2.2 The Stochastic Approach 8-3
8.2.3 Recommended Water Intake Rates for Pregnant and Lactating Subpopulations 8-4
8.2.4 Recommended Water Intake Rates for High Activity Levels/Hot Climates . 8-4

8.3 Water Intake Algorithm 8-5

8.4 Water Intake Rate Studies 8-8
8.4.1 Canadian Ministry of National Health and Welfare (1981) 8-8
8.4.2 Ershow and Cantor (1989), Ershow et al. (1991) 8-9
8.4.3 Roseberry and Burmaster (1992) 8-10
8.4.4 Levy et al. (1995)……. 8-10
8.4.5 Exposure Factors Handbook (U.S. EPA, 1997) 8-10
8.4.6 OEHHA (2000) Exposure and Stochastic Guidance 8-11
8.4.7 U.S. EPA Office of Drinking Water (2004) 8-12
8.4.8 Child-Specific Exposure Factors Handbook (2008) 8-13
8.4.9 CEFH Table 3-19 8-14
8.4.10 Michaud et al. (2007) 8-15
8.4.11 Barraj et al. (2008) 8-15
8.4.12 Kahn and Stralka (2008) 8-15
8.4.13 OEHHA Derived Water Intake Rates for Hot Spots Program Age Groups and Exposure Duration Scenarios 8-16
8.4.14 Fitted Distributions of OEHHA Derived Water Intake Rates 8-21

8.5 Special Subpopulations of Concern 8-23
8.5.1 Infants 8-23
8.5.2 Pregnant and Lactating Women 8-26
8.5.3 High Activity Levels / Hot Climates 8-27

8.6 References 8-28

Chapter 9: Fish Consumption 9-1

9.1 Introduction 9-1

9.2 Recommendations for Angler-Caught Fish Concsumption Rates 9-2

9.3 List of “Hot Spots” Chemicals for Which Evaluation of the Fish Pathway Is Recommended 9-4

9.4 Algorithm for Dose via Fish Ingestion 9-5

9.5 Studies Evaluated for Sport Fish Consumption Rate 9-7
9.5.1 Marine and Delta Fish Consumption Studies 9-8
9.5.1.1 1998-1999 San Francisco Bay Seafood Consumption Study 9-8
9.5.1.2 1991-1992 Santa Monica Bay Seafood Consumption Study 9-9
9.5.1.3 1980 Los Angeles Metropolitan Area Survey 9-10
9.5.1.4 1988-1989 San Diego Bay Health Risk Study 9-10
9.5.1.5 1993 San Francisco Bay Seafood Consumption and Information Project 9-11
9.5.1.6 2010 California Central Valley Delta Fish Consumption Study 9-11
9.5.2 Freshwater Fish Consumption Studies 9-12
9.5.2.1 Washington King County Lakes Study 9-12
9.5.2.2 Michigan Freshwater Fish Consumption Studies 9-12
9.5.2.3 1992-1993 Freshwater Fish Consumption by Alabama Anglers 9-13
9.5.3 Studies of Household Members who eat Sport-Caught Fish..... 9-14
9.5.3.1 U.S. EPA analysis of West et al. (1989a) child fish consumption data subset 9-15
9.5.3.2 Child sport fish consumption rate for the Washington King County Lakes Study..... 9-15
9.5.3.3 California sport fish consumption survey among low-income women 9-15
9.5.3.4 California Central Valley Delta study of household fish consumption 9-16
9.5.3.5 Household sport fish consumption frequency surveys 9-17

9.6 Comparison of Marine Fish Consumption Rates among California Studies 9-17

9.8 Comparison of Freshwater and Marine Fish Consumption Rate Studies 9-18

9.8 Determination of Fish Consumption Distribution 9-19
9.8.1 Choice of Study 9-19
9.8.2 Statistical Correction for Unequal Sampling Probabilities 9-20
9.7.2.1 Avidity Bias 9-20
9.7.2.2 Influence of Interview Decliners on the Fish Consumption Rate ... 9-21
9.8.3 Graphical and Statistical Presentation of Consumption Rate Distributions 9-21

9.9 References 9-26

Chapter 10: Body Weight 10-1

10.1 Introduction 10-1

10.2 Recommendations 10-1

10.3 Body Weights Derived from the National Health and Nutrition Examination Surveys (NHANES) 10-2
10.3.1 NCHS Analysis of NHANES 2003-2006 body weight data 10-3
10.3.2 U.S. EPA Analysis of NHANES 1999-2006 body weight data 10-5
10.3.3 OEHHA Analysis of NHANES 1999-2004 body weight data 10-5
10.3.4 Analysis of NHANES data for body weight changes over time 10-6
10.3.5 Child Growth Charts Derived from NHANES data 10-7

10.4 California Health Interview Survey 10-8

10.5 Analysis of CSFII body weight data 10-9

10.6 International Commission on Radiological Protection 10-9

10.7 References 10-11

Chapter 11: Residential and Worker Exposure Duration, Individual vs. Population Cancer Risks, and Evaluation of Short Term Projects 11-1

11.1 Introduction 11-1
11.1.1 Residential Exposure Duration for Cancer Risk Assessment 11-1
11.1.2 Offsite Worker Exposure Duration for Cancer Risk Assessment 11-2

11.2 Recommendations 11-3
11.2.1 Exposure Duration for Estimating Cancer Risks in the Residential and Offsite Worker Exposure Scenarios 11-3
11.2.2 Activity Patterns and Time Spent at Home 11-5
11.2.3 Recommendations for Presenting Population Risks 11-5
11.2.3 Recommendations for Exposure Duration for Short-term Projects 11-5

11.4 Cancer Risk Algorithm and Exposure Duration 11-6

11.5 Available Studies for Evaluating Residency Time and Exposure Duration for the Residential Exposure Scenario 11-7
11.5.1 National Studies 11-7

11.5.2 California-Specific Data on Residency Time 11-9

11.6 Available Studies for Assessing Job Tenure and Exposure Duration for the Offsite Worker Exposure Scenario 11-10
11.6.1 Key National Studies on Job Tenure 11-10
11.6.2 Supporting Studies 11-12
11.6.2.1 Current Population Survey 11-12
11.6.2.2 National Survey of Youth 1979 11-15
11.6.2.3 Comparison of the CPS and the NLSY79 11-16

11.7 Individual Resident Cancer Risk vs. Residential Population Risk..... 11-17

11.8 Factors that Can Impact Population Risk……..11-18

11.9 Cancer Risk Evaluation of Short Term Projects 11-18

11.10 References 11-20

Appendix A: List of Substances A-1

Appendix B: Health and Safety Code Related to Air Toxics Hot Spots B-1

Appendix C: Spatial Averaging C-1
C.1 Summary C-2

C.2 Introduction C-2

C.3 Source Types..... C-3

C.4 Meteorological Data C-9

C.5 Receptors C-11

C.6 Results..... C-12

C.7 Recommendations C-13

Appendix C.1 – Hourly Variation for Traffic Line Source C-20

Appendix C.2 – Meteorological Data C-21

Appendix C.3 – Sources, Receptors, Concentrations C-27

Appendix C.4 – Spatial Average Tables C-60

Appendix C.5 – Tilted Spatial Averaging C-64

Appendix D: Food Codes for NHANES D-1

Appendix E: Determination of Chemicals for Multipathway Analysis E-1

E.1 Introduction E-2

E.2 Criteria for Selection of Chemicals for Multipathway Analysis E-2

E.3 Evidence for Inclusion of Hexachlorobenzene for Multipathway Assessment... E-15

E.4 Summary E-17

E.5 References E-18

Appendix F: Dermal Exposure to Soil-Bound Hot Spots Multipathway Chemicals: Fractional Absorption (ABS) Values F-1

F.1 Introduction F-2
F.1.1 Point Estimate Approach for ABS Derivation F-2
F.1.2 Skin Morphology and Dermal Absorption Issues for ABS Determination F-3

F.2 Risk Assessment Issues F-4
F.2.1Definition of Dermal Uptake F-4
F.2.2 Dermal Bioavailability of Chemicals in Soil F-5
F.2.3 Soil - Chemical - Tissue Interaction F-6
F.2.4 Effect of soil organic content on dermal absorption F-7
F.2.5 Soil aging effects F-8
F.2.6 Dermal soil loading and adherence characteristics F-9
F.2.7 In Vivo Vs. In Vitro Experiments F-10
F.2.8 Inter- and Intra-Species Specificity F-12
F.2.9 Metabolism of Absorbed Chemicals in the Skin F-12
F.2.10 Human Adult and Infant Variability in Skin Permeability F-13
F.2.11Use of Default ABS Values F-15

F.3 Point Estimates for Dermal Absorption (ABS) of Inorganic Compounds F-16
F.3.1Arsenic and Arsenic Compounds F-16
F.3.1.1Studies Considered F-16
F.3.1.2 Discussion and Recommendation for Arsenic and Arsenic Compounds ABS F-19
F.3.2 Beryllium and Beryllium Compounds F-20
F.3.2.1Studies Considered F-20
F.3.2.2 Discussion and Recommendation for the Beryllium and Beryllium Compound ABS F-22
F.3.3 Cadmium and Cadmium Compounds F-22
F.3.3.1 Studies Considered F-22
F.3.3.2 Discussion and Recommendation for a Cadmium and Cadmium Compounds ABS F-24
F.3.4 Soluble Compounds of Hexavalent Chromium F-24
F.3.4.1 Studies Considered F-24
F.3.4.2 Discussion and Recommendation for a Hexavalent Chromium (Soluble Compounds) ABS F-28
F.3.5 Fluoride and Soluble Fluoride Compounds F-30
F.3.5.1 Studies Considered F-30
F.3.5.2 Discussion and Recommendation for a Fluoride and Soluble Fluoride Compound ABS F-30

F.3.6 Lead and Inorganic Lead Compounds F-30
F.3.6.1 Studies Considered F-31
F.3.6.2 Discussion and Recommendation for a Lead and Inorganic Lead Compound ABS F-34
F.3.7 Inorganic Mercury Compounds F-35
F.3.7.1 Studies Considered F-35
F.3.7.2 Discussion and Recommendation for an Inorganic Mercury Compound ABS F-39
F.3.8 Nickel and Nickel Compounds F-40
F.3.8.1 Studies Considered F-40
F.3.8.2 Discussion and Recommendation for a Nickel and Nickel Compound ABS F-43
F.3.9 Selenium and Selenium Compounds F-43
F.3.9.1Studies Considered F-44
F.3.9.2 Discussion and Recommendation for a Selenium and Selenium Compounds ABS F-44

F.4 Point Estimates for Dermal Absorption (ABS) of Organic Compounds F-44
F.4.1 Polychlorinated Biphenyls (PCBs) F-44
F.4.1.1 Studies Considered F-45
F.4.1.2 Discussion and Recommendation for a Polychlorinated Biphenyl ABS F-48
F.4.2 Polychlorinated Dibenzo-p-dioxins and Dibenzofurans F-49
F.4.2.1 Studies Considered F-49
F.4.2.2 Discussion and Recommendation for a Polychlorinated Dibenzo-p-dioxin and Dibenzofuran ABS F-52
F.4.3 Polycyclic Aromatic Hydrocarbons as Benzo[a]pyrene (BaP) F-53
F.4.3.1 Studies Considered F-53
F.4.3.2 Discussion and Recommendation for a Polycyclic Aromatic Hydrocarbon ABS F-56
F.4.4 Hexachlorobenzene F-57
F.4.4.1 Studies Considered F-58
F.4.4.2 Discussion and Recommendation for a Hexachlorobenzene Compound ABS F-58
F.4.5 Hexachlorocyclohexanes F-58
F.4.5.1 Studies Considered F-59
F.4.5.2 Discussion and Recommendation for a Hexachlorocyclohexane ABSF-60
F.4.6 Diethylhexylphthalate (DEHP) F-61
F.4.6.1 Studies Considered F-61
F.4.6.2 Discussion and Recommendation for a Diethylhexylphthalate ABS F-64
F.4.7 Dermal Absorption Fraction for 4,4' –Methylenedianiline F-65
F.4.7.1 Studies Considered F-65
F.4.7.2 Discussion and Recommendation for a 4,4' –Methylenedianiline ABS F-66

F.5 Comparison with Other Published Dermal Absorption Factors F-67

F.6 References F-69

Appendix G: Chemical Specific Soil Half-Lives G-1

G.1 Metals G-3

G.2 Organics G-5
G.2.1 Creosotes G-6
G.2.2 Diethylhexylphthalate G-6
G.2.3 Hexachlorobenzene G-7
G.2.3 Hexachlorocyclohexanes G-8
G.2.4 4,4'-Methylenedianiline G-9
G.2.5 Polychlorinated Biphenyls (PCBs) G-10
G.2.6 Polycyclic Aromatic Hydrocarbons (PAHs) G-11
G.2.7 Polychlorinated Dibenzo-p-dioxins and Dibenzofurans (PCDD/F) G-14
G.2.8 Summary G-16

G.3 References G-17

Appendix H: Root Uptake Factors H-1

H.1 Introduction H-2

H.2 Arsenic H-4

H.3 Beryllium H-5

H.4 Cadmium H-5

H.5 Chromium VI H-7

H.6 Fluoride H-9

H.7 Lead H-10

H.8 Mercury H-11

H.9 Nickel H-12

H.10 Selenium H-13

H.11 Database H-15

H.12 References H-48

Appendix I: Fish Bioaccumulation Factors I-1

I.1 Introduction I-2
I.1.1 Uptake and Accumulation of Semi- or Non-Volatile Organic Chemicals in Fish Tissues I-5
I.1.2 Uptake and Accumulation of Inorganic and Organic Metals in Fish Tissues. I-7

I.2 Derivation of Fish BAFs I-9
I.2.1 Semi- or Non-Volatile Organic Chemicals I-9
I.2.1.1 Diethylhexylphthalate (DEHP) I-9
I.2.1.2 Hexachlorobenzene I-10
I.2.1.3 Hexachlorocylcohexanes I-11
I.2.1.4 Polycyclic Aromatic Hydrocarbons (PAHs) I-13
I.2.1.5 Polychlorinated biphenyls (PCBs) I-14
I.2.2 Derivation of Fish BCFs – Metallic and Organometalllic Compounds I-16
I.2.2.1 Arsenic I-16
I.2.2.2 Beryllium I-19
I.2.2.3 Cadmium I-19
I.2.2.4 Chromium I-21
I.2.2.5 Lead I-22
I.2.2.6 Mercury (inorganic) and Methylmercury I-24
I.2.2.7 Nickel I-28
I.2.2.8 Selenium I-28

I.3 Non-Bioaccumulated Chemicals I-30

I.4 References I-31

Appendix J: Lactational Transfer J-1

J.1 Introduction J-2

J.2 Mothers' Milk Transfer Coefficients for PCDD/Fs and PCBs J-5
J.2.1 Biotransfer of PCDD/Fs and PCBs to Human Milk J-6
J.2.2 Oral Biotransfer J-8
J.2.3 Mothers' Milk Transfer Coefficients (Tco) for PCDD/Fs and PCBs J-11
J.2.4 Carryover Rate J-17

J.3 Mothers' Milk Transfer Coefficients for PAHs J-17
J.3.1 Inhalation Biotransfer of PAHs to Mother's Milk J-20
J.3.2 Oral Biotransfer of PAHs to Mother's Milk J-27
J.3.3 Comparison and Use of Inhalation and Oral PAH Tcos J-33

J.4 Mothers' Milk Transfer Coefficients for Inorganic Lead J-34

J.4.1 Inorganic Lead in Human Milk J-35
J.4.2 Biotransfer from Bone to Blood during Pregnancy and Lactation J-38
J.4.3 Inhalation Biotransfer of Lead to Mother's Milk J-41
J.4.4 Population Transfer Coefficient (Tco) for Lead J-43
J.4.4.1 Biotransfer from Blood to Milk J-43
J.4.4.2 Transfer from Air to Blood J-44
J.4.3.3 Transfer from Air and Body Stores to Milk J-45
J.4.4 Study Limitations, Influencing Factors and Uncertainty (inorganic compounds) J-46

J.5 Summary and Recommendations J-46
J.5.1 Dioxins and Furans J-46
J.5.2 PAHs J-47
J.5.3 Inorganic Lead J-48
J.5.4 Recommendations J-48

J.6 References J-50

Appendix K: Meat, Milk, and Egg Transfer Coefficients K-1

K.1 Chemical Transfer Coefficient (Tco) Derivation Methodology K-2

K.2 Tco Derivations for Milk, Meat and Eggs K-7
K.2.1 Semi- and Non-Volatile Organic Chemicals K-7
K.2.1.1 Diethylhexylphthalate (DEHP) K-8
K.2.1.2 Hexachlorobenzene (HCB) K-8
K.2.1.3 Hexachlorocyclohexanes (HCH) K-9
K.2.1.4 Polycyclic Aromatic Hydrocarbons (PAH) K-10
K.2.1.5 Polychlorinated Biphenyls (PCB) K-12
K.2.1.6 Polychlorinated Dibenzo-p-Dioxins and Furans (PCDD/F) K-14
K.2.2 Tcos for Inorganic and Organic Metals K-17
K.2.2.1 Arsenic K-17
K.2.2.2 Beryllium K-18
K.2.2.3 Cadmium K-19
K.2.2.4 Chromium (Hexavalent) K-24
K.2.2.5 Fluoride K-21
K.2.2.6 Lead K-21
K.2.2.7 Mercury (Inorganic and Methyl Mercury) K22
K.2.2.8 Nickel K-24
K.2.2.9 Selenium K-24

K.3 References K-26

Appendix L: Activity Data Analysis Report L-1

L.1 Introduction L-2

L.2 Data Sources Analyzed L-3
L.2.1 IPUMS-USA data L-3
L.2.2 SCAG Year 2000 Post-Census Regional Household Travel Survey Data .. L-3
L.2.3 Caltrans 2000-2001 California Statewide Household Travel Survey Data .. L-3
L.2.4 Data Sources Summary L-4

L.3 Methodologies and Findings L-4
L.3.1 IPUMS-USA data L-4
L.3.1.1 Methodology L-4
L.3.1.2 Findings and Discussions L-5
L.3.1.2.1 California Statewide Residency Duration Distributions L-5
L.3.1.2.2 Evaluation of Populations and Residency Duration Distributions for California Cities L-9
L.3.1.3 Limitations of the IPUMS-USA data for Our Purposes L-16
L.3.2 SCAG Year 2000 Post-Census Regional Household Travel Survey Data L-16
L.3.2.1 Methodology L-16
L.3.2.2 Findings and Discussions L-16
L.3.2.3 Limitations on the Use of SCAG Household Travel Survey Data L-16
L.3.3 Caltrans 2000-2001 California Statewide Household Travel Survey Data L-17
L.3.3.1 Methodology L-17
L.3.3.2 Findings and Discussions L-17
L.3.3.2.1 California Statewide Average Time Spent at Home and Distributions by Age, Income, and Ethnicity L-17
L.3.3.2.2 Comparison of Time at Home Results from CHTS Data with Time inside Home Results from ARB Activity Pattern Studies L-24
L.3.3.3 Limitations on the Use of 2000-2001 CHTS data L-25

L.4 Other Data Sources Not Used in This Report L-26
L.4.1 The 2009 National Household Travel Survey L-26
L.4.2 National Human Activity Pattern Survey L-26

L.5 Conclusion L-26

L.6 References L-27

Appendix M: How to Post-Process Offsite Worker Concentrations using the Hourly Raw Results from AERMOD M-1

M.1 Determine the Averaging Periods Required for the Offsite Worker Analysis M-3

M.2 Output the Hourly Raw Results from AERMOD M-4
M.2.1 Modify the Control (CO) Pathway to Identify Calm and Missing Hours M-4
M.2.2 Modify the Source (SO) Pathway if Unit Emission Rates are used M-4
M.2.3 Modify the Receptor (RE) Pathway to Reduce the Processing Time M-6

M.2.4 Modify the Output (OU) Pathway to Output the Hourly Raw Results M-6

M.3 Extract the Hourly Concentrations when the Offsite Worker is Present..... M-7
M.3.1 Description of the POSTFILE File Format..... M-7
M.3.2 Determine the Day-of-Week and Hour-of-Day M-9
M.3.3 Extract the Hourly Concentrations Based on the Offsite Worker's Schedule Count the Number of Calm and Missing Hours that Occur During the Offsite M-10
M.3.4 Worker's Schedule..... M-11

M.4 Calculate the Refined Averaging Periods for the Offsite Worker Analysis..... M-11
M.4.1 How to Determine the Maximum 1-Hour Average for a Simple Acute Assessment M-11
M.4.2 Equation for Calculating the Average Concentration for the 8-Hour Non Cancer Chronic from a Non-Continuous Emitting Source..... M-12
M.4.3 Equation for Calculating the Average Concentration for the 8-Hour Non Cancer Chronic from a Continuous Emitting Source..... M-12
M.4.4 Equation for Calculating the Period Average for the Inhalation Cancer Pathway from a Non-Continuous Emitting Source..... M-13
M.4.5 Equation for Calculating the Period Average for the Inhalation Cancer Pathway from a Continuous Emitting Source..... M-13

M.5 References..... M-14

Appendix N: Sensitivity Study of the Worker Adjustment Factor using AERMOD N-1

N.1 Introduction.....N-2

N.2 Background on the Worker Adjustment Factor for Inhalation Cancer Assessments N-3

N.3 Method and Modeling Parameters.....N-5
N.3.1 Point Source Release Parameters N-5
N.3.2 Temporal Emission Rate N-5
N.3.3 Receptor Grid Parameters N-7
N.3.4 Meteorological Data N-7
N.3.5 Post-Processing the Period Average Concentrations for the Offsite Worker.... .....N-9

N.4 Results.....N-10

N.5 Conclusions N-13

N.6 References N-15

Appendix N-1 – Scenario Data Details N-16

1. Introduction

The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, Connelly, stat. 1987; Health and Safety Code Section 44300 et seq.) is designed to provide information on the extent of airborne emissions from stationary sources and the potential public health impacts of those emissions. Facilities provide emissions inventories of chemicals specifically listed under the "Hot Spots" Act to the local Air Pollution Control and Air Quality Management Districts (Districts) and ultimately to the state Air Resources Board. Following prioritization of facilities by the Districts, facilities may be required to conduct a health risk assessment.

Health risk assessment involves a comprehensive analysis of the dispersion of the specific facility's air emissions, and the extent of human exposure via all relevant pathways (exposure assessment), the toxicology of those chemicals (dose-response assessment), and the estimation of cancer risk and noncancer health impacts to the exposed community (risk characterization). Most "Hot Spots" risk assessments are conducted by contractors for the facility; some are conducted in-house and some by the local air districts. AB-2588 mandates the Office of Environmental Health Hazard Assessment (OEHHA) to review Hot Spots risk assessments and the findings are conveyed to the District by letter. The District may require the facility to notify the impacted public if the risk assessment shows risks above a level deemed acceptable by the District.

The Air Toxics "Hot Spots" Act was amended to require that the Office of Environmental Health Hazard Assessment (OEHHA) develop risk assessment guidelines for the Air Toxics "Hot Spots" program (SB 1731, Calderon, stat. 1992; Health and Safety Code Section 44360(b)(2)). The amendment specifically requires OEHHA to develop a "likelihood of risks" approach to health risk assessment. Therefore, the OEHHA developed a stochastic, or probabilistic, approach to exposure assessment to fulfill this requirement. The previous version of this document, the *Technical Support Document for Exposure Assessment and Stochastic Analysis,* was final in September 2000 (OEHHA, 2000a). This revision of the document updates OEHHA 2000a by incorporating scientific advances in the field of exposure assessment, and newer data on exposure variates. Exposure variates are consumption estimates for various media and values for fate and transport modeling such as fish bioaccumulation factors.

All facilities are required to conduct a point estimate risk assessment using OEHHA's recommended exposure variates. Fcilities may choose to also conduct a stochastic assessment of exposure (and risk) to provide more information to the risk managers and the public. The stochastic approach described in this document provides guidance to the facility operators who want to conduct a stochastic risk assessment, and facilitates use of supplemental information to be considered in the health risk assessment. It provides a method for quantification of the portion of exposure variability for which sufficient data exist to permit estimation. This document does not present an approach for quantification of uncertainty in exposure assessment.

OEHHA has developed a series of documents describing the information supporting the dose-response assessment for "Hot Spots" chemicals and the exposure assessment methodologies. The Children's Environmental Health Protection Act (SB-25) was passed in 1999 and mandated that OEHHA ensure that our risk assessment procedures were protective of children's health. OEHHA developed the methodology presented in the *Air Toxics Hot Spots Risk Assessment Guidelines Technical Support Document for the Derivation of Non-cancer Reference Exposure Levels* (RELs) (OEHHA, 2008) to ensure that our procedures for REL development were protective of children. The 2008 document supersedes the earlier documents for acute RELS, (OEHHA 1999a) and chronic RELS (OEHHA, 2000b). However, RELs developed under the previous OEHHA Guidance (1999a and 2000b) that have not undergone re-evaluation under the OEHHA (2008) updated methodology remain in effect for the Hot Spots program. New and revised RELs are being developed using the 2008 Guidelines and periodically released for public comment and review by the State's Scientific Review Panel on Toxic Air Contaminants (SRP).

OEHHA also developed the *Technical Support Document for Cancer Potency Factors: Methodologies for Derivation, Listing of Available Values, and Adjustments to Allow for Early Life Stage Exposures* (OEHHA, 2009) after the passage of SB-25 to ensure that cancer dose-response takes into account the vulnerability of children. The 2009 document supersedes the *Technical Support Document for Determining Cancer Potency Factors* (OEHHA, 1999b).

This revision of the *Technical Support Document for Exposure Assessment and Stochastic Analysis* describes the exposure algorithms, and point estimates and distributions of key exposure variates that can be used for the exposure analysis component of Air Toxics "Hot Spots" risk assessments. OEHHA reassessed exposure variates for children to ensure they would not underestimate exposure under our SB-25 mandate. We also incorporated advances in the field of exposure assessment since the previous version of the document. The document includes a description of the point estimate and stochastic multipathway exposure assessment approaches and a brief summary of the information supporting the selection of default assumptions. OEHHA developed this document in consultation with the Air Resources Board (ARB) and the California Air Pollution Control Officers Association (CAPCOA). The ARB provided Chapter 2 and associated appendices describing the air dispersion and deposition modeling.

A tiered approach to risk assessment, which allows for both consistency and flexibility, is described in Section 1.4. OEHHA's proposed algorithms, default point estimates and distributions of variates for each major exposure pathway are described in Chapters 3 through 10. The algorithms, with one exception, are identical to the previous version of this document (OEHHA, 2000). We condensed portions of the algorithm for dermal absorption, simplifying the equation and calculation. The algorithms used in our exposure model are largely consistent with the U.S. EPA (1991) Risk Assessment Guidance for Superfund Sites, with some modifications. The point estimates and distributions were updated based on newer data.

Finally, we are updating the *Air Toxics 'Hot Spots' Risk Assessment Guidance Manual* (OEHHA, 2003). This updated document, which will be available soon for public comment and peer review by the SRP, contains the essential information to conduct a health risk assessment based on the three technical support documents described above.

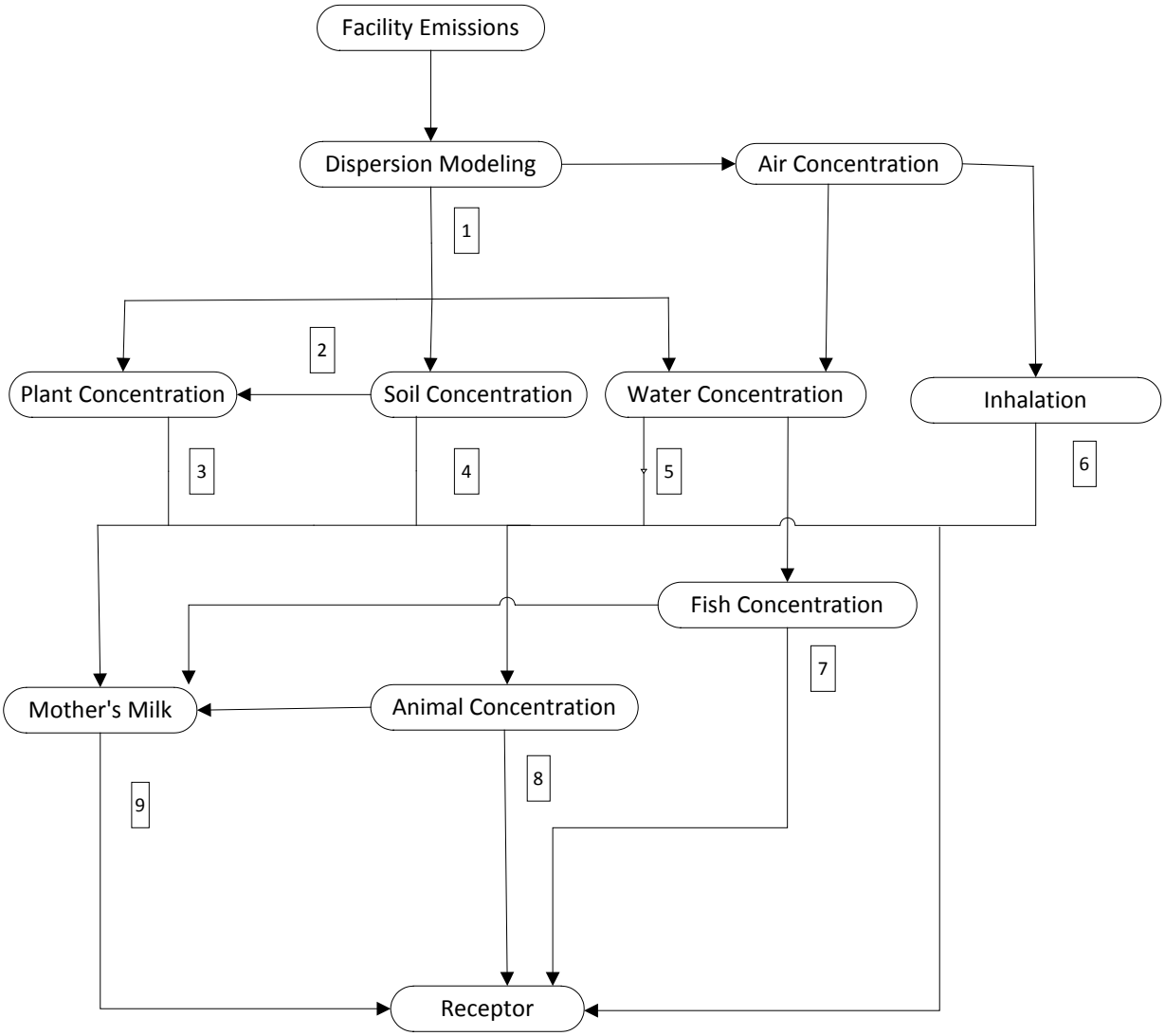
1.1 Multipathway Nature of Exposure Assessment

Exposure assessment of airborne emissions includes not only an analysis of exposure via the inhalation pathway, but also noninhalation pathways of indirect exposure to airborne toxicants. There are data in the literature demonstrating that for some compounds, significant exposure occurs following deposition of airborne material onto surface water, soils, edible plants (both food, pasture and animal feed), and through ingestion of breast milk. Examining both direct inhalation and indirect noninhalation exposure pathways reveals the full extent of exposure to airborne emissions (see Figure 1.1).

However, only certain chemicals are evaluated via the multipathway approach in the Air Toxics "Hot Spots" risk assessments. In general, there is a higher potential for indirect exposure to chemicals which tend to bioconcentrate or bioaccumulate (e.g., lipophilic semi-volatile organics), or otherwise accumulate in the environment (e.g., metals). Semi-volatile and non-volatile organic and metal toxicants can be directly deposited onto surface waters, soil, leaves, fruits and vegetables, grazing forage, and so forth. This is particularly important when these chemicals are associated with particulate matter. Cows, chickens, and other food animals can become contaminated through inhalation, and ingestion of contaminated surface water, pasture, feed and soil. Fish can become contaminated via bioconcentration from water and bioaccumulation from their food. Produce can become contaminated via root uptake from soils and direct deposition. Thus, humans can be exposed through ingestion of contaminated meat, fish, produce, water and soil, as well as from breathing contaminated air, and via dermal exposure. In addition, nursing infants can be exposed via breast milk.

The exposure variates are presented by chapter in this Document roughly in order of importance to an Air Toxics Hot Spots facility risk assessment. The breathing rate (Chapter 3) is the most important pathway; all chemicals must include an inhalation assessment. The breathing rate chapter is followed by chapters discussing the pathways that are automatically included if a risk assessment finds semi- or non-volatile Hot Spots chemicals: the soil ingestion pathway (Chapter 4), the mother's milk pathway (Chapter 5), and the dermal exposure pathway (Chapter 6). The remaining chapters contain the pathways that are only presented in a risk assessment in cases where it has been shown that these exposure pathways exist: the home-produced food pathway (Chapter 7), the water intake pathway (Chapter 8), and the fish consumption pathway (Chapter 9).

Figure 1.1 Exposure Routes



1. Deposition
2. Root Uptake by plants.
3. Human Consumption of Leafy, Protected, Exposed and Root Produce. Animal consumption of pasture and feed.
4. Soil Ingestion by humans and animals, and dermal exposure to soil.
5. Water consumption from surface water sources
6. Inhalation by humans and animals
7. Fish consumption
8. Consumption of beef, chicken and pork.
9. Mother's milk consumption.

Inhalation exposure is assessed for all "Hot Spots"-listed chemicals which have either Cancer Potency Factors and/or Reference Exposure Levels (see the Technical Support Documents mentioned in paragraph 2 for information on these values (OEHHA,2008, 2009), available at http://www.oehha.ca.gov/air/hot_spots/index.html). The noninhalation exposures are assessed only for semivolatile organics and metals listed in Appendix E, Table E.2. These chemicals have oral RELs and/or oral cancer potency factors. Appendix E contains a description of the process used to decide which chemicals should be evaluated by multipathway exposure assessment.

Only the exposure pathways which exist at a particular site need to be assessed in the Air Toxics Hot Spots program. For example, if a fishable body of water is impacted by facility emissions, then exposure through consumption of angler-caught fish is assessed. Otherwise, that pathway may be omitted from the risk assessment. Likewise if no backyard or local commercial produce or animals are raised in the impacted area, then the risk assessment need not consider dose through the ingestion of animal food products or produce. The "Hot Spots" program does not currently assess run off into surface drinking water sources because of the complex site-specific information required. The water consumption of surface waters pathway is rarely invoked in the "Hot Spots" program.

All risk assessments of facilities emitting chemicals listed in Table E.2 need to include an evaluation of exposure from breast milk consumption, soil ingestion, and dermal absorption from soil, since these exposure pathways are likely to exist at all sites. Table E.3 lists the chemicals that should be evaluated by the breast milk exposure pathway. The determination of the appropriate exposure pathways for consideration in the risk assessment should be made in conjunction with the local Air Pollution Control or Air Quality Management District. Justification for excluding an exposure pathway should be clearly presented.

1.2 The Point Estimate Approach

The point estimate approach is the traditional approach for site-specific risk assessments (sometimes referred to as deterministic) in the Hot Spots program. In the point estimate approach, a single value is assigned to each variate in the model (e.g., a breathing rate in L/kg BW-day). The point estimates chosen sometimes represent upper-end values for the variate and sometimes reflect a mean or central tendency estimate. The outcomes of a point estimate model are single estimates of either cancer risk or of the hazard index for noncancer effects. The point estimates of risk are generally considered near the high-end of the range of estimated risks, based on variability in exposure; quantitative information on population variability is generally lacking. However, the older point estimate approach to exposure assessment left open the question of variability in exposures of the general population. For example, it was unclear what percentage of the population would breathe more or less than a 20 m^3/day inhalation rate. The research stimulated by the desire to incorporate population variability in stochastic approaches has allowed informed selection of point estimates

that cover a defined percentage of the population, within the limitations and uncertainties of the available scientific data.

1.2.1. Need for Exposure Variates for Specific Age Groupings

In the previous exposure guideline, we presented distributions and point estimates for use in exposure assessment for children less than 12 years of age and for adolescents and adults up to age 70 years. Risk assessments were conducted for different durations of exposure based on estimates of how long people live at a single location (9 years for the average, 30 years for a high end estimate, and 70 years for a lifetime).

This update retains the evaluation of the 9, 30 and 70 year exposure durations, which represent approximately the mean, 90th and lifetime of residence time. However, *The Technical Support Document for Cancer Potency Factors: Methodologies for Derivation, Listing of Available Values, and Adjustments to Allow for Early Life Stage Exposures* (OEHHA, 2009) concludes that the potency of carcinogens, and thus cancer risk, varies based on the lifestage at exposure. To address this concern, OEHHA applies a weighting factor to early life exposures, termed the Age Sensitivity Factor (ASF) (see OEHHA, 2009 for details). Cancer risk is multiplied by an ASF of ten to weight lifetime risk from exposures occurring from the third trimester of pregnancy to age less than 2. Likewise, for exposure from age 2 to less than 16 years, an ASF of three is applied.

Using these Age Sensitivity Factors (ASFs) requires a different approach to calculation of cancer risk from the traditional methods. Accounting for effects of early-in life exposure requires accounting for both the increased potency of early in life exposure to carcinogens and the greater exposure on a per kg body weight that occurs early in life due to behavioral and physiological differences between infants and children, and adults.

The lifetime risk is a summation of risks from the third trimester to age 2 yrs, 2 to age 16 and 16 to age 70 years. Similarly, when estimating cancer risk for a 9 year (average duration living at given residence) exposure to facility emissions or a 30 year (high-end duration living at a given residence) exposure to facility emissions, the cancer risks are similarly summed, starting with early-in-life exposures. These calculations are as follows:

9-year exposure duration - Calculation of Cancer Risk from the Third Trimester to Age Nine:

$$\text{Cancer Risk} = [(ADD_{\text{third trimester}} \times CPF \times 10)\cancel{0} \times 0.3\ \text{yrs}/70\ \text{yrs}] + [(ADD_{0\ \text{to}\ <2\text{yrs}} \times CPF \times 10) \times 2\ \text{yrs}/70\ \text{yrs}] + [(ADD_{2 < 9\text{yrs}} \times CPF \times 3) \times 7\ \text{yrs}/70\ \text{yrs}]$$

30-year exposure duration - Calculation of Cancer Risk from Third Trimester to Age 30:

Cancer Risk = [($ADD_{third\ trimester}$ X CPF X 10) X 0.3 yrs/70 yrs] + [($ADD_{0\ to\ <2yrs}$ X CPF X 10) X 2 yrs/70 yrs] + [($ADD_{2\ <\ 16yrs}$ X CPF X 3) X 14 yrs/70 yrs] + [($ADD_{16\ <\ 30yrs}$ X CPF X 1) X 14yrs/70 yrs

Lifetime (70 year) exposure duration - Calculation of Cancer Risk from Third Trimester to Age 70:

Cancer Risk = [($ADD_{third\ trimester}$ X CPF X 10) X 0.3 yrs/70 yrs] + [($ADD_{0\ to\ <2yrs}$ X CPF X 10) X 2 yrs/70 yrs] + [($ADD_{2\ <\ 16yrs}$ X CPF X 3) X 14 yrs/70 yrs]+ [($ADD_{16\ <\ 70yrs}$ X CPF X 1) X 54 yrs/70 yrs

where:

ADD = Average Daily Dose, mg/kg-d, for the specified time period (estimated using the exposure variates presented in the TSD)
CPF = Cancer Potency Factor $(mg/kg\text{-}d)^{-1}$
Age Sensitivity Factor third trimester to less than 2 years = 10
Age Sensitivity Factor age 2 to less than 16 years = 3
Age Sensitivity Factor age 16 to less than 70 years = 1

Exposure from all pathways evaluated by the Hot Spots program tends to be greater for children on per kilogram body weight basis, particularly for the third trimester to less than age 2 years. Therefore exposure variates are needed for the third trimester (mother's exposure), ages 0 to <2 years, 2 to <9 years, 2 < 16 years,16 to <30 years, and 16 to 70 years in order to properly estimate cancer risk for the age ranges specified in OEHHA (2009) as well as the residential exposure duration periods (9, 30, and 70 years). This document presents intake rates for the necessary age groupings for inhalation, food consumption, drinking water consumption, breast milk consumption, inadvertent soil ingestion, and dermal exposure useful to estimate exposure and thus cancer risk.

Estimating dose for the fetus during the third trimester of pregnancy is not easy because it will vary from chemical to chemical depending on the toxicokinetics. An approximation of the dose during the third trimester can be made by assuming the dose (mg/kg body weight) is the same as the mother's dose (mg/kg-body weight). The mother is assumed to fall into the age range sixteen to less than thirty. This approximation is uncertain and will over or underestimate dose in some instances. The dose during the third trimester tends to be considerably less than the dose during ages zero to less than two, so separate calculations of dose during the third trimester and ages zero to two years are needed.

The point estimate approach has the advantages of simplicity and consistency, and in the Air Toxics "Hot Spots" program consistent application across the state is critical to comparing risks across facilities for the notification and risk reduction provisions of the statute. Risk communication is relatively straightforward with a point estimate approach. However, a single point estimate approach does not provide information on

the variability in the dose or risk estimates. Some Information about the potential range of risks in the population can be presented as average or high-end point estimates of risk.

1.3 The Stochastic Approach ("Likelihood of Risks" Approach)

As noted earlier, the amended Act specifically requires OEHHA to develop a "likelihood of risks" approach to health risk assessment. Therefore, the OEHHA developed a stochastic, or probabilistic, approach to exposure assessment to fulfill this requirement. The stochastic approach to Hot Spots risk assessment developed by OEHHA estimates the population variability in cancer risk resulting from variability in intake rates such as breathing rate, infant breast milk ingestion, and meat and produce ingestion. The data on variability in risk assessment variates are largely limited to intake rates of contaminated media. Data are particularly sparse on the variability in fate and transport variates (e.g., soil half life). Therefore only a portion of the overall variability in exposure can be characterized in our model. However, for the less complicated pathways such as the inhalation pathway, the variability in breathing rate probably represents a major portion of the overall variability in exposure.

As noted in U.S. EPA (1995), true uncertainty represents lack of knowledge about a variate or factor that impacts risk which may be reduced by further study. There are uncertainties associated with measurement, with models of environmental fate (e.g., air dispersion models), and with dose-response models. Uncertainty may stem from data gaps that are filled by the use of assumptions. Although methods such as expert elicitation have been occasionally used to try to quantify true uncertainty in individual risk assessments, the cost of such methods is outside the scope of what would be reasonable for the Hot Spots program.

Variability can be measured empirically in data describing an exposure variate. Variability arises from true heterogeneity in characteristics of a population such as differences in rate of intake of various media (air, water, food, soil). The stochastic analysis approach presented in this document attempts to quantify some of the variability in exposure in the risk estimates by using measured variability in data describing key exposure variates. A parametric model (e.g., lognormal) can be fit to measures of, for example, food consumption in a representative sample of a population in order to characterize the variability of that variate for a population. The stochastic approach uses a distribution of values, or a parametric model for the distribution, as input for one or more variates in the model. Risk estimates can be expressed as a distribution by propagating the variance of exposure variates through the model using Monte Carlo simulation. This allows estimation of some of the variability in exposure in the risk estimate.

The primary benefits of stochastic analysis are the quantitative treatment of some of the variability in risk estimates and the increase in information on which to base decisions. The risk manager can determine what percentage of the population would be protected if emissions were reduced by a certain amount. However, it can be difficult to

communicate the results of a stochastic risk assessment to the public and risk managers.

Better characterization of total variability in exposure would require more research. Typical intake rates for various age ranges and longitudinal data on the same individuals over time are not usually available. Short term survey data on representative samples of populations of interest are all that are available for many variates. Such data can overestimate exposure particularly in the upper percentiles when considerable intraindividual variability occurs. Some important exposure variates such as soil ingestion lack sufficient data to characterize variability.

Neither the stochastic approach nor the point estimate approach to exposure assessment presented in this document deals with uncertainty or variability in the dose-response assessment. While human variability in response to toxicants is an increasingly active area of research, more data are needed to better account for human interindividual variability in risk assessments. We have evaluated the impact of age-at-exposure on carcinogenic potency (OEHHA, 2009). As noted above, that analysis resulted in application of ASFs to account semi-quantitatively for variability in response to carcinogens due to age. OEHHA also modified the methodology for developing Reference Exposure Levels (OEHHA, 2008) to more explicitly account for potential sensitivity of infants and children.

OEHHA carefully evaluated the available literature characterizing variability for important exposure variates. In some cases, we obtained unpublished raw data from published studies or performed our own analyses on publically available databases such as the Continuing Survey of Food Intake for Individuals (CSFII) or the National Health and Nutrition Examination Survey (NHANES). The methodology is described in the individual chapters in this document as well as in the peer reviewed scientific literature for some variates. If the data or studies were not adequate to characterize varia~~i~~bility in a variate (e.g., soil ingestion) point estimates were recommended. Even though in some cases there were studies presenting valid parametric models for exposure variates in the literature, the age ranges did not correspond to our current needs.

We have taken the approach that enough data must be available to adequately characterize a distribution. While some papers in the risk assessment literature make speculative assumptions about the shape of an input distribution in the absence of data, this cannot be readily justified in most cases. Additional assumptions regarding a distribution in the absence of data may increase uncertainty and may not improve the knowledge about the range of risks in a population.

Distributions of exposure variates are presented in this document for the age ranges needed to assess cancer risk using the age sensitivity factors for specific age groups. Thus, estimation of dose using the stochastic approach for the various age groupings is similar to the point estimate approach. The intake distributions for ages 16 to 30 years

are used for the third trimester. Distributions for the ages specified In Section 1.2.1 above should be used to determine the dose ranges.

1.4 Tiered Approach to Risk Assessment

During the development of risk assessment guidelines for the Hot Spots program, a number of stakeholders wanted the option of using non-default site-specific point estimates and distributions for assessing exposure where more appropriate. Thus OEHHA developed a tiered approach to accommodate this concern (Table 1). The first Tier is the simplest point estimate approach to estimating exposure to facility emissions. In Tier 1, the risk assessor must use the point estimates developed by OEHHA for all exposure variates, other than obvious site-specific parameters such as the volume of a body of impacted water. Tier ~~3~~ 2 allows use of site-specific point estimates of exposure variates as long as these estimates can be justified. The risk assessor must supply the data and methods used for the site-specific estimates, and the site-specific estimates must be reproducible and justified, and approved by OEHHA. Tier ~~2~~ 3 allows use of OEHHA-derived distributions of a number of exposure variates so that a "likelihood of risks" approach can be utilized, as called for in the statutory language. This allows one to estimate risk based on a distribution of exposures, rather than a single point estimate. Tier 4 allows use of site-specific distributions of exposure parameters as long as they can be justified and are approved by OEHHA. The risk assessor must supply the data and methods used for the site-specific distributions for exposure variates, and the site-specific estimates must be reproducible and justified.

Most facilities in the Air Toxics "Hot Spots" program may not require a complicated stochastic analysis for sufficient characterization of risks from emissions. In order to allow the level of effort in a risk assessment to be commensurate with the importance of the risk management decision, a tiered approach to risk assessment is recommended. The tiers are meant to be applied sequentially to retain consistency across the state in implementing the Air Toxics "Hot Spots" program while allowing flexibility.

The benefits of a tiered approach to site-specific risk assessment include consistency across the state, comparability across facilities, and flexibility in the approach to assessing risks. A simple health-protective point estimate risk assessment will indicate whether a more complex approach is warranted, and will help prioritize limited resources. The tiered risk assessment approach facilitates use of site-specific supplemental information in the risk assessment to better characterize the risks. Finally, more information is available to risk managers and the public when a tiered approach is fully utilized.

Table 1 – The Tiered Approach to Risk Assessment

Tier	Description	When Applied
Tier 1	Utilizes OEHHA default point estimates of exposure variates	All risk assessments must include a Tier 1 assessment
Tier 2	Utilizes site-specific point estimates for exposure variates (justified and approved by OEHHA)	If desired by risk assessor, a Tier 2 approach may also be presented
Tier 3	Utilizes OEHHA distributions of exposure variates	A Tier 3 approach may be presented in addition to Tier 1
Tier 4	Utilizes site-specific justified distributions of exposure variates (justified and approved by OEHHA)	A Tier 4 approach may be presented in addition to Tier 1

1.4.1 Tier 1

Tier 1 is the first step in conducting a comprehensive risk assessment with a point estimate approach, using algorithms and point estimates of input values presented in the following chapters. Each facility conducts a Tier 1 risk assessment to promote consistency across the state for all facility risk assessments and allow comparisons across facilities.

Condensed guidance, including tables of the point estimate values recommended by OEHHA in the following chapters, is given in the companion document *Air Toxics Hot Spots Risk Assessment Guidance Manual*, which we are in the process of updating. Site-specific values (e.g. the volume of water in an impacted lake) have to be provided by the risk assessor.

Mean and high-end point estimates for key exposure variates were estimated by OEHHA from available data. To be health-protective, high-end estimates for the key intake exposure variates are used for the dominant pathways in Tier 1.

If a risk assessment involves multipathway exposures, then the risk assessor needs to evaluate which pathways are dominant by conducting an initial assessment using the high-end point estimates for those key intake variates, that have been evaluated by OEHHA. Dominant pathways are defined for these purposes as the two pathways that contribute the most to the total cancer risk estimate when using high-end estimates of key intake variates. High-end estimates for key intake variates for the two dominant

pathways and mean values for key variates in the exposure pathways that are not dominant are then used to estimate risks. If the food pathway is the dominant pathway then the highest single produce or meat type (e.g., exposed produce) using the high end estimates should be determined. The risk for the other food pathways then should be estimated using the average intake values.

This approach will lessen the problem of compounding high-end exposure estimates while still retaining a health-protective approach for the more important exposure pathway(s). It is unlikely that any one person would be on the high-end for all the intake variates. It is our experience that inhalation is generally a dominant pathway posing the most risk in the Air Toxics "Hot Spots" program; occasionally risks from other pathways may also be dominant for lipophilic compounds or metals. Therefore, for many facilities emitting volatile chemicals, the inhalation pathway will be the only pathway whose risks are assessed using a high-end intake estimate. For the Air Toxics "Hot Spots" program, the point of maximum impact for cancer risks is the location with the highest risks using this method.

OEHHA is recommending the hazard index (HI) approach to assess the potential for noncancer health impacts (OEHHA, 2008). The hazard index is calculated by dividing the concentration in air by the Reference Exposure Level for the substance in question and summing the ratios for all chemicals impacting the same target organ. (OEHHA, 2008)

There may be instances where a noninhalation pathway of exposure contributes substantially to a noncancer chronic hazard index. In these cases, the high-end estimate of dose is appropriate to use for the two dominant pathways' noninhalation hazard indices. The point of maximum impact for noncancer chronic health effects is the modeled point having the highest non cancer chronic hazard index (adding noninhalation and inhalation hazard indices when appropriate for systemic effects). The inhalation chronic HI calculation does not involve a high end and average inhalation rate, as the airborne concentration is divided by the REL to calculate an HI (OEHHA, 2008).

There are 8-hour RELs for a number of chemicals. These RELs can be used in different exposure scenarios , such as, to evaluate noncancer risk to offsite workers (and other offsite receptors impacted routinely by facility emissions) who are repeatedly exposed for approximately eight hours at the workplace. The 8 hr RELs may also be useful for assessing impacts to residents when assessing the emissions from a non-continuously operating facility (see Chapter 2) . In cases where there are only chronic RELs for a chemical, the Hazard Index for offsite workers can be calculated by adding the Hazard Quotient for a chemical with an 8-hour REL to a chemical where only a chronic REL is available. Eventually 8-hour and chronic RELs will be developed for all Hot Spots chemicals as OEHHA completes its evaluation of RELs under SB-25. There are no noninhalation pathways to consider in calculation of acute hazard indices.

The relatively health-protective assumptions incorporated into the Tier 1 risk assessment (e.g., high-end values for key variates in the driving pathways) make it unlikely that the risks are underestimated for the general population. If the results indicate that a facility's estimated cancer risk and noncancer hazard are below the level of regulatory concern, further analysis may not be warranted. If the results are above a regulatory level of concern, the risk assessor may want to proceed with further analysis as described in Tier 2 or a more resource-intensive stochastic modeling effort described in Tiers 3 and 4 to provide the risk manager with more information on which to base decisions. While further evaluation may provide more information to the risk manager, the Tier 1 evaluation is useful in comparing risks among a large number of facilities.

1.4.2 Tier 2

The risk assessor may want to analyze the risks using point estimates more appropriate for the site being evaluated. This second tier approach would replace some of the defaults recommended in this document with values more appropriate to the site. A Tier 2 risk assessment would use the point estimate approach with justifiable point estimates for important site-specific variates. Use of this supplemental site-specific information may help to better characterize the risks.

Certain exposure variates such as breast milk consumption or inhalation rate would not be expected to vary much from site to site. Other variates for which OEHHA has provided point estimates may vary significantly from site-to-site. If the facility has data indicating that an OEHHA point estimate value is not appropriate in their circumstance, they may provide an alternative point estimate value. For example, if there are data indicating that consumption of fish from an impacted fishable body of water is lower than the OEHHA-recommended fish consumption rate, then the facility can use that data to generate a point estimate for fisher-caught fish consumption from that body of water.

If site-specific values are substituted this should be justified. All data and procedures used to derive them should be clearly documented, and reasonable justification should be provided for using the alternative value. The Districts and OEHHA should be able to reproduce the point estimate from the data presented in the risk assessment. As noted above, OEHHA must approve the site-specific point estimates.

In a Tier 2 approach, the risk assessor may want to present multiple alternative point estimate scenarios with several different assumptions encompassing reasonable "average" and "high-end" exposures for important pathways. This may be an issue in the case where data on a key exposure variate for that particular site are lacking. For example, in a case where soil ingestion is a dominant pathway, if a key variate in the model is the number of days children spend outdoors in contact with soil, it may be most appropriate to run the model more than once using several different assumptions about the exposure frequency. Such scenario development is easily communicated to the risk manager and the public, and serves as a semi-quantitative analysis of the exposure variability using a point estimate approach to risk assessment. In any risk assessment where alternative point estimates representing different exposure scenarios are

presented, all information used to develop the point estimates needs to be presented clearly in the risk assessment. Also, a justification for the exposure scenarios needs to be included.

If the risk is below a level of regulatory concern, further analysis may not be warranted. If the risk estimate is still above a level of concern, then the risk assessor may want to proceed with a more complex stochastic analysis as described in Tier 3 to get a fuller characterization of the variability in the exposure estimate.

1.4.3 Tier 3

The third tier risk assessment involves stochastic analysis of exposure using algorithms and distributions for the key exposure variates specified in this document. Point estimates specified in this document for those exposure variates without distributions should be used. Since a stochastic approach to risk assessment provides more information about the range and probability of risk estimates, Tier 3 can serve as a useful supplement to the Tier 1 and 2 approach. In the third tier, variance propagation methods (e.g., Monte Carlo analysis) are used to derive a range of risk estimates reflecting the known variability in the inputs as described in the distributions characterized in this document. Recommended distributions for use in a stochastic analysis and the scientific bases for these distributions are provided in Chapters 3 through ~~11~~ 9 of this document.

OEHHA is recommending that a stochastic analysis be performed for cancer risk assessment only. OEHHA has not currently identified a stochastic approach to the exposure part of noncancer risk assessment that would provide value. OEHHA is recommending a point estimate approach only for assessing the impact of AB-2588 facilities on workers employed at nearby work sites (i.e., the offsite worker). We have not developed a breathing rate distribution that would be appropriate for a stochastic offsite worker risk assessment.

Commercial software is available that can be used to conduct a stochastic analysis. The Air Resources Board has developed the Hot Spots Analysis and Reporting Program (HARP) that can perform Tier 3 stochastic analyses as well as Tier 1 risk assessments. The HARP software includes an air modeling module and emissions reporting modules.

1.4.4 Tier 4

OEHHA's stochastic model is based on the best available scientific data that have undergone public comment and peer review. However, a fourth tier risk assessment could also be conducted if site-specific conditions suggest that alternative or additional distributions (and point estimates) for variates may be more appropriate than those provided by OEHHA. In a Tier 4 risk assessment, the risk assessor could characterize the distribution of variates that are important to the overall calculation of risk for which OEHHA provides only a point estimate. Or, the risk assessor may wish to use distributions other than those supplied by OEHHA for important variates that impact the

risk. The scientific basis and documentation for alternative and additional distributions should be presented clearly in the risk assessment. Clear, reasonable justification would need to be provided in the risk assessment for using alternative distributions or point estimates, and OEHHA must approve the site-specific distributions. Such distributions would be based on data from the literature or site-specific data gathered by the facility.

The quality of data would need to be sufficient to reasonably justify the selection of the parametric model (e.g., normal, lognormal, etc.) used to characterize the empirical distribution. It is not necessary, however, that the data fit a given parametric model as defined by conservative statistical criteria such as the Kolmogrov-Smirnoff test. If a distribution is nonparametric, it may be used as a custom distribution in a variance propagation model such as a Monte Carlo simulation.

In each case where alternate distributions or point estimates are used, it is important that the results be compared with the results obtained using any point estimates and/or distributions recommended in this document by OEHHA (e.g., the Tier 1 and 3 risk assessments). This is necessary to identify the contribution of the new information to the risk assessment. The District and OEHHA staff and any interested parties should be able to easily verify the assumptions, and duplicate the results.

1.5 Exposure Assessment Pathways

Chapters 3 through ~~11~~ 9 are organized by exposure pathway, and present the algorithms used for both the point estimate and stochastic approach to exposure assessment. The scientific basis for each recommended point estimate and distribution for key variates is presented. In the instances where the variate is site-specific (e.g., volume of a body of water), default point estimates or distributions are not provided. In general, key studies used in evaluating a point estimate value or distribution are briefly discussed along with procedures used to characterize the distribution. OEHHA procedure for significant figures is to round at the end of any calculation. Thus the exposure variates are generally rounded to 2 or 3 significant figures. The risk estimates are generally rounded to 1or 2 significant figures in the risk assessments conducted by facilities.

1.6 Individual Risk, versus Population Risk, and Duration of Exposure to Facility Emissions

In past practice, the risk managers generally made decisions on the lifetime cancer risk to the “Maximally Exposed Individual” at the site of highest modeled concentration(s) of carcinogen(s). However, relying on estimated cancer risk to the maximally exposed individual is problematic for scenarios where there may be a risk of cancer that falls below the typical risk management threshold of 10^{-5}, but a large number of people are exposed at that level. Facilities with cancer risks estimated above 10^{-5} but that expose few people may face risk management actions, but a facility that exposed thousands of people just below the risk management threshold would not. Both the concept of

population risk and individual risk are important for public health protection (discussed in Chapter 11).

In trying to resolve this dilemma, OEHHA reconsidered the issues of individual risk, population risk, duration of time at a single residence and activity patterns. The previous recommendation for risk managers was to rely on the 70 year risk estimate without consideration of whether or not people resided at the same address for 70 years, or were away from home parts of the day. The previous guidelines also suggested estimating cancer risk for shorter residence times (9 and 30 years, based on EPA analyses of duration of residence at a single address). Thirty years is approximately the 90th percentile of residency in California, according to newer data and is consistent with estimates of thirty years for the 90th percentile of residency duration nationally, and is thus a more realistic portrayal of the maximum reasonable length of exposure that would occur at the residential point of maximal impact. The previous recommendation of relying on the cancer risk estimate to the maximally exposed individual for a 70 year exposure duration contained an element of protection for the population since individual exposure was defined as an entire lifetime, although the risk was likely spread over different individuals living at the maximally exposed location since very few people live at the same address longer than 30 years. Presenting individual cancer risk as a thirty year risk rather than a seventy year risk is easier from a risk communication standpoint because it is a more realistic exposure scenario. OEHHA is thus suggesting that the risk manager when making a decision based on cancer risk to the MEIR use the risk estimated for a 30 year exposure scenario. However, this lessens the element of protection for the population – someone is always living around a given facility. Thus, OEHHA ~~sees a need~~makes a recommendation to consider population risk separately in assessing public health impacts (Chapter 11).

In the example above, there will be more theoretical cancer cases when a larger facility with estimated cancer risk just under the 10^{-5} threshold has a large populated zone of impact, than for the small facility impacting a few people with a cancer risk estimate just over the 10^{-5} threshold. The public health impacts may not be adequately addressed if the cancer risks at the residential or worker point of maximum impact are below the level of significant risk determined by the District. It is important to look at improved methods of assessing the public health impact of facilities with more diffuse emissions impacting larger areas with large impacted populations. Therefore, OEHHA recommends that the number of people residing within the 1×10^{-6} and greater cancer risk isopleths be determined using census data and that the risk managers use this information to decide on appropriate risk management. This is in addition to simply basing a risk management decision on the cancer risk to the maximally exposed individual without regard to the size of the zone of impact and the population exposed. Strengthening population protection will help protect public health.

1.7 SB-352

SB-352 was passed in 2003 and requires California school districts to perform a risk assessment for proposed school sites located within 500 feet, or 150 m, of a freeway or busy roadway. SB-352 specifies that OEHHA's Hot Spots risk assessment guidance procedures be used for the assessment. School children and staff are present at the school site for less than 24 hours so hourly breathing rates that reflect playground activities and classroom activities are appropriate for such assessments. We have included recommended breathing rates in Chapter 3 of this document for appropriate age ranges for elementary, junior high and high school and staff at such schools for such assessments. The age ranges provided also allow for early-in-life exposure age ranges. The South Coast Air Quality Management District has a document that discusses air quality concerns when selecting school sites (SCAMD, 2005).

1.8 Summary

This revision of the Exposure Assessment and Stochastic Analysis Document allows estimation of exposure for age ranges of children. In addition we have incorporated advances in the field of exposure assessment since the last revision and new point estimates and distributions of exposure variates, based on new data. The Exposure Assessment and Stochastic Analysis document retains the option of tiered risk assessment so that site-specific factors can be taken into account.

OEHHA has reviewed and incorporated the extensive body of exposure assessment literature that has been published since the 2000 Exposure and Stochastic Analysis Technical Support Document in order to refine our exposure assessment model.

1.6 References

OEHHA (1999a). *Air Toxics Hot Spots Risk Assessment Guidelines Part I: Technical Support Document for the Determination of Acute Reference Exposure Levels for Airborne Toxicants*. Office of Environmental Health Hazard Assessment, Cal/EPA. March 1999.

OEHHA (1999b). *Air Toxics Hot Spots Risk Assessment Guidelines Part II: Technical Support Document for Describing Available Cancer Potency Factors*. Office of Environmental Health Hazard Assessment, Cal/EPA. April 1999.

OEHHA (2000a). *Air Toxics Hot Spots Risk Assessment Guidelines Part IV: Technical Support Document for Exposure Assessment and Stochastic Analysis*, Office of Environmental Health Hazard Assessment, Cal/EPA.

OEHHA (2000b). *Air Toxics Hot Spots Risk Assessment Guidelines Part III: Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels for Airborne Toxicants*. Office of Environmental Health Hazard Assessment, Cal/EPA. February 2000.

OEHHA (2008). *Air Toxics Hot Spots Risk Assessment Guidelines. Technical Support Document for the Derivation of Non-cancer Reference Exposure Levels.* Office of Environmental Health Hazard Assessment, Cal/EPA.

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SCAQMD (2005) South Coast Air Quality Management District (SCAQMD) Air Quality Issues in School Site Selection Guidance Document June 2005 www.aqmd.gov/prdas/aqguide/doc/School_Guidance.pdf

U.S. EPA (1991) Risk Assessment Guidance for Superfund: Volume I –Human Health Evaluation Manual. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, DC 20460 EPA/540/R-92/003 Publication 9285.7-01 B December 1991

U.S. EPA (1995). Policy for Risk Characterization at the U.S. Environmental Protection Agency. Memorandum from Carol Browner to Administrators, U.S. Environmental Protection Agency, Washington, D.C., March 21, 1995.

2. Air Dispersion Modeling

2.1 Air Dispersion Modeling in Risk Assessment: Overview

Estimates of air concentrations of emitted toxicants in the surrounding community from a facility's air emissions are needed ~~In~~ in order to determine cancer and noncancer risks. One approach to determining the concentration of air pollutants emitted from the facility is to do air monitoring in the surrounding community. However, there are a number of disadvantages to this approach. Ambient air monitoring is costly because good estimates of an annual average concentration typically require monitoring at least one day in six over a year. Because it is costly, monitoring is usually limited to a select number of pollutants, and a limited number of sites. There can be significant risks from some chemicals at or even below the monitoring detection limit, which can add considerable uncertainty to risk estimates if many of the measurements are below or near the detection limit. Monitoring measures not only facility emissions but also general ambient background as well. It can be difficult and expensive to distinguish between the two using monitoring, particularly if general ambient background levels are high relative to the contribution of facility emissions. These limitations often make it impractical to use monitoring in a program such as the Air Toxics Hot Spots program with hundreds of facilities.

Air dispersion models have several advantages over monitoring. Modeling can provide greater spatial detail and the costs are relatively cheap by comparison. For example, dispersion models can estimate the pollutant concentration in air at many receptor locations (hundreds to thousands) and for a multitude of averaging periods. Air dispersion models have been validated using air monitoring.

There are, however, ~~significant~~ uncertainties associated with the typical usage of air dispersion modeling. The use of meteorological data ~~typically~~ from the nearest airport may not ideally be the best representation of ~~reflect~~ localized conditions. Gaussian plume air dispersion models ignore calm hours. This can bias model predictions towards underestimation. Some dispersion models offer limited chemical reactions within the algorithms; however, we generally assume the pollutant is inert for the near-field atmospheric travel time. This may ~~has the tendency to~~ bias estimated concentrations towards over-prediction for those pollutants that are highly reactive in the atmosphere. Air dispersion model results are only as good as the emissions estimates and emissions estimates can be uncertain. However, on the whole, the advantages of air dispersion modeling for a program like the Air Toxics Hot Spots far out weigh the disadvantages.

Professional judgment is required throughout the dispersion modeling process. The local air quality district has final authority on modeling protocols. The following guidance is intended to assist in the understanding of dispersion modeling for risk assessments.

Air dispersion modeling includes the following steps (see Figure 1):

(1) Create an emission inventory of the toxic releases (Section 2.2)

(2) Identify the source types (Section 2.3)

(3) Identify the terrain type (Section 2.4)

(4) Determine the detail needed for the analysis: screening or refined (Section 2.5)

(5) Identify the population exposure (Section 2.6)

(6) Identify the receptor network (Section 2.7)

(7) Obtain meteorological data (for refined air dispersion modeling only) (Section 2.8)

(8) Select an air dispersion model (Section 2.9)

(9) Prepare a modeling protocol and submit to the local Air District (hereafter referred to as “the District”) (Section 2.14)

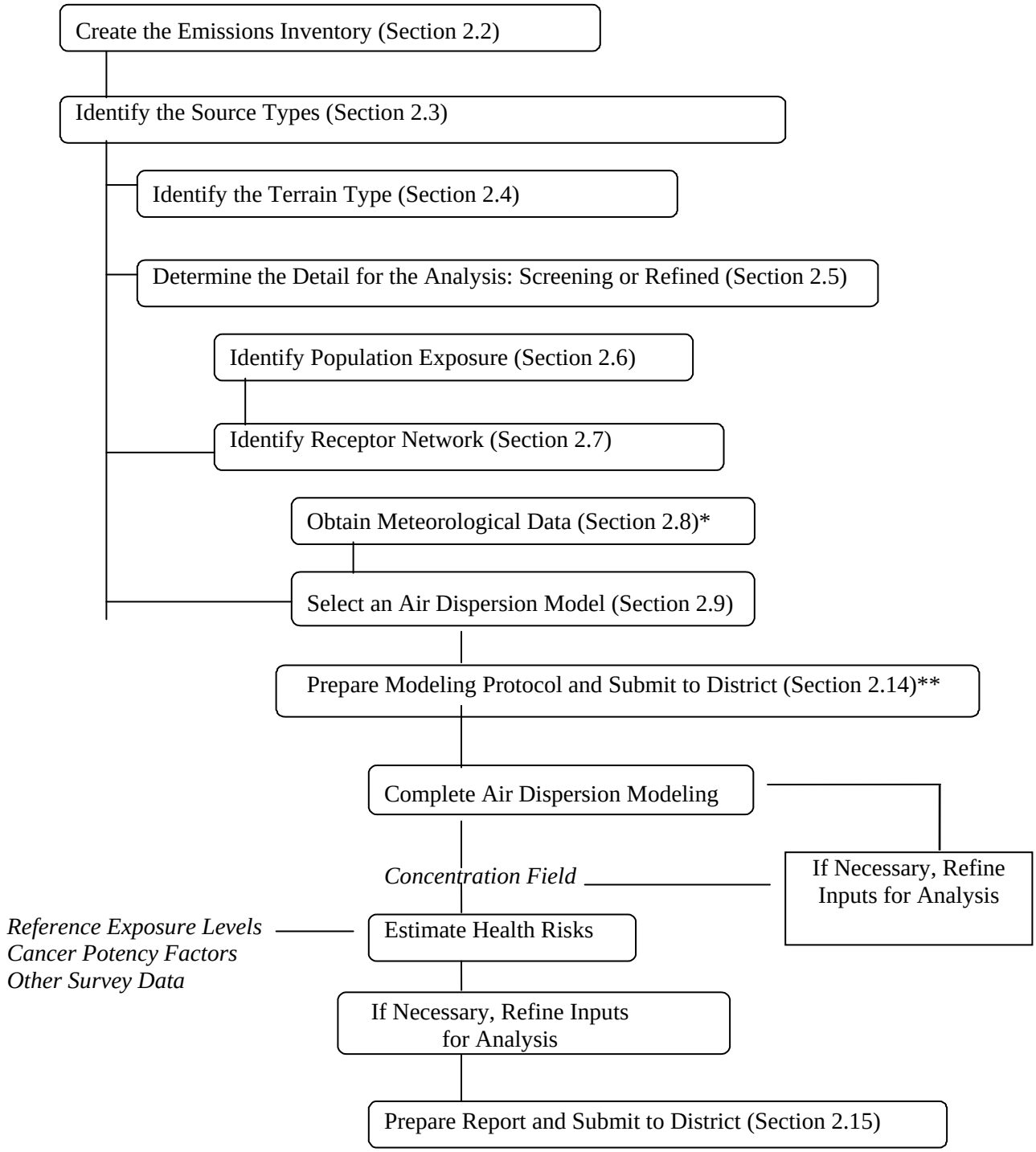
(10) Complete the air dispersion analysis

(11) If necessary, redefine the receptor network and return to Step 10

(12) Complete the risk assessment

(13) If necessary, refine the inputs and/or the model selection and return to Step 8

Figure 1. Overview of the Air Dispersion Modeling Process.



*Some screening models do not require any meteorological data.
** Optional but strongly recommended.

The output of the air dispersion modeling analysis includes a receptor field of ground level concentrations of the pollutant in ambient air. These concentrations can be used

to estimate an inhaled dose for estimation of inhalation cancer risk, or used to determine a hazard index for acute, and chronic noncancer risks. It should be noted that in the Air Toxics "Hot Spots" program, facilities simulate the dispersion of the chemical emitted as an inert compound, and do not model any atmospheric transformations or dispersion of products from such reactions. The U.S. EPA Guideline on Air Quality Models (U.S. EPA, 2005) should be consulted when evaluating reactive pollutants for other regulatory purposes.

2.2 Emission Inventories

The Emission Inventory Reports ("Inventory Reports"), developed under the Air Toxics "Hot Spots" Information and Assessment Act (AB2588), contain data that are used in air dispersion modeling and risk assessment evaluations. The Inventory Reports include emission sources, emitted substances, emission rates, emission factors, process rates, and release parameters (area and volume sources may require additional release data generally available in Emissions Inventory Reports). This information is developed according to the California Air Resources Board (CARB) Emission Inventory Criteria and Guidelines ("Inventory Guidelines") Regulation[1] and the Emission Inventory Criteria and Guidelines Report ("Inventory Guidelines Report"), which is incorporated by reference into the Regulation.

Updated emission data for process changes, emission factor changes, material/fuel changes, or shutdown must be approved by the District prior to the submittal of the health risk assessment (HRA). Ideally, the District review of updated emissions could be completed within the modeling protocol. In addition, it must be stated clearly in the risk assessment if the emission estimates are based on updated or revised emissions (e.g., emission reductions). This section summarizes the requirements that apply to the emission data which are used for Air Toxics "Hot Spots" Act risk assessments.

2.2.1 Air Toxics "Hot Spots" Emissions

2.2.1.1 Substances Emitted

The risk assessment should identify all substances emitted by the facility which are on the Air Toxics "Hot Spots" Act list of substances (Appendix A I-III, Inventory Guideline Report). The list of substances is compiled by the CARB for the Air Toxics "Hot Spots" Program.

The Inventory Guidelines specify that Inventory Reports must identify and account for all listed substances used, manufactured, formulated, or released during the routine and predictable operations of the facility (e.g., including, but not limited to, continuous and intermittent releases and predictable process upsets or leaks). Under the regulations, the list is divided into three groups for reporting purposes[2]. The first group (listed in Appendix A-I of the Inventory Guidelines Report) has all pollutants whose emissions

[1] Title 17, California Code of Regulations, Sections 93300-93300.5
[2] The most recent amendments became effective September 26, 2007.

must be quantified. The second group (listed in Appendix A-II of the Inventory Guidelines Report) includes substances where emissions do not need to be quantified; however, facilities must report whether the substance is used, produced, or otherwise present on-site. The third group (listed in Appendix A-III of the Emissions Inventory Guidelines Report) includes substances whose emissions need not be reported unless the substance is manufactured by the facility. Chemicals or substances in the second and third groups should be listed in a table in the risk assessment.

Facilities that must comply with the Resource Conservation and Recovery Act and Comprehensive Environmental Response, Compensation and Liability Act (RCRA/CERCLA) requirements for risk assessment need to consult the Department of Toxic Substances Control (DTSC) Remedial Project Manager to determine which substances must be evaluated in their risk assessment in addition to the list of "Hot Spots" chemicals. Some RCRA/CERCLA facilities may emit chemicals that are not currently listed under the "Hot Spots" Program.

2.2.1.2 Emission Estimates Used in the Risk Assessment

The risk assessment must include emission estimates for all substances that are required to be quantified in the facility's emission inventory report. Specifically, risk assessments should include both the annual average emissions and maximum 1-hour emissions for each pollutant. Emissions for each substance must be reported for the individual emitting processes and devices within a facility. Total facility emissions for an individual air contaminant will be the sum of emissions reported, by process, for that facility. Information on daily and annual hours of operation and relative monthly activity must be reported for each emitting process. Devices and emitting processes must be clearly identified and described and must be consistent with those reported in the emissions inventory report.

The HRA should include tables that present the emission information (i.e., emission rates for each substance released from each process) in a clear and concise manner. The District may allow the facility operator to base the HRA on more current emission estimates than those presented in the previously submitted emission inventory report (i.e., actual enforceable emission reductions realized by the time the HRA is submitted to the District). If the District allows the use of more current emission estimates, the District must review and approve the new emissions estimates prior to use in the risk assessment. The risk assessment report must clearly state what emissions are being used and when any reductions became effective. Specifically, a table identifying both the previous and current emission estimates should be included. The District should be consulted concerning the specific format for presenting the emission information.

Facilities that must also comply with RCRA/CERCLA requirements for risk assessments need to consult the DTSC Remedial Project Manager to determine what constitutes appropriate emissions data for use in the risk assessment. Source testing may be required for such facilities even if it is not required under the "Hot Spots" Program.

Additional requirements for statistical treatment of source test results may also be imposed by the DTSC on RCRA/CERCLA facilities.

2.2.1.3 Emission Release Parameters

Emission release parameters (e.g., stack height and inside diameter, stack gas exit velocity, release temperature and emission source location in UTM coordinates) are needed as inputs to the air dispersion model. The Inventory Guidelines specify the release parameters that must be reported for each stack, vent, ducted building, exhaust site, or other site of exhaust release. Additional information may be required to characterize releases from non-stack (volume and area) sources; see U.S. EPA dispersion modeling guidelines or specific user's manuals. This information should also be included in the air dispersion section of the risk assessment. This information must be presented in tables included in the risk assessment. Note that some dimensional units needed for the dispersion model may require conversion from the units reported in the Inventory Report (e.g., Kelvin (K) vs. degrees Fahrenheit (°F)).

2.2.1.4 Operation Schedule

The risk assessment should include a discussion of the facility operation schedule and daily emission patterns. Weekly or seasonal emission patterns may vary and should be discussed. This is especially important in a refined risk assessment. Diurnal emission patterns should be simulated in the air dispersion model because of diurnal nature of meteorological observations. A table should be included with emission schedule on an hourly and yearly basis. In addition, for the purposes of exposure adjustment, the emission schedule and exposure schedule should corroborate any exposure adjustment factors. For more information about exposure adjustment factors, see Section 2.8(a). Alternatively, exposure adjustment can be made through refining the air dispersion analysis. See Section 2.11.1.2(h) for special case modeling.

2.2.1.5 Emission Controls

The risk assessment should include a description of control equipment, the emitting processes it serves, and its efficiency in reducing emissions of substances on the Air Toxics “Hot Spots” list. The Inventory Guidelines require that this information be included in the Inventory Reports, along with the emission data for each emitting process. If the control equipment did not operate full-time, the reported overall control efficiency must be adjusted to account for downtime of control equipment. Any entrainment of toxic substances to the atmosphere from control equipment should be accounted for; this includes fugitive releases during maintenance and cleaning of control devices (e.g., baghouses and cyclones).

2.2.2 Landfill Emissions

Emission estimates for landfill sites should be based on testing required under Health and Safety Code Section 41805.5 (AB 3374, Calderon) and any supplemental AB 2588 source tests performed to characterize air toxics emissions from landfill surfaces or through off-site migration. The District should be consulted to determine the specific Calderon data to be used in the risk assessment. The Air Toxics "Hot Spots" Program risk assessment for landfills should also include emissions of listed substances for all applicable power generation and maintenance equipment at the landfill site. Processes that need to be addressed include stationary IC engines, flares, evaporation ponds, composting operations, boilers, and gasoline dispensing systems.

2.3 Source Characterization

Pollutants are released into the atmosphere in many different ways. The release conditions need to be properly identified and characterized to appropriately use the air dispersion models.

2.3.1 Source Type

Source types can be identified as point, line, area, or volume sources for input to the air dispersion model. Several air dispersion models have the capability to simulate more than one source type.

2.3.1.1 Point Sources

Point sources are probably the most common type of source and most air dispersion models have the capability to simulate them. Typical examples of point sources include: isolated vents and stacks.

2.3.1.2 Line Sources

In terms of modeling, line sources are treated as a special case of either an area or a volume source. Consequently, they are normally modeled using either an area or volume source model as described below. Examples of line sources include: conveyor belts and rail lines, freeways, and busy roadways. Mobile sources and rail lines do not come under the purview of the Hot Spots program, but they are required to be evaluated under SB-352. SB-352 requires a risk assessment performed under the Hot Spots risk assessment guidance for proposed school sites within 500 feet of a busy roadway. Dedicated air dispersion models are available for motor vehicle emissions from roadways which are a special type of line source. These models (i.e., CALINE3, CAL3QHCR, and CALINE4) are designed to simulate the mechanical turbulence and thermal plume rise due to the motor vehicle activity on the roadway. However, these dedicated models use the Pasquill-Gifford dispersion stability classes for dispersion; the AERMOD dispersion model uses a more advanced continuous stability estimation method based on observations. The limitation with AERMOD is that the user needs to estimate initial mixing (Szo, and Syo) for mechanical turbulence and thermal plume rise

is not available. Consult with the District prior to conducting roadway modeling to determine model use.

For practical information on how to simulate roadway emission dispersion using these models, see the California Air Pollution Control Officer's Association (CAPCOA) website at http://www.capcoa.org or the Sacramento Metropolitan AQMD (SMAQMD) website at http://www.airquality.org/ceqa/RoadwayProtocol.shtml. The SMAQMD has a document titled, "Recommended Protocol for Evaluating the Location of Sensitive Land Uses Adjacent to Major Roadways"(January, 2010). The ARB recommends this document for SB-352 risk assessments.

2.3.1.3 Area Sources

Emissions that are to be modeled as area sources include fugitive sources characterized by non-buoyant emissions containing negligible vertical extent of release (e.g., no plume rise or distributed over a fixed level).

Fugitive particulate ($PM_{2.5}$, PM_{10}, TSP) emission sources include areas of disturbed ground (open pits, unpaved roads, parking lots) which may be present during operational phases of a facility's life. Also included are areas of exposed material (e.g., storage piles and slag dumps) and segments of material transport where potential fugitive emissions may occur (uncovered haul trucks or rail cars, emissions from unpaved roads). Fugitive emissions may also occur during stages of material handling where particulate material is exposed to the atmosphere (uncovered conveyors, hoppers, and crushers).

Other fugitive emissions emanating from many points of release may be modeled as area sources. Examples include fugitive emissions from valves, flanges, venting, and other connections that occur at ground level, or at an elevated level or deck if on a building or structure. Modern dispersion models include an option for an initial vertical extent (Szo) where needed.

2.3.1.4 Volume Sources

Non-point sources where emissions include an initial vertical extent should be modeled as volume sources. The initial vertical extent may be due to plume rise or a vertical distribution of numerous smaller sources over a given area. Examples of volume sources include buildings with natural fugitive ventilation, building roof monitors, and line sources such as conveyor belts and rail lines.

2.3.2 Quantity of Sources

The number of sources at a facility may influence the selection of the air dispersion model. Some dispersion models are capable of simulating only one source at a time, and are therefore referred to as single-source models (e.g., AERSCREEN).

In some cases, for screening purposes, single-source models may be used in situations involving more than one source using one of the following approaches:

- combining all sources into one single “representative” source

  In order to be able to combine all sources into one single source, the individual sources must have similar release parameters. For example, when modeling more than one stack as a single “representative” stack, the stack gas exit velocities and temperatures must be similar. In order to obtain a conservative estimate, the values leading to the higher concentration estimates should typically be used (e.g., the lowest stack gas exit velocity and temperature, the height of the shortest stack, and a receptor distance and spacing that will provide maximum concentrations, etc.).

- running the model for each individual source and superimposing results

  Superimposition of results of single sources of emissions is the actual approach followed by all the Gaussian models capable of simulating more than one source. Simulating sources in this manner may lead to conservative estimates if worst-case meteorological data are used or if the approach is used with a model that automatically selects worst-case meteorological conditions, especially wind direction. The approach will typically be more conservative the farther apart the sources are because each run would use a different worst-case wind direction.

Additional guidance regarding source merging is provided by the U.S. EPA (1995a). It should be noted that depending upon the population distribution, the total burden can actually increase when pollutants are more widely dispersed. If the total burden from the facility or zone of impact (see Section 2.6.1) could increase for the simplifying modeling assumptions described above, the District should be consulted.

2.4 Terrain Type

Two types of terrain characterizations are needed for input to the appropriate model. One classification is made according to land use and another one according to topography.

2.4.1 Terrain Type – Land Use

Some air dispersion models (e.g., CALINE) use different dispersion coefficients (sigmas) depending on the land use over which the pollutants are being transported. The land use type is also used by some models to select appropriate wind profile exponents. Traditionally, the land type has been categorized into two broad divisions for the purposes of dispersion modeling: urban and rural. Accepted procedures for determining the appropriate category are those suggested by Irwin (1978): one based on land use classification and the other based on population.

The land use procedure is generally considered more definitive. Population density should be used with caution and should not be applied to highly industrialized areas where the population density may be low. For example, in low population density areas a rural classification would be indicated, but if the area is sufficiently industrialized the classification should already be "urban" and urban dispersion parameters should be used.

If the facility is located in an area where land use or terrain changes abruptly, for example, on the coast, the District should be consulted concerning the classification. If need be, the model should be run in both urban and rural modes and the District may require a classification that biases estimated concentrations towards overprediction. As an alternative, the District may require that receptors be grouped according to the terrain between source and receptor.

AERMOD is the recommended model for a wide range of applications in rural or urban conditions. AERMOD uses a planetary boundary layer scaling parameter to characterize stability. This approach is a departure from stability categories estimated with the land use procedures. Rather AERMOD preprocessors, AERMET and AERMAP, are used to characterize land type as they process meteorological data and terrain receptors, respectively.

As it applies to plume models other than AERMOD, the Land Use Procedure is described as follows.

2.4.1.1 Land Use Procedure

(1) Classify the land use within the total area A, circumscribed by a 3 km radius circle centered at the source using the meteorological land use typing scheme proposed by Auer (1978) and shown in Table 2.1.

(2) If land use types I1, I2, C1, R2 and R3 account for 50 percent or more of the total area *A* described in (1), use urban dispersion coefficients. Otherwise, use appropriate rural dispersion coefficients.

2.4.1.2 Population Density Procedure

(1) Compute the average population density (*p*) per square kilometer with *A* as defined in the Land Use procedure described above. (Population estimates are also required to determine the exposed population; for more information see Section 2.6.3.)

(2) If *p* is greater than 750 people/km^2 use urban dispersion coefficients, otherwise, use appropriate rural dispersion coefficients.

Table 2.1 Identification and classification of land use types (Auer, 1978)

***Used to define rural and urban dispersion coefficients in certain models*.**

Type	Use and Structures	Vegetation
I1	*Heavy Industrial* Major chemical, steel and fabrication industries; generally 3-5 story buildings, flat roofs	Grass and tree growth extremely rare; <5% vegetation
I2	*Light-moderate industrial* Rail yards, truck depots, warehouses, industrial parks, minor fabrications; generally 1-3 story buildings, flat roofs	Very limited grass, trees almost totally absent; <5% vegetation
C1	*Commercial* Office and apartment buildings, hotels; >10 story heights, flat roofs	Limited grass and trees; <15% vegetation
R1	*Common residential* Single family dwelling with normal easements; generally one story, pitched roof structures; frequent driveways	Abundant grass lawns and light-moderately wooded; >70% vegetation
R2	*Compact residential* Single, some multiple, family dwelling with close spacing; generally <2 story, pitched roof structures; garages (via alley), no driveways	Limited lawn sizes and shade trees; <30% vegetation
R3	*Compact residential* Old multi-family dwellings with close (<2 m) lateral separation; generally 2 story, flat roof structures; garages (via alley) and ashpits, no driveways	Limited lawn sizes, old established shade trees; <35% vegetation
R4	*Estate residential* Expansive family dwelling on multi-acre tracts	Abundant grass lawns and lightly wooded; >80% vegetation
A1	*Metropolitan natural* Major municipal, state, or federal parks, golf courses, cemeteries, campuses; occasional single story structures	Nearly total grass and lightly wooded; >95% vegetation

A2	*Agricultural rural*	Local crops (e.g., corn, soybean); >95% vegetation
A3	*Undeveloped* Uncultivated; wasteland	Mostly wild grasses and weeds, lightly wooded; >90% vegetation
A4	*Undeveloped rural*	Heavily wooded; >95% vegetation
A5	*Water surfaces* Rivers, lakes	

2.4.2 Terrain Type - Topography

Surface conditions and topographic features generate turbulence, modify vertical and horizontal winds, and change the temperature and humidity distributions in the boundary layer of the atmosphere. These in turn affect pollutant dispersion and models differ in their need to take these factors into account.

The classification according to terrain topography should ultimately be based on the topography at the receptor location with careful consideration of the topographical features between the receptor and the source. Differentiation of simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the well-known dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. For other plume models, such as SCREEN3, topography can be classified as follows:

2.4.2.1 Simple Terrain (also referred to as "Rolling Terrain")

Simple terrain is all terrain located below stack height including gradually rising terrain (i.e., rolling terrain). Note that *Flat Terrain* also falls in the category of simple terrain.

2.4.2.2 Intermediate Terrain

Intermediate terrain is terrain located above stack height and below plume height. The recommended procedure to estimate concentrations for receptors in intermediate terrain is to perform an hour-by-hour comparison of concentrations predicted by simple and complex terrain models. The higher of the two concentrations should be reported and used in the risk assessment.

2.4.2.3 Complex Terrain

Complex terrain is terrain located above plume height. Complex terrain models are necessarily more complicated than simple terrain models. There may be situations in which a facility is "overall" located in complex terrain but in which the nearby surroundings of the facility can be considered simple terrain. In such cases, receptors close to the facility in this area of simple terrain will "dominate" the risk analysis and

there may be no need to use a complex terrain model. It is unnecessary to determine which terrain dominates the risk analysis for users of AERMOD.

2.5 Level of Detail: Screening vs. Refined Analysis

Air dispersion models can be classified according to the level of detail which is used in the assessment of the concentration estimates as "screening" or "refined". Refined air dispersion models use more robust algorithms capable of using representative meteorological data to predict more representative and usually less conservative estimates. Refined air dispersion models are, however, more resource intensive than their screening counterparts. It is advisable to first use a screening model to obtain conservative concentration estimates and calculate health risks. If the health risks are estimated to be above the threshold of concern, then use of a refined model to calculate more representative concentration and health risk estimates would be warranted. There are situations when screening models represent the only viable alternative (e.g., when representative meteorological data are not available).

It is acceptable to use a refined air dispersion model in a "screening" mode for this program's health risk assessments. In this case, a refined air dispersion model is used:

- with worst-case meteorology instead of representative meteorology
- with a conservative averaging period conversion factor to calculate longer term concentration estimates

Note that use of worst case meteorology in a refined model is not the normal practice in New Source Review or Ambient Air Quality Standard evaluation modeling.

2.6 Population Exposure

The level of detail required for the analysis (e.g., screening or refined), and the procedures to be used in determining geographic resolution and exposed population require case-by-case analysis and professional judgment. The District should be consulted before beginning the population exposure estimates and as results are generated, further consultation may be necessary. Some suggested approaches and methods for handling the breakdown of population and performance of a screening or detailed risk analysis are provided in this section.

In addition to estimating individual cancer risk at specific points such as the MEI (maximally exposed individual), OEHHA recommends determining the number of people who reside with the 1×10^{-6}, 1×10^{-5}, 1×10^{-4}, and higher cancer risk isopleths. The information can be used to assess the population risk.

2.6.1 Zone of Impact

As part of the estimation of the population exposure for the cancer risk analysis, it is necessary to determine the geographic area affected by the facility's emissions. An initial approach to define a "zone of impact" surrounding the source is to generate an isopleth where the total excess lifetime cancer risk from inhalation exposure to all

emitted carcinogens is greater than 10^{-6} (one in 1,000,000). For noncarcinogens, a second and third isopleth (to represent both the chronic and acute impacts) should be created to define the zone of impact for the hazard index from both inhalation and noninhalation pathways greater than or equal to 1.0. For clarity these isopleths may need to be presented on separate maps in the HRA.

The initial "zone of impact" can be determined as follows:

- Use a screening dispersion model (e.g., AERSCREEN) to obtain concentration estimates for each emitted pollutant at varying receptor distances from the source. Several screening models feature the generation of an automatic array of receptors which is particularly useful for determining the zone of impact. In order for the model to generate the array of receptors the user needs to provide some information normally consisting of starting distance, increment and number of intervals.

- Calculate total cancer risk and hazard index (HI) for each receptor location by using the methods provided in the risk characterization sections of the Air Toxics Hot Spots Risk Assessment Guidance Manual.

- Find the distance where the total inhalation cancer risk is equal to 10^{-6}; this may require redefining the receptor array in order to have two receptor locations that bound a total cancer risk of 10^{-6}. Secondly and thirdly, find the distance where the chronic and acute health hazard indices are declared significant by the District (e.g., acute or chronic HI = 1.0).

Some Districts may prefer to use a cancer risk of 10^{-7} as the zone of impact. Therefore, the District should be consulted before modeling efforts are initiated. If the zone of impact is greater than 25 km from the facility at any point, then the District should be consulted. The District may specify limits on the area of the zone of impact. Ideally, these preferences would be presented in the modeling protocol (see Section 2.14).

Note that when depicting the risk assessment results, risk isopleths must present the total cancer and noncancer risk from both inhalation and noninhalation pathways. The zone of impact should be clearly shown on a map with geographic markers of adequate resolution (see Section 2.6.3.1).

2.6.2 Population Estimates for Screening Risk Assessments

A screening risk assessment should include an estimate of the maximum exposed population. For screening risk assessments, a detailed description of the exposed population is not required. The impact area to be considered should be selected to be health protective (i.e., will not underestimate the number of exposed individuals). A health-protective assumption is to assume that all individuals within a large radius of the facility are exposed to the maximum concentration. If a facility must also comply with

the RCRA/CERCLA risk assessment requirements, health effects to on-site workers may also need to be addressed. The DTSC's Remedial Project Manager should be consulted on this issue. The District should be consulted to determine the population estimate that should be used for screening purposes.

2.6.3 Population Estimates for Refined Risk Assessments

The refined risk assessment requires a detailed analysis of the population that is exposed to emissions from the facility. Where possible, a detailed population exposure analysis provides estimates of the number of individuals in residences and off-site workplaces, as well as at sensitive receptor sites such as schools, daycare centers and hospitals. The District may require that locations with high densities of sensitive individuals be identified (e.g., schools, daycare centers, hospitals). The overall exposed residential and worker populations should be apportioned into smaller geographic subareas. The information needed for each subarea is:

(1) the number of exposed persons, and
(2) the receptor location where the calculated ambient air concentration is assumed to be representative of the exposure to the entire population in the subarea.

A multi-tiered approach is suggested for the population analysis. First, the census tracts impacted by the facility should be identified (see Section 2.6.3.1). A census tract may need to be divided into smaller subareas if it is close to the facility where ambient concentrations vary widely. The District may determine that census tracts provide sufficient resolution near the facility to adequately characterize population exposure. The HARP software will provide population estimates that are consistent with the methodology discussed in this document.

Further downwind where ambient concentrations are less variable, the census tract level may be acceptable to the District. The District may determine that the aggregation of census tracts (e.g., the census tracts making up a city are combined) is appropriate for receptors which are considerable distances from the facility. If a facility must also comply with the RCRA/CERCLA risk assessment requirements, health effects to on-site workers may also need to be addressed. The DTSC's Remedial Project Manager should be consulted on this issue. In addition, the district should be consulted about special cases where evaluation of on-site receptors is appropriate, such as facilities frequented by the public or where people may reside (e.g., military facilities).

2.6.3.1 Census Tracts

For a refined risk assessment, the boundaries of census tracts can be used to define the geographic area to be included in the population exposure analysis. Digital maps showing the census tract boundaries in California can be obtained from "The Thomas Guide"® on the World Wide Web. Statistics for each census tract can be obtained from the U.S. Census Bureau. The website address for the U.S. Census Bureau is http://www.census.gov. Numerous additional publicly accessible or commercially available sources of census data can be found on the World Wide Web. A specific

example of a census tract is given in Appendix J. The HARP software includes U.S. census data and is a recommended tool for performing population exposure estimates.

The two basic steps in defining the area under analysis are:

(1) Identify the "zone of impact" (as defined previously in Section 2.6.1) on a map detailed enough to provide for resolution of the population to the subcensus tract level. (The U.S. Geological Survey (USGS) 7.5-minute series maps and the maps within the HARP software provide sufficient detail.) This is necessary to clearly identify the zone of impact, location of the facility, and sensitive receptors within the zone of impact. If significant development has occurred since the USGS survey, this should be indicated. A specific example of a 7.5-minute series map is given in Appendix J.

(2) Identify all census tracts within the zone of impact using a U.S. Bureau of Census or equivalent map (e.g., Thomas Brothers, HARP Software). If only a portion of the census tract lies within the zone of impact, then only the population that falls within the isopleth should be used in the population estimate or burden calculation. To determine this level of detail, local planning and zoning information may need to be collected. When this more detailed information is not available, then a less refined approach is to include the census data if the centroid of the census block falls within the isopleths of interest. The census tract boundaries should be transferred to a map, such as a USGS map (referred to hereafter as the "base map".)

An alternative approach for estimating population exposure in heavily populated urban areas is to apportion census tracts to a Cartesian grid cell coordinate system. This method allows a Cartesian coordinate receptor concentration field to be merged with the population grid cells. This process can be computerized and minimizes manual mapping of centroids and census tracts. The HARP software includes this function and will provide population estimates that are consistent with the methodology discussed here.

The District may determine that aggregation of census tracts (e.g., which census tracts making up a city can be combined) is appropriate for receptors that are located at considerable distances from the facility. If the District permits such an approach, it is suggested that the census tract used to represent the aggregate be selected in a manner to ensure that the approach is health protective. For example, the census tract included in the aggregate that is nearest (downwind) to the facility should be used to represent the aggregate.

2.6.3.2 Subcensus Tract

Within each census tract are smaller population units. These units [urban block groups (BG) and rural enumeration districts (ED)] contain about 1,100 persons. BGs are further broken down into statistical units called blocks. Blocks are generally bounded by

four streets and contain an average of 70 to 100 persons. However, the populations presented above are average figures and population units may vary significantly. In some cases, the EDs are very large and identical to a census tract.

The area requiring detailed (subcensus tract) resolution of the exposed residential and worker population will need to be determined on a case-by-case basis through consultation with the District. The District may determine that census tracts provide sufficient resolution near the facility to adequately characterize population exposure.

Employment population data can be obtained at the census tract level from the U.S. Census Bureau or from local planning agencies. This degree of resolution will generally not be sufficient for most risk assessments. For the area requiring detailed analysis, zoning maps, general plans, and other planning documents should be consulted to identify subareas with worker populations.

The boundaries of each residential and employment population area should be transferred to the base map.

2.6.4 Sensitive Receptor Locations

Individuals who may be more sensitive to toxic exposures than the general population are distributed throughout the total population. Sensitive populations may include young children and chronically ill individuals. The District may require that locations with high densities of sensitive individuals be identified (e.g., schools, daycare centers, hospitals). The risk assessment should state what the District requirements were regarding identification of sensitive receptor locations.

Although protection of sensitive individuals is incorporated into OEHHA's risk assessment methodology in both cancer risk and noncancer risk assessment, the assessment of risk at the specific location of such sensitive individuals (e.g., schools, hospitals, or nursing homes) may be useful to assure the public that such individuals are being considered in the analysis. For some chemicals (e.g., mercury and manganese) children have been specifically identified as the sensitive subpopulation for noncancer health impacts, so it can be particularly appropriate to assess school sites.

2.7 Receptor Siting

2.7.1 Receptor Points

The modeling analysis should contain a network of receptor points with sufficient detail (in number and density) to permit the estimation of the maximum concentrations. Locations that must be identified include the maximum estimated off-site risk or point of maximum impact (PMI), the maximum exposed individual at an existing residential receptor (MEIR) and the maximum exposed individual at an existing occupational receptor (worker) (MEIW). All of these locations (i.e., PMI, MEIR, and MEIW) must be identified for assessing cancer and noncancer risks. It is possible that the estimated

~~2.7 Receptor Siting~~

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2.7.1.1 Receptor Height

To evaluate localized impacts, receptor height should be taken into account at the point of maximum impact on a case-by-case basis. For example, receptor heights may have to be included to account for receptors significantly above ground level. Flagpole receptors at the height of the breathing zone of a person may need to be considered when the source receptor distance is less than a few hundred meters. Consideration must also be given to the noninhalation pathway analysis which requires modeling of chemical deposition onto soil or water at ground level as a first step. A health protective approach is to select a receptor height from 0 meters to 1.8 meters that will result in the highest predicted downwind concentration. Final approval of this part of the modeling protocol should be with the District, or reviewing authority.

2.7.2 Centroid Locations

For each subarea analyzed, a centroid location (the location at which a calculated ambient concentration is assumed to represent the entire subarea) should be determined. When population is uniformly distributed within a population unit, a geographic centroid based on the shape of the population unit can be used. If only a

portion of the census tract lies within the isopleth or area of interest, then only the population that falls within the isopleth should be used in the calculation for population exposure. To determine this level of detail, local planning and zoning information may need to be collected. Where populations are not uniformly distributed, a population-weighted centroid may be used. Another alternative uses the concentration at the point of maximum impact within that census tract as the concentration to which the entire population of that census tract is exposed. While this less refined approach is commonly accepted, Districts should be contacted to approve this method prior to its use in a risk assessment.

The centroids represent locations that should be included as receptor points in the dispersion modeling analysis. Annual average concentrations should be calculated at each centroid using the modeling procedures presented in this chapter.

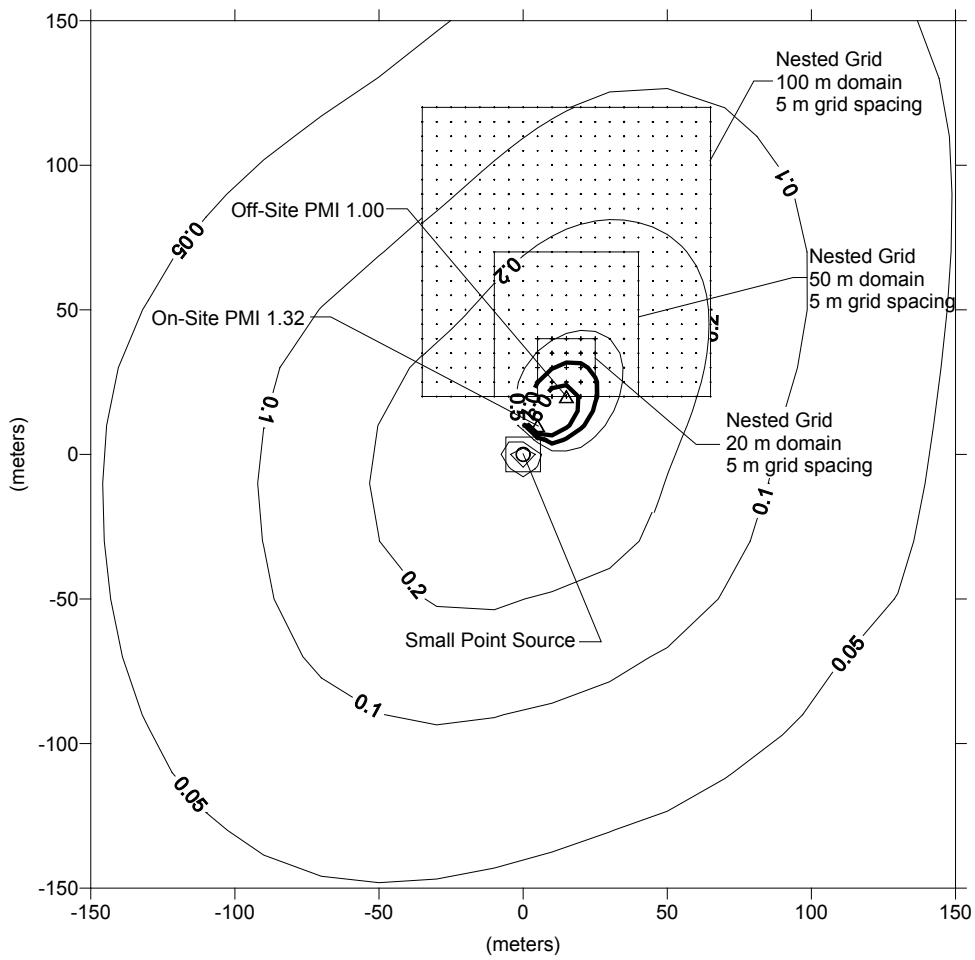
For census tracts and BG/EDs, judgments can be made using U.S. census data, census tracts maps, and street maps to determine the centroid location. At the block level, a geographic centroid is sufficient.

2.7.3 Spatial Averaging of Modeling Results

Since the inception of the “Hot Spots” and the air toxics programs in California, health risk assessment (HRA) results for an individual have typically been based on air dispersion modeling results at a single point or location. With a few exceptions, this method has been traditionally used for all types of receptors (e.g., PMI, MEIR, MEIW, pathway receptors, etc.). The assumptions used in risk assessment are designed to prevent underestimation of health impacts to the public – a health protective approach.

To identify the individual receptor (e.g., PMI, MEIR, etc), air dispersion modeling of pollutant emissions estimate ground level concentrations (GLC) at downwind receptors, which are distributed in a grid pattern of sufficient size and density to capture the maximum concentration. Figure 2 shows an example of the PMI and concentration isopleths. Under some conditions, the PMI may be significantly higher than receptors only a few meters away. In these cases, it may be unrealistic for the PMI to represent the 70-year exposure for long-term risk calculations.

Figure 2 – Concentration Isopleths



It is prudent public health practice to err on the side of public health protection in face of uncertainty; however, when exposure models can be refined, better scientific estimates of exposure and risk can be obtained. Basing risk estimates on a single highest point (PMI, MEIR, or MEIW) does not take into account that a person does not remain at one location on their property, or often in one location at the workplace over an extended period of time. Thus, using a single point with the highest air concentration that is not representative of the average concentration at a residence will tend to overestimate exposure and risk. One to five years of meteorological data do not necessarily fully characterize the variability in meteorological conditions over longer periods (e.g., 30 to 70 years) and thus the concentrations at a single point are likely to be more diffuse than the modeling estimates based on one year of meteorological data. U.S.EPA modeling guidance suggests that five years of consecutive meteorological data strongly represent a longer average such as 70 years. The average air concentration over a small area is likely to be more representative than the determination the air concentration at a single point, particularly in those situations where the concentrations falls off rapidly around the single point.

In order to understand how spatial averaging would impact air dispersion modeling results with various types of facilities, the ARB, in conjunction with the OEHHA, performed sensitivity analyses to evaluate the impacts of spatially averaging air dispersion modeling results. That information is presented in detail in Appendix C. Based on these sensitivity analyses, we feel it is reasonable and appropriate to include spatial averaging techniques in air toxic risk assessments as supplemental information to Tier 1 information (i.e., modeling results that are based on the air concentration from a single point or location). While all risk assessments must include results based on Tier 1 methodology, the spatially-averaged concentrations around the point of interest (e.g., PMI, MEIR, MEIW, multipathway exposure evaluations, etc.) could also be included as an option in risk assessments and for risk management decisions subject to approval by the District or reviewing agency.

A few reasons that support the inclusion of spatially-averaged modeled concentrations in risk assessment include the following.

- Averaging results over a small domain will give a more representative picture of individual exposure and risk than an estimate based on one single location within their property.
- Spatial averaging will allow air dispersion modeling and risk assessment results to be characterized as the estimated concentration and risk in a discrete area of interest, rather than an exact value for a single location.
- From a risk communication standpoint, the ARB and OEHHA feel it is more appropriate to present the modeling output and the calculated health impacts as the potential impacts within a small or discrete area, rather than an exact value at a specific point on a grid or map.
- Spatial averaging is the recommended procedure in ARB's Lead Risk Management Guidelines (2001) and has been used in several complex source HRAs [e.g., Roseville Railyard (2004), Ports of LA/LB (2006), Port of Oakland (2008)].
- Spatially averaging the deposition concentrations over pasture land or a water body for multipathway exposure scenarios is a planned upgrade for the HARP Software. This will provide an option that will appropriately refine multipathway exposure assessments. Average deposition on a water body is not necessarily well represented by the single highest point of deposition, or deposition at the geographic center of the water body. Likewise, since produce is grown over the entire surface of the garden and cows graze the entire pasture, deposition is better estimated by evaluating the entire area rather than using a single point.

2.7.4 Spatial Averaging Method

The spatial averaging sensitivity study in Appendix C is based on simulating emissions from a point, volume, area, and line sources. Each source type (e.g., point) is simulated as a small, medium or large source. Line sources are only simulated as small and large. In addition, meteorological data collected at five different locations in California were used. Nested spatial average grids of various domains were used to study the

differences on the spatial average concentration. In the case of the 20 meter by 20 meter spatial average nested grid, the spatial average concentration showed little change over the PMI for medium and large sources. In the case for small sources, the spatial average concentration is 45% to 80% of the PMI concentration. Individual source type and meteorological conditions will cause variations in these results.

The results of the spatial averaging sensitivity study in Appendix C shows that sources with low plume rise that result in a PMI, MEIW, or MEIR located at or near the property fence line are most sensitive to spatial averaging. Source types with high plume rise (e.g., tall stacks) show a PMI far downwind where the concentration gradient is more gradual and therefore spatial averaging has a lesser effect. While spatial averaging can be used regardless of source size or the location of the PMI, the following conditions generally apply when a source is a good candidate for spatial averaging

- The MEIR, MEIW, or PMI is located at the fence line or close to the emission source.
- The concentration gradient is high near the PMI. This is more associated with low level plumes such as fugitive, volume, area, or short stacks.
- A long term average is being calculated to represent a multi-year risk analysis based on one to five years of meteorological data. Note that spatial averaging should **not** be used for short term (acute) calculations.

2.7.4.1 Residential Receptors

To remain health protective when evaluating a residential receptor, spatial averaging should not take place using large nested domains. The domain used for spatial averaging should be no larger than 20 meters by 20 meters with a maximum grid spacing resolution of five meters. This domain represents and area that is approximately the size of a small urban lot.

In general, the method for calculating the spatial average in air toxic risk assessments includes the following steps.

1. Locate the off-site PMI, MEIW, or MEIR with a grid resolution spacing of no greater than five meters. Two or more model runs with successively finer nested grid resolutions centered on the new PMI may be required to locate the final PMI.
2. Center the spatial average nested grid on the off-site receptors about the PMI, MEIW, or MEIR. Limit the nested grid to no larger than 20 meters by 20 meters. The grid resolution spacing should be no greater than five meters. With a five meter grid resolution, the 20 meter by 20 meter nest will result in 25 receptors.
3. Some configurations of source activity and meteorological conditions result in a predominant downwind plume center line that is significantly askew from one of the four ordinate directions. In this case, a tilted nested grid is necessary to coincide with the dominant plume centerline. Polar receptors

are easier to implement than a tilted rectangular grid. The domain of the polar receptor field should be limited to a 15 meter radius. See Appendix C for detailed instructions on tilted polar receptors.

4. Calculate the arithmetic mean of the long term period average concentration (e.g., annual average) of the nested grid of receptors to represent the spatial average.

Appendix C shows explicit details for selecting, placing, and tilting a nested grid for rectangular or polar receptor grids. In addition, the sensitivity study is also available.

2.7.4.2 Worker Receptors

Offsite worker locations (e.g. MEIW) may also be a candidate for spatial averaging. However, workers can be at the same location during almost their entire work shift (e.g., desk/office workers). When this is the situation, then a single location and corresponding modeled concentration are appropriate to use. If spatial averaging is used, care should be taken to determine the proper domain size and grid resolution that should be used. To be consistent with the residential receptor assumptions and remain health protective, a maximum domain size should be no larger than 20 meters by 20 meters with a maximum grid spacing resolution of five meters. However, if workers routinely and continuously move throughout the worksite over a space greater than 20 meters by 20 meters, then a larger domain may be considered. The HRA or modeling protocol shall support all assumptions used, including, but not limited to, documentation for all workers showing the area where each worker routinely performs their duties. The final domain size should not be greater than the smallest area of worker movement. Other considerations for determining domain size and grid spacing resolution may include an evaluation of the concentration gradients across the worker area. The grid spacing used within the domain should be sufficient in number and detail to obtain a representative concentration across the area of interest. The size of the domain and resolution of points shall be subject to approval by the District, ARB, or other reviewing authority.

2.7.4.3 Pastures or Water Bodies

The simplified approach of using the deposition rate at the centroid, a specific point of interest, or the PM location for an area being evaluated for noninhalation exposures(e.g. a body of water used for fishing, a pasture used for grazing, etc) is still acceptable for use in HRA. However, evaluating deposition concentrations over pasture land or a water body for multipathway exposure scenarios using spatial averaging could give more representative estimates of the overall deposition rate. Use of spatial averaging in this application is subject to approval by the District, ARB, or other reviewing authority.

When using spatial averaging over the deposition area, care should be taken to determine the proper domain size to make sure it includes all reasonable areas of potential deposition. The size and shape of the pasture or water body of interest should be identified and used for the modeling domain. The grid spacing or resolution used

within the domain should be sufficient in detail to obtain a representative deposition concentration across the area of interest. One way to determine the grid resolution is to include an evaluation of the concentration gradients across the deposition area. The HRA or modeling protocol shall support all assumptions used, including, but not limited to, documentation of the deposition area (e.g., size and shape of the pasture or water body, maps, representative coordinates, grid resolution, concentration gradients, etc.). The size of the domain and grid resolution are subject to approval by the reviewing authority.

In lieu of the details required in the above description, the approach used for the other receptors (e.g., MEIR, MEIW) that uses a domain size not greater than 20 meters by 20 meters, centered on the PMI or point of interest, with a maximum grid spacing resolution of five meters can be used. This default refined approach would apply to deposition areas greater than 20 meters by 20 meters. For smaller deposition areas, the simplified approach of using the PMI or the actual smaller domain can be used.

The HRA or modeling protocol shall support all assumptions used, including, but not limited to, documentation of the deposition area (e.g., size and shape of the lake or water body, maps, representative coordinates, etc.). Other considerations for determining domain size and grid spacing resolution should include an evaluation of the concentration gradients across the deposition area. The grid spacing used within the domain should be sufficient in number and detail to obtain a representative deposition concentration across the area of interest. This information should also be included in the HRA and modeling protocols

2.8 Meteorological Data

Refined air dispersion models require hourly meteorological data. The first step in obtaining meteorological data should be to check with the District for data availability. Other sources of data include the National Weather Service (NWS), National Climatic Data Center (NCDC), Asheville, North Carolina, military stations and private networks. Meteorological data for a subset of NWS stations are available from the U.S. EPA Support Center for Regulatory Air Models (SCRAM). The SCRAM can be accessed at www.epa.gov/scram001/main.htm. All meteorological data sources should be approved by the District. Data not obtained directly from the District should be checked for quality, representativeness and completeness. U.S. EPA provides guidance (U.S. EPA, 1995e) for these data. The risk assessment should indicate if the District required the use of a specified meteorological data set. All memos indicating District approval of meteorological data should be attached in an appendix. If no representative meteorological data are available, screening procedures should be used.

The analyst should acquire enough meteorological data to ensure that the worst-case meteorological conditions are represented in the model results. The US-EPA Guideline on Air Quality Models (U.S. EPA 2005) prefers that the latest five years of consecutive meteorological data be used to represent long term averages (i.e., cancer and chronic). Previous OEHHA guidance allowed the use of the worst-case year to save computer

time. The processing speed of modern computers has increased to the point where processing five years of data over one year is no longer burdensome. However, the District may determine that one year of representative meteorological data is sufficient to adequately characterize the facility's impact. This may especially be the case when five years of quality consecutive data are not available.

During the transitional period from night to day (i.e., the first one to three hours of daylight) the meteorological processor may interpolate some very low mixing heights. This is a period of time in which the mixing height may be growing rapidly. When predicted concentrations are high and the mixing height is very low for the corresponding averaging period, the modeling results deserve additional consideration. For receptors in the near field, it is within the model formulation to accept a very low mixing height for short durations. However, it would be unlikely that the very low mixing height would persist long enough for the pollutants to travel into the far field. In the event that the analyst identifies any of these time periods, they should be discussed with the District on a case-by-case basis.

~~*2.8.1 Modeling to Obtain Annual Average Concentrations for Shorter Durations (e.g., 8-Hours)*~~

2.8.1 Modeling to Obtain Concentrations used for Various Health Impacts

The following section outlines how air dispersion modeling results are used or adjusted for a receptor that is exposed to either a non-continuous or continuously emitting source.

2.8.1.1 Modeling and Adjustments for Inhalation Cancer Risk at a Worksite

Modeled long-term averages are typically used for cancer risk assessments. In an inhalation cancer risk assessment for an offsite worker, the long-term average should represent what the worker breathes during their work shift. However, the long-term averages calculated from AERMOD typically represent exposures for receptors that were present 24 hours a day and seven days per week (i.e., residential receptors). To estimate the offsite worker's concentration, there are two approaches. The more refined, complex, and time consuming approach is to post-process the hourly raw dispersion model output and examine the hourly concentrations that fall within the offsite worker's shift. See Appendix M for information on how to simulate the long-term concentration for the offsite worker that can be used to estimate inhalation cancer risk.

In lieu of post-processing the hourly dispersion model output, the more typical approach is to obtain the long-term average concentration as you would for modeling a residential receptor and approximate the worker's inhalation exposure using an adjustment factor. The actual adjustment factor that is used to adjust the concentration may differ from the example below based on the specifics of the source and worker receptor (e.g., work-shift overlap). Once the worker's inhalation concentration is determined, the

inhalation dose is calculated using additional exposure frequency and duration adjustments. See Chapter 3 for more information on the inhalation dose equation.

Non-Continuous Sources

When modeling a non-continuously emitting source (e.g., operating for eight hours per day and five days per week), the modeled long-term average concentrations are based on 24 hours a day and seven days per week for the period of the meteorological data set. Even though the emitting source is modeled using a non-continuous emissions schedule, the long-term concentration is still based on 24 hours a day and seven days per week. Thus, this concentration includes the zero hours when the source was not operating. For the offsite worker inhalation risk, we want to determine the long-term concentration the worker is breathing during their work shift. Therefore, the long-term concentration needs to be adjusted so it is based only on the hours when the worker is present. For example, assuming the emitting source and worker's schedules are the same, the adjustment factor is 4.2 = (24 hours per day/8 hours per shift)x(7 days in a week/5 days in a work week). In this example, the long term residential exposure is adjusted upward to represent the exposure to a worker. Additional concentration adjustments may be appropriate depending on the work shift overlap. These adjustments are discussed below.

The calculation of the adjustment factor from a non-continuous emitting source is summarized in the following steps.

a. Obtain the long-term concentrations from air dispersion modeling as is typical for residential receptors (all hours of a year for the entire period of the meteorological data set).

b. Determine the coincident hours per day and days per week between the source's emission schedule and the offsite worker's schedule.

c. Calculate the worker adjustment factor (WAF) using Equation 2.1. When assessing inhalation cancer health impacts, a discount factor (*DF*) may also be applied if the offsite worker's schedule partially overlaps with the source's emission schedule. The discount factor is based on the number of coincident hours per day and days per week between the source's emission schedule and the offsite worker's schedule (see Equation 2.2). The DF is always less than or equal to one.

Please note that worker adjustment factor does not apply if the source's emission schedule and the offsite worker's schedule do not overlap. Since the worker is not around during the time that the source is emitting, the worker is not exposed to the source's emission (i.e., the DF in Equation 2.2 becomes 0).

$$WAF = \frac{H_{residential}}{H_{source}} \times \frac{D_{residential}}{D_{source}} \times DF \qquad \text{Eq. 2.1}$$

Where:

WAF = the worker adjustment factor
$H_{residential}$ = the number of hours per day the long-term residential concentration is based on (always 24 hours)
H_{source} = the number of hours the source operates per day
$D_{residential}$ = the number of days per week the long-term residential concentration is based on (always 7 days).
D_{source} = the number of days the source operates per week.
DF = a discount factor for when the offsite worker's schedule partially overlaps the source's emission schedule. Use 1 if the offsite worker's schedule occurs within the source's emission schedule. If the offsite worker's schedule partially overlaps with the source's emission schedule, then calculate the discount factor using Equation 2.2 below.

$$DF = \frac{H_{coincident}}{H_{worker}} \times \frac{D_{coincident}}{D_{worker}} \qquad \text{Eq. 2.2}$$

Where:

DF = the discount factor for assessing cancer impacts
$H_{coincident}$ = the number of hours per day the offsite worker's schedule and the source's emission schedule overlap
$D_{coincident}$ = the number of days per week the offsite worker's schedule and the source's emission schedule overlap.
H_{worker} = the number of hours the offsite worker works per day
D_{worker} = the number of days the offsite worker works per week.

d. The final step is to estimate the offsite worker's inhalation concentration by multiplying the worker adjustment factor with the long-term residential concentration. The worker's concentration is then plugged into the dose equation and risk calculation.

The HARP software has the ability to calculate worker impacts using an approximation factor and, in the future, it will have the ability to post-process refined worker concentrations using the hourly raw results from an air dispersion analysis.

Continuous Sources

If the source is continuously emitting, then the worker is assumed to breathe the long-term annual average concentration during their work shift. Equation 2.1 becomes one and no concentration adjustments are necessary in this situation when estimating the inhalation cancer risk. Note however, if an assessor does not wish to apply the assumption the worker breathes the long-term annual average concentration during the work shift, then a refined concentration can be post-processed as described in

Appendix M. All alternative assumptions should be approved by the reviewing authority and supported in the presentation of results.

2.8.1.2 Modeling and Adjustments for 8-Hour RELs

For 8-hour noncancer health impacts, we evaluate if the receptor (e.g., worker or resident) is exposed to a daily (e.g., 8-hour) average concentration that exceeds the 8-hour REL. For ease, we use a worker receptor in this discussion and in the discussion below for a non-continuously emitting source. The daily average concentration is intended to represent the long-term average concentration the worker is breathing during their work shift. In general, there are two approaches for estimating the concentration used for the 8-hour hazard index. The more refined, complex, and time consuming approach is to post-process the hourly dispersion model output and use only the hourly concentrations that are coincident with the offsite worker hours to obtain the long-term concentration. See Appendix M for information on how to simulate the daily average concentration through air dispersion modeling. Before proceeding through a refined analysis described in Appendix M, the assessor may wish to approximate the long-term concentration, as described below, and calculate the 8-hour hazard index. Based on those results, the assessor can contact OEHHA for assistance in determining whether further evaluation may be necessary. The results from the 8-hour hazard index calculations are not combined with the chronic or acute hazard indices. All potential noncancer health impacts should be reported independently.

In lieu of post-processing the hourly dispersion model output described in Appendix M, the more typical approach is to obtain the long-term average concentration as you would for modeling a residential receptor and approximate the worker's inhalation concentration using an adjustment factor. The method for applying the adjustment factor is described below.

Non-Continuous Sources

When modeling a non-continuously emitting source (e.g., operating for eight hours per day and five days per week), the modeled long-term average concentrations are based on 24 hours a day and seven days per week for the period of the meteorological data set. Even though the emitting source is modeled using a non-continuous emissions schedule, the long-term concentration is still based on 24 hours a day and seven days per week. Thus, this concentration includes the zero hours when the source was not operating. For the offsite worker 8-hour hazard index, we want to determine the long-term average daily concentration the worker may be breathing during their work shift. This is similar to the cancer approximation adjustment method with one difference; there is no adjustment for partial overlap between the worker's schedule and the source's emission schedule. The reason for difference in methodology is because the 8-hour REL health factors are designed for repeated 8-hour exposures and cannot readily be adjusted to other durations of exposure.

When calculating the long-term average daily concentration for the 8-hour REL comparison, the long-term residential concentration needs to be adjusted so it is based only on the operating hours of the emitting source with the assumption the offsite worker's shift falls within the emitting source's schedule. For example, assuming the emitting source operates 8 hours per day, 5 days per week and the offsite worker's schedules fall within this period of emissions, then the adjustment factor is 4.2 = (24 hours per day/8 hours of emissions per day)x(7 days in a week/5 days of emissions per week). In this example, the long term residential exposure is adjusted upward to represent the 8-hour exposure to a worker. No adjustments are applied for partial work shift overlap with the emitting source. If the source emits at night, then see Appendix N for additional recommendations.

Using the approximation factor is a screening method. If the 8-hour hazard index is above a threshold of concern with this method, the district or assessor should contact OEHHA for further guidance regarding the substance of concern. If necessary, further evaluation can be performed using the refined daily average modeling methodology discussed in Appendix M.

The calculation of the adjustment factor from a non-continuous emitting source is summarized in the following steps.

a. Obtain the long-term concentrations from air dispersion modeling as is typical for residential receptors (all hours of a year for the entire period of the meteorological data set).

b. Calculate the worker adjustment factor (WAF) using Equation 2.3. The source's emission schedule is assumed to overlap offsite worker's schedule. Note that the worker adjustment factor and the 8-hour REL do not apply if the source's emission schedule and the offsite worker's schedule do not overlap at some point.

$$WAF = \frac{H_{residential}}{H_{source}} \times \frac{D_{residential}}{D_{source}} \qquad \text{Eq. 2.3}$$

Where:

WAF = the worker adjustment factor
$H_{residential}$ = the number of hours per day the long-term residential concentration is based on (always 24 hours)
H_{source} = the number of hours the source operates per day
$D_{residential}$ = the number of days per week the long-term residential concentration is based on (always 7 days).
D_{source} = the number of days the source operates per week

c. The final step is to estimate the offsite worker's daily average inhalation concentration by multiplying the WAF with the long-term residential concentration. The worker's concentration is then used to calculate the

8-hour hazard index. This method using the approximation factor is a screening method. If the 8-hour hazard index is above a threshold of concern, the district or assessor should contact OEHHA for further guidance regarding the substance of concern.

In the future, the HARP software will have the ability to use 8-hour RELs, calculate worker impacts using an approximation factor, and to post-process worker concentrations using the hourly raw results from an air dispersion analysis.

Continuous Sources

If the source is continuously emitting, then the worker is assumed to breathe the long-term annual average concentration during their work shift and no concentration adjustments are made when estimating 8-hour health impacts. Note however, if an assessor does not wish to assume the worker breathes the long-term annual average concentration during the work shift, then a refined concentration can be post-processed as described in Appendix M. All alternative assumptions should be approved by the reviewing authority and supported in the presentation of results.

Eight-hour RELs are not used for residential receptors that are exposed to continuously emitting sources. In this situation, chronic RELs are used.

2.8.1.3 Modeling and Adjustment Factors for Chronic RELs

Potential chronic noncancer health impacts use the long-term annual average concentration regardless of the emitting facility's schedule. No adjustment factors should be used to adjust this concentration. Chronic RELs are used to assess both residential or worker health impacts. The results from the chronic hazard index calculations are not combined with the 8-hour or acute hazard indices. All potential noncancer results should be reported independently.

2.8.1.4 Modeling and Adjustments for Oral Cancer Potencies and Oral RELs

When estimating the cancer risk or noncancer health impacts from noninhalation pathways, no adjustment is made to the long-term annual average concentration regardless of the emitting facility's schedule. Since the media (e.g., soil) at the receptor location where deposition takes place for noninhalation pathways is continuously present, the concentrations used for all noninhalation pathways are not adjusted (up or down) by an adjustment factor. However, some adjustments are made to the concentration once the pollutants reach the media, for example, pollutants undergo decay in soils. In addition, when the dose for each pathway is calculated, exposure adjustments may also be made. See the individual chapters for each exposure pathway to get more information on these types of adjustments. Oral cancer potencies and oral RELs are used to assess both residential or worker health impacts.

~~The exposure duration for the 8-hour RELs is daily 8-hour exposures including weekends for a significant fraction of a lifetime. Therefore, the air concentration that the~~

~~offsite workers are exposed to during their presumed 40 hour workshift must be averaged with the zero concentration that they will be exposed to when away from the worksite over the weekend. Thus for offsite workers, the operating schedule of the adjacent facility, and work schedule for the offsite workers are two determinants of exposure. The annual average concentration during work shift multiplied by 5/7 to adjust for the weekend time away from the worksite is what needs to be divided by the 8 hour REL. The exposure duration for the 8-hour RELs is daily 8-hour exposures including weekends. A facility that only emits Monday through Friday during the day will have no emissions during the weekend and since the offsite workers are typically not exposed during the weekend, the air concentration that the workers are exposed to during the week needs to be reduced by 5/7 before it is compared to the REL. For estimating residential noncancer chronic risks and inhalation cancer risk the air dispersion modeling results are based on the facility's hourly emission profile coincident with hourly meteorological data for a complete year (or more) of simulations, to give an annual average air concentration. However, when evaluating the offsite worker receptor, we need the average concentration that the offsite worker is exposed to (i.e., breathing) during their shift.~~

~~There are two approaches for estimating the concentration for the offsite worker exposure. The more complex approach is to post process the hourly dispersion model output and selectively sample the hourly concentrations that are co-incident with the offsite worker hours. The long term exposure to offsite workers is the average of the sampled hourly concentrations. See Appendix M for information on how to simulate the long term concentration for the offsite worker that can be used to estimate the carcinogenic or chronic impacts. This approach is the most refined and can be time consuming.~~

~~In lieu of these special modeling runs, the more typical approach is to obtain the annual average concentration as you would for modeling a residential receptor and approximate the worker's 8-hour concentration using an adjustment factor. The adjustment factor is a function of exposure assumptions and whether you are calculating carcinogenic or non carcinogenic impacts. The HARP software has the ability to calculate worker impacts using an approximation or to model special scenarios for determining concentrations for shorter durations.~~

~~Residents can be exposed to emissions from facilities operating 8 hours a day, five days a week. The 8-hour RELs can be used to assess chronic risks to residents in this case. The annual average concentration during the 8 hours that the facility operates multiplied time 5/7 can be used if the facility does not operate during the weekend. The 8-hour RELs can be used to assess noncancer chronic risks for facilities that emit up to 12 hours a day. If the facility emits more than 12 hours a day, the chronic REL should be used with the 24 hour annual average air concentration.~~

- ~~Adjustment Factor for Continuously Emitting Source~~

~~For a continuously emitting source (i.e., facility operating 24 hours a day, 7 days a week), no adjustment factor is used with this scenario to estimate the concentration the offsite worker is exposed to for either cancer risks or chronic noncancer risks (including use of the 8-hour RELs for workers) . The annual average air concentration from the modeling output should be used for estimating both cancer and non-cancer impacts.~~

- ~~Adjustment Factor for a Non-Continuously Emitting Source when using 8-hour RELs~~

~~For a non-continuously emitting source where the impacted offsite worker has an overlapping schedule (i.e., emitting facility is operating during part or all of shift for the impacted offsite worker), the annual average concentration from the modeling output should be multiplied by a factor of 3, or 24 hours/8 hours. An additional factor of 5/7 should be used to account for the absence of the workers on the weekend. This will result in an approximation of the long term 8-hour exposure of a coincident schedule between the emitting facility and an offsite work shift lasting 8 hours. If the offsite workers are only present during part of the time that the facility is operating, the air concentration for the eight hours that the worker is present can be adjusted downward. For example, if offsite workers and the facility emissions only overlap for 4 hours then the air concentration during the four hours could be divided by 2 to give an average 8-hour concentration.~~

~~For estimating cancer risks, If the facility only operates 5 days a week, then (in addition to the factor of 3 (24 hours/8 hours), a factor of 7 days/5 days, or 1.4, should also be multiplied times the annual average. Typically, the total adjustment factor applied to the modeled annual average air concentration will be 4.2. This 4.2 approximation factor was evaluated with the AERMOD model to determine how it compares with 8-hour concentrations from actual meteorological data. Based on the evaluation, the 4.2 approximation factor is suitable for most cases. However, in the event of predominant night time emissions and worker schedule or if only one year of meteorological data are available, then we recommend using a 4.8 approximation factor for 8-hour work shifts. See Appendix N for a discussion of the 4.2 approximation factor sensitivity analysis.~~

~~For carcinogenic calculations, the 4.2 approximation factor can be adjusted to account for partial overlap of the workers schedule and the schedule of the emitting facility. For example, if the worker is always only present for four of the eight hours that a facility is emitting, then a factor of 0.5 (4 hours/8 hours) could be multiplied against the 4.2 factor, yielding an adjustment factor of 2.1. The reason these worker-related adjustments can be applied is because cancer risk is assumed proportional to lifetime average daily dose. See the OEHHA~~

~~Guidelines Document for more detailed discussions related to calculating potential carcinogenic impacts.~~

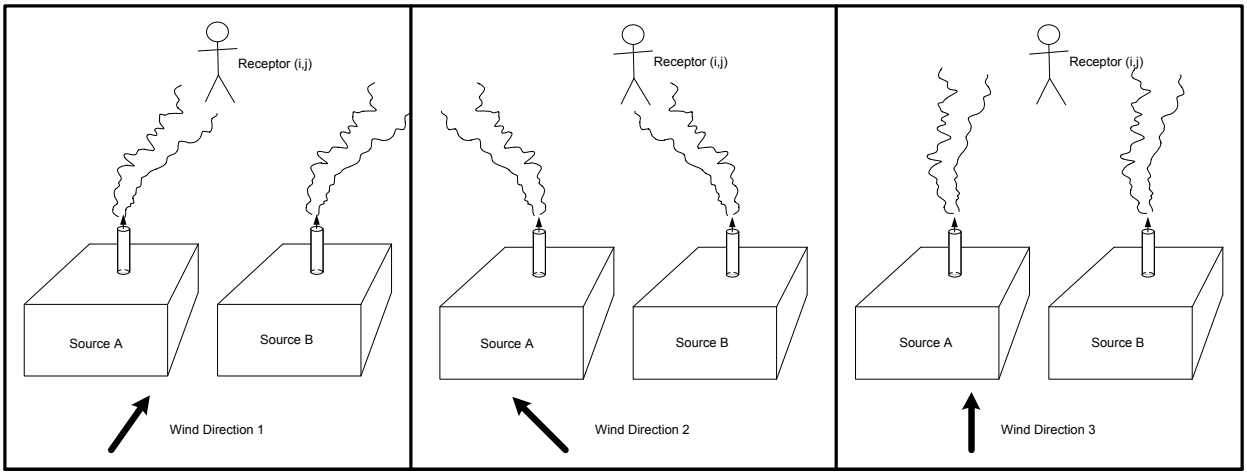
2.8.2 Modeling One-Hour Concentrations using Simple and Refined Acute Calculations

Modeled one-hour concentrations are needed for the acute health hazard index calculations. HARP has two methods to calculate this concentration; Simple and Refined. As an aid to understanding the differences between Simple and Refined, Figure 3 shows three possible conditions showing how wind direction may vary and impact a downwind receptor (i,j) differently from just two sources (A and B).

For the Simple calculation, HARP stores only the maximum one-hour concentration at each receptor (i,j) from each source (A and B) as the dispersion model marches down each hour of the simulation (e.g., one to five years of hourly data). At the end of the simulation period, HARP reports back only the maximum impacts at each receptor from each source regardless of which hour of the simulation period this occurred. For example, the Simple Maximum Acute Impacts would be the summation of Source A impacts from Wind Direction 1 and Source B impacts from Wind Direction 2 as shown in Figure 3.

For the Refined simulation, HARP stores each hourly concentration at each receptor (i,j) from each source. At the end of the simulation period, HARP evaluates the coincident impact at each receptor from all sources for each hour of the simulation period. In this case the maximum impacts will be identified by a particular hour of the period with associated wind speed, direction, and atmospheric conditions. For example, the Refined Maximum Acute impact from Sources A and B on receptor (i,j) could be from any wind direction (1,2, or 3) as shown in Figure 3. As HARP stores all simulations for all sources – at all receptors – for all hours to calculate the refined impacts, there is great potential to fill large amounts of disk storage space. However the Refined simulation provides a more representative picture of the Maximum acute hazard index from a facility. The Simple calculation will provide an upper bound to the acute hazard index.

Figure 3 – Acute Scenarios



The following sections, taken mostly from the document "On-Site Meteorological Program Guidance for Regulatory Modeling Applications" (U.S. EPA, 1995e), provide general information on data formats and representativeness. Some Districts may have slightly different recommendations from those given here.

2.8.3 Meteorological Data Formats

Most short-term dispersion models require input of hourly meteorological data in a format which depends on the model. U.S. EPA provides software for processing meteorological data for use in U.S. EPA recommended dispersion models. U.S. EPA recommended meteorological processors include the Meteorological Processor for Regulatory Models (MPRM), PCRAMMET, and AERMET. Use of these processors will ensure that the meteorological data used in an U.S. EPA recommended dispersion model will be processed in a manner consistent with the requirements of the model.

Meteorological data for a subset of NWS stations are available on the World Wide Web at the U.S. EPA SCRAM address, http://www.epa.gov/scram001.

2.8.4 Treatment of Calms

~~Calms are normally considered to be wind speeds below the starting threshold of the anemometer or vane (whichever is greater).~~ Calms are hours when the wind speed is below the starting threshold of the anemometer. Gaussian plume models require a wind speed and direction to estimate plume dispersion in the downwind direction. U.S. EPA's policy is to disregard calms until such time as an appropriate analytical approach is available. The recommended U.S. EPA models contain a routine that eliminates the effect of the calms by nullifying concentrations during calm hours and recalculating short-term and annual average concentrations. Certain models lacking this built-in feature can have their output processed by U.S. EPA's CALMPRO program (U.S. EPA, 1984a) to achieve the same effect. Because the adjustments to the concentrations for calms are made by either the models or the postprocessor, actual

measured on-site wind speeds should always be input to the preprocessor. These actual wind speeds should then be adjusted as appropriate under the current U.S. EPA guidance by the preprocessor.

Following the U.S. EPA methodology, measured on-site wind speeds of less than l.0 m/s, but above the instrument threshold, should be set equal to l.0 m/s by the preprocessor when used as input to Gaussian models. Calms are identified in the preprocessed data file by a wind speed of 1.0 m/s and a wind direction equal to the previous hour. For input to AERMOD, no adjustment should be made to the site specific wind data. AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s but still greater than the instrument threshold. Some air districts provide pre-processed meteorological data for use in their district that treats calms differently. Local air districts should be consulted for available meteorological data.

If the fraction of calm hours is excessive, then an alternative approach may need to be considered to characterize dispersion. The Calpuff model modeling system can simulate calm winds as well as complex wind flow and therefore is a viable alternative. The local air district should be consulted for alternative approaches.

2.8.5 Treatment of Missing Data

Missing data refer to those hours for which no meteorological data are available from the primary on-site source for the variable in question. When missing values arise, they should be handled in one of the following ways listed below, in the following order of preference:

(1) If there are other on-site data, such as measurements at another height, they may be used when the primary data are missing. If the height differences are significant, corrections based on established vertical profiles should be made. Site-specific vertical profiles based on historical on-site data may also be appropriate to use if their determination is approved by the reviewing authority. If there is question as to the representativeness of the other on-site data, they should not be used.

(2) If there are only one or two missing hours, then linear interpolation of missing data may be acceptable, however, caution should be used when the missing hour(s) occur(s) during day/night transition periods.

(3) If representative off-site data exist, they may be used. In many cases this approach may be acceptable for cloud cover, ceiling height, mixing height, and temperature. This approach will rarely be acceptable for wind speed and direction. The representativeness of off-site data should be discussed and agreed upon in advance with the reviewing authority.

(4) Failing any of the above, the data field should be coded as missing using missing data codes appropriate to the applicable meteorological pre-processor.

Appropriate model options for treating missing data, if available in the model, should be employed. Substitutions for missing data should only be made in order to complete the data set for modeling applications, and should not be used to attain the "regulatory completeness" requirement of 90%. That is, the meteorological data base must be 90% complete on a monthly basis (before substitution) in order to be acceptable for use in air dispersion modeling.

2.8.6 Representativeness of Meteorological Data

The atmospheric dispersion characteristics at an emission source need to be evaluated to determine if the collected meteorological data can be used to adequately represent atmospheric dispersion for the project.

Such determinations are required when the available meteorological data are acquired at a location other than that of the proposed source. In some instances, even though meteorological data are acquired at the location of the pollutant source, they still may not correctly characterize the important atmospheric dispersion conditions.

Considerations of representativeness are always made in atmospheric dispersion modeling whether the data base is "on-site" or "off-site." These considerations call for the judgment of a meteorologist or an equivalent professional with expertise in atmospheric dispersion modeling. If in doubt, the District should be consulted.

2.8.6.1 Spatial Dependence

The location where the meteorological data are acquired should be compared to the source location for similarity of terrain features. For example, in complex terrain, the following considerations should be addressed in consultation with the District:

- Aspect ratio of terrain, i.e., ratio of:
  - Height of valley walls to width of valley;
  - Height of ridge to length of ridge; and
  - Height of isolated hill to width of hill at base.
- Slope of terrain
- Ratio of terrain height to stack/plume height.
- Distance of source from terrain (i.e., how close to valley wall, ridge, isolated hill)
- Correlation of terrain feature to prevailing meteorological conditions

Likewise, if the source is located on a plateau or plain, the source of meteorological data used should be from a similar plateau or plain.

Judgments of representativeness should be made only when sites are climatologically similar. Sites in nearby, but different air sheds, often exhibit different weather patterns.

For instance, meteorological data acquired along a shoreline are not normally representative of inland sites and vice versa.

Meteorological data collected need to be examined to determine if drainage, transition, and synoptic flow patterns are characteristics of the source, especially those critical to the regulatory application. Consideration of orientation, temperature, and ground cover should be included in the review.

An important aspect of space dependence is height above the ground. Where practical, meteorological data should be acquired at the release height, as well as above or below, depending on the buoyancy of the source's emissions. AERMOD at a minimum requires wind observations at a height above ground between seven times the local surface roughness height and 100 meters.

2.8.6.2 Temporal Dependence

To be representative, meteorological data must be of sufficient duration to define the range of sequential atmospheric conditions anticipated at a site. As a minimum, one full year of on-site meteorological data is necessary to prescribe this time series. Multiple years of data are used to describe variations in annual and short-term impacts. Consecutive years from the most recent, readily available 5-year period are preferred to represent these yearly variations.

2.8.6.3 Further Considerations

It may be necessary to recognize the non-homogeneity of meteorological variables in the air mass in which pollutants disperse. This non-homogeneity may be essential in correctly describing the dispersion phenomena. Therefore, measurements of meteorological variables at multiple locations and heights may be required to correctly represent these meteorological fields. Such measurements are generally required in complex terrain or near large land-water body interfaces.

It is important to recognize that, although certain meteorological variables may be considered unrepresentative of another site (for instance, wind direction or wind speed), other variables may be representative (such as temperature, dew point, cloud cover). Exclusion of one variable does not necessarily exclude all. For instance, one can argue that weather observations made at different locations are likely to be similar if the observers at each location are within sight of one another - a stronger argument can be made for some types of observations (e.g., cloud cover) than others. Although by no means a sufficient condition, the fact that two observers can “see” one another supports a conclusion that they would observe similar weather conditions.

Other factors affecting representativeness include change in surface roughness, topography and atmospheric stability. Currently there are no established analytical or statistical techniques to determine representativeness of meteorological data. The

establishment and maintenance of an on-site data collection program generally fulfills the requirement for "representative" data. If in doubt, the District should be consulted.

2.8.7~~6~~ Alternative Meteorological Data Sources

It is necessary, in the consideration of most air pollution problems, to obtain data on site-specific atmospheric dispersion. Frequently, an on-site measurement program must be initiated. As discussed in Section 2.8.5, representative off-site data may be used to substitute for missing periods of on-site data. There are also situations where current or past meteorological records from a National Weather Service station may suffice. These considerations call for the judgment of a meteorologist or an equivalent professional with expertise in atmospheric dispersion modeling. More information on Weather Stations including: National Weather Service (NWS), military observations, supplementary airways reporting stations, upper air and private networks, is provided in "On-Site Meteorological Program Guidance for Regulatory Modeling Applications" (U.S. EPA, 1995e).

2.8.7~~6~~.1 Recommendations

On-site meteorological data should be processed to provide input data in a format consistent with the particular models being used. The input format for U.S. EPA short-term regulatory models is defined in U.S. EPA's MPRM. The input format for AERMOD is defined in the AERMET meteorological pre-processor. Processors are available on the SCRAM web site. The actual wind speeds should be coded on the original input data set. Wind speeds less than 1.0 m/s but above the instrument threshold should be set equal to 1.0 m/s by the preprocessor when used as input to Gaussian models. Wind speeds below the instrument threshold of the cup or vane, whichever is greater, should be considered calm, and are identified in the preprocessed data file by a wind speed of 1.0 m/s and a wind direction equal to the previous hour. For input to AERMOD, no adjustment should be made to the site specific wind data. AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s but still greater than the instrument threshold.

If data are missing from the primary source, they should be handled as follows, in order of preference: (I) substitution of other representative on-site data; (2) linear interpolation of one or two missing hours; (3) substitution of representative off-site data; or (4) coding as a missing data field, according to the discussions in Section 2.8.5.

If the data processing recommendations in this section cannot be achieved, then alternative approaches should be developed in conjunction with the District.

2.8.8~~6~~ Quality Assurance and Control

The purpose of quality assurance and maintenance is the generation of a representative amount (90% of hourly values for a year on a monthly basis) of valid data. For more information on data validation consult reference U.S. EPA (1995e). Maintenance may

be considered the physical activity necessary to keep the measurement system operating as it should. Quality assurance is the management effort to achieve the goal of valid data through plans of action and documentation of compliance with the plans.

Quality assurance (QA) will be most effective when following a QA Plan which has been signed-off by appropriate project or organizational authority. The QA Plan should contain the following information (paraphrased and particularized to meteorology from Lockhart):

1. Project description - how meteorology data are to be used
2. Project organization - how data validity is supported
3. QA objective - how QA will document validity claims
4. Calibration method and frequency - for data
5. Data flow - from samples to archived valid values
6. Validation and reporting methods - for data
7. Audits - performance and system
8. Preventive maintenance
9. Procedures to implement QA objectives - details
10. Management support - corrective action and reports

It is important for the person providing the quality assurance (QA) function to be independent of the organization responsible for the collection of the data and the maintenance of the measurement systems. Ideally, the QA auditor works for a separate company.

2.9 Model Selection

There are several air dispersion models that can be used to estimate pollutant concentrations and new ones are likely to be developed. U.S. EPA added AERMOD, which incorporates the PRIME downwash algorithm, to the list of preferred models in 2005 as a replacement to ISCST3. CalPuff was added in 2003. The latest version of the U.S. EPA recommended models can be found at the SCRAM Bulletin board located at http://www.epa.gov/scram001. However, any model, whether a U.S. EPA guideline model or otherwise, must be approved for use by the local air district. Recommended models and guidelines for using alternative models are presented in this section. All air dispersion models used to estimate pollutant concentrations for risk assessment analyses must be in the public domain. Classification according to terrain, source type and level of analysis is necessary before selecting a model (see Section 2.4). The selection of averaging times in the modeling analysis is based on the health effects of concern. Annual average concentrations are required for an analysis of carcinogenic or other chronic effects. One-hour maximum concentrations are generally required for analysis of acute effects.

2.9.1 Recommended Models

Recommended air dispersion models to estimate concentrations for risk assessment analyses are generally referenced in US EPA's Guideline on Air Quality Models available at http://www.epa.gov/scram001. Currently AERMOD is recommended for most refined risk assessments in flat or complex terrain and in rural or urban environments[3]. In addition, CalPuff is available where spatial wind fields are highly variable or transport distances are large (e.g., 50 km). AERSCREEN is a screening model based on AERMOD. AERSCREEN can be used when representative meteorological data are unavailable. CTSCREEN is available for screening risk assessments in complex terrain. The most current version of the models should be used for risk assessment analysis. Some facilities may also require models capable of special circumstances such as dispersion near coastal areas. For more information on modeling special cases see Sections 2.12 and 2.13.

Most air dispersion models contain provisions that allow the user to select among alternative algorithms to calculate pollutant concentrations. Only some of these algorithms are approved for regulatory application such as the preparation of health risk assessments. The sections in this guideline that provide a description of each recommended model contain information on the specific switches and/or algorithms that must be selected for regulatory application.

To further facilitate the model selection, the District should be consulted for additional recommendations on the appropriate model(s) or a protocol submitted for District review and approval (see Section 2.14.1).

2.9.2 Alternative Models

Alternative models are acceptable if applicability is demonstrated or if they produce results identical or superior to those obtained using one of the preferred models referenced in Section 2.9.1. For more information on the applicability of alternative models refer to the following documents:

- U.S. EPA (2005). "Guideline on Air Quality Models" Section 3.2.2
- U.S. EPA (1992). "Protocol for Determining the Best Performing Model"
- U.S. EPA (1985a). "Interim Procedures for Evaluating Air Quality Models – Experience with Implementation"
- U.S. EPA (1984b). "Interim Procedures for Evaluating Air Quality Models (Revised)"

2.10 Screening Air Dispersion Models

A screening model may be used to provide a maximum concentration that is biased toward overestimation of public exposure. Use of screening models in place of refined modeling procedures is optional unless the District specifically requires the use of a refined model. Screening models are normally used when no representative

[3] AERMOD was promulgated by U.S. EPA as a replacement to ISCST3 on November 9, 2006.

meteorological data are available and may be used as a preliminary estimate to determine if a more detailed assessment is warranted.

Some screening models provide only 1-hour average concentration estimates. Other averaging periods can be estimated based on the maximum 1-hour average concentration in consultation and approval of the responsible air district. Because of variations in local meteorology, the exact factor selected may vary from one district to another. Table 2.2 provides guidance on the range and typical values applied. The conversion factors are designed to bias predicted longer term averaging periods towards overestimation.

Table 2.2. Recommended Factors to Convert Maximum 1-hour Avg. Concentrations to Other Averaging Periods (U.S. EPA, 2011, 1995a; ARB, 1994).

Averaging Time	Range	Typical SCREEN3 Recommended	AERSCREEN Recommended
3 hours	0.8 - 1.0	0.9	1.0
8 hours	0.5 - 0.9	0.7	0.9
24 hours	0.2 - 0.6	0.4	0.6
30 days	0.2 - 0.3	0.3	
Annual	0.06 - 0.1	0.08	0.1

AERSCREEN automatically provides the converted concentration for longer than 1-hour averaging periods. For area sources, the AERSCREEN 3, 8, and 24-hour average concentration are equal to the 1-hour concentration. No annual average concentration is calculated. SCREEN3 values are shown for comparison purposes.

2.10.1 AERSCREEN

The AERSCREEN (U.S. EPA, 2011) model is now available and should be used in lieu of SCREEN3 with approval of the local District. AERSCREEN is a screening level air quality model based on AERMOD. AERSCREEN does not require the gathering of hourly meteorological data. Rather, AERSCREEN requires the use of the MAKEMET program which generates a site specific matrix of meteorological conditions for input to the AERMOD model. MAKEMET generates a matrix of meteorological conditions based on local surface characteristics, ambient temperatures, minimum wind speed, and anemometer height.

AERSCREEN is currently limited to modeling a single point, capped stack, horizontal stack, rectangular area, circular area, flare, or volume source. More than one source may be modeled by consolidating the emissions into one emission source.

2.10.2 Valley Screening

The Valley model is designed to simulate a specific worst-case condition in complex terrain, namely that of a plume impaction on terrain under stable atmospheric conditions. The algorithms of the VALLEY model are included in other models such as SCREEN3 and their use is recommended in place of the VALLEY model. The usefulness of the VALLEY model and its algorithms is limited to pollutants for which only long-term average concentrations are required. For more information on the Valley model consult the user's guide (Burt, 1977).

Regulatory Options

Regulatory application of the Valley model requires the setting of the following values during a model run:

- Class F Stability (rural) and Class E Stability (urban)
- Wind Speed = 2.5 m/s
- 6 hours of occurrence of a single wind direction (not exceeding a 22.5 deg sector)
- 2.6 stable plume rise factor

2.10.3 CTSCREEN

The CTSCREEN model (Perry et al., 1990) is the screening mode of the Complex Terrain Dispersion Model (CTDMPLUS). CTSCREEN can be used to model single point sources only. It may be used in a screening mode for multiple sources on a case by case basis in consultation with the District. CTSCREEN is designed to provide conservative, yet theoretically more sound, worst-case 1-hour concentration estimates for receptors located on terrain above stack height. Internally-coded time-scaling factors are applied to obtain other averages (see Table 2.3). These factors were developed by comparing the results of simulations between CTSCREEN and CTDMPLUS for a variety of scenarios and provide conservative estimates (Perry et al., 1990). CTSCREEN produces identical results as CTDMPLUS if the same meteorology is used in both models. CTSCREEN accounts for the three-dimensional nature of the plume and terrain interaction and requires detailed terrain data representative of the modeling domain. A summary of the input parameters required to run CTSCREEN is given in Table 2.4. The input parameters are provided in three separate text files. The terrain topography file (TERRAIN) and the receptor information file (RECEPTOR) may be generated with a preprocessor that is included in the CTSCREEN package. In order to generate the terrain topography file the analyst must have digitized contour information.

Table 2.3. Time-scaling factors internally coded in CTSCREEN

Averaging Period	Scaling Factor
3 hours	0.7
24 hour	0.15
Annual	0.03

Table 2.4. Input Parameters Required to Run CTSCREEN

Parameter	File
Miscellaneous program switches	CTDM.IN
Site latitude and longitude (degrees)	CTDM.IN
Site TIME ZONE	CTDM.IN
Meteorology Tower Coordinates (user units)	CTDM.IN
Source Coordinates: x and y (user units)	CTDM.IN
Source Base Elevation (user units)	CTDM.IN
Stack Height (m)	CTDM.IN
Stack Diameter (m)	CTDM.IN
Stack Gas Temperature (K)	CTDM.IN
Stack Gas Exit Velocity (m/s)	CTDM.IN
Emission Rate (g/s)	CTDM.IN
Surface Roughness for each Hill (m)	CTDM.IN
Meteorology: Wind Direction (optional)	CTDM.IN
Terrain Topography	TERRAIN
Receptor Information (coordinates and associated hill number)	RECEPTOR

2.11 Refined Air Dispersion Models

Refined air dispersion models are designed to provide more representative concentration estimates than screening models. In general, the algorithms of refined models are more robust and have the capability to account for site-specific meteorological conditions.

2.11.1 AERMOD

For a wide variety of applications in all types of terrain, the recommended model is AERMOD. AERMOD is a steady-state plume dispersion model for assessment of pollutant concentrations from a variety of sources. AERMOD simulates transport and dispersion from multiple point, area, or volume sources based on an up-to-date characterization of the atmospheric boundary layer. Sources may be located in rural or urban areas and receptors may be located in simple or complex terrain. AERMOD accounts for building wake effects (i.e., plume downwash) based on the PRIME building downwash algorithms. The model employs hourly sequential preprocessed meteorological data to estimate concentrations for averaging times from one hour to one year (also multiple years). AERMOD is designed to operate in concert with two pre-processor codes: AERMET processes meteorological data for input to AERMOD, and AERMAP processes terrain elevation data and generates receptor information for input to AERMOD. Guidance on input requirements may be found in the AERMOD Users Guide.

2.11.1.1 Regulatory Options

U.S. EPA regulatory ~~Regulatory~~ application of AERMOD requires the selection of specific switches (i.e., algorithms) during a model run. All the regulatory options can be set by selecting the DFAULT keyword. The U.S. EPA regulatory options, automatically selected when the DFAULT keyword is used, are:

- Stack-tip downwash
- Incorporates the effects of elevated terrain
- Includes calms and missing data processing routines
- Does not allow for exponential decay for applications other than a 4-hour half life for SO_2

Additional information on these options is available in the AERMOD User's Guide.

2.11.1.2 Special Cases

a. Building Downwash

AERMOD automatically determines if the plume is affected by the wake region of buildings when their dimensions are given. The specification of building dimensions does not necessarily mean that there will be downwash. See section 2.12.1 for guidance on how to determine when downwash is likely to occur.

b. Area Sources

The area source algorithm in AERMOD does not account for the area that is 1 m upwind from the receptor and, therefore, caution should be exercised when modeling very small area sources (e.g., a few meters wide) with receptors placed within them or within 1 m from the downwind boundary.

c. Volume Sources

The volume source algorithms in AERMOD require an estimate of the initial distribution of the emission source. Tables that provide information on how to estimate the initial distribution for different sources are given in the AERMOD User's Guide (U.S. EPA, 2004a).

d. Line Sources

Line sources are a special case of a series of volume or area sources. Where the emission source is neutrally buoyant, such as a conveyor belt, AERMOD can be used according to the user guide. In the event that the line source is a roadway, then additional considerations are required.

At the present time, CALINE (CALINE3, CAL3QHCR, and CALINE4) is the only model dedicated to modeling the enhanced mechanical and thermal turbulence created by motor vehicles traveling on a roadway. Of these, CAL3QHCR is the only model that accepts hourly meteorological data and can estimate annual average concentrations. However, CALINE uses the Pasquill-Gifford stability categories which are used in the ISCST model. AERMOD is now the preferred plume model over ISCST3 with continuous plume dispersion calculations based on observations but AERMOD does not include the enhanced roadway turbulence. ~~Therefore, roadway modeling should be treated on a case-by-case basis in accordance with the District.~~

In the case where roadway emissions dominate the risk assessment, it may be most important to simulate the enhanced thermal and mechanical turbulence from motor vehicles with the CAL3QHCR model. In the case where roadway emissions are a subset of all emissions for the risk assessment, in the case of including roadway emissions along with facility emissions, it may be best to use AERMOD for all emissions, roadway and facility, in order to maintain continuity with one dispersion model for the risk assessment. Most importantly, roadway modeling should be treated on a case-by-case basis in consultation with the District.

Line sources inputs include a composite fleetwide emission factor, roadway geometry, hourly vehicle activity (i.e., diurnal vehicle per hour pattern), hourly meteorological data, and receptor placement. For practical information on how to simulate roadway emissions using these models, see CAPCOA's website at http://www.capcoa.org or the Sacramento Metropolitan AQMD (SMAQMD) website at http://www.airquality.org/ceqa/RoadwayProtocol.shtml. The SMAQMD has a document titled, "Recommended Protocol for Evaluating the Location of Sensitive Land Uses Adjacent to Major Roadways"(January , 2010).

e. Complex Terrain

AERMOD uses the Dividing Streamline (H_c) concept for complex terrain. Above H_c, the plume is assumed to be "terrain following" in the convective boundary layer. Below H_c, the plume is assumed to be "terrain impacting" in the stable boundary layer. AERMOD computes the concentration at any receptor as a weighted function between the two plume states (U.S. EPA, 2004b)

f. Deposition

AERMOD contains algorithms to model settling and deposition and require additional information to do so including particle size distribution. For more information consult the AERMOD User's Guide (U.S. EPA, 2004a).

g. Diurnal Considerations

Systematic diurnal changes in atmospheric conditions are expected along the coast (or any large body of water) or in substantially hilly terrain. The wind speed and direction are highly dependent on time of day as the sun rises and begins to heat the Earth. The sun heats the surface of the land faster than the water surface. Therefore the air above the land warms up sooner than over water. This creates a buoyant effect of warm air rising over land and the cool air from over water moves in to fill the void. Near large bodies of water (e.g., the ocean) this is known as a sea breeze. In complex terrain this is known as upslope flow as the hot air follows the terrain upwards. When the sun sets and the surface of the land begins to cool, the air above also cools and creates a draining effect. Near the water this is the land breeze; in complex terrain this is known as downslope or drainage flow. In addition, for the sea breeze, the atmospheric conditions change rapidly from neutral or stable conditions over water to unstable conditions over land.

Near the large bodies of water the sea breeze is typical in the afternoon and the land breeze is typical for the early morning before sunrise. In complex terrain upslope flow is typical in the afternoon, while drainage flow is typical at night. For these reasons, it is especially important to simulate facility emissions with a hourly diurnal pattern reflective of source activity so that the risk assessment is representative of daily conditions.

h. 8-hour Modeling for the Offsite Worker's Exposure and Residential Exposure

If the ground level air concentrations from a facility operation 5 days a week/ 8 hours per day have been estimated by a 24 hour per day annual average, an adjustment factor can be applied to estimate the air concentration that offsite worker with the same schedule would be exposed to. The 24 hour annual average concentration is multiplied times 4.2.

If the meteorology during the time that the facility is emitting is used, hourly model simulations need to be post-processed to cull out the data needed for the offsite worker exposure. See Appendix M for information on how to calculate the refined offsite worker concentrations using the hourly raw results from the AERMOD air dispersion model. For more discussion on worker exposure, see Section 2.8.1.

2.11.5 CTDMPLUS

CTDMPLUS is a Gaussian air quality model for use in all stability conditions in complex terrain. In comparison with other models, CTDMPLUS requires considerably more detailed meteorological data and terrain information that must be supplied using specifically designed preprocessors.

CTDMPLUS was designed to handle up to 40 point sources.

2.12 Modeling Special Cases

Special situations arise in modeling some sources that require considerable professional judgment; a few of which are outlined below. It is recommended that the reader consider retaining professional consultation services if the procedures are unfamiliar.

2.12.1 Building Downwash

The entrainment of a plume in the wake of a building can result in the “downwash” of the plume to the ground. This effect can increase the maximum ground-level concentration downwind of the source. Therefore, stack sources must be evaluated to determine whether building downwash is a factor in the calculation of maximum ground-level concentrations.

The PRIME algorithm, included with AERMOD, has several advances in modeling building downwash effects including enhanced dispersion in the wake, reduced plume rise due to streamline deflection and increased turbulence, and continuous treatment of the near and far wakes (Schulman, 2000).

Complicated situations involving more than one building may necessitate the use of the Building Profile Input Program (BPIP) which can be used to generate the building dimension section of the input file of the ISC models (U.S. EPA, 1993). The BPIP program calculates each building’s direction-specific projected width. The Building Profile Input Program for PRIME (BPIPPRM) is the same as BPIP but includes an algorithm for calculating downwash values for input into the PRIME algorithm which is contained in such models as AERMOD. The input structure of BPIPPRM is the same as that of BPIP.

2.12.2 Deposition

There are two types of deposition; wet deposition and dry deposition. Wet deposition is the incorporation of gases and particles into rain-, fog- or cloud water followed by a precipitation event and also rain scavenging of particles during a precipitation event. Wet deposition of gases is therefore more important for water soluble chemicals; particles (and hence particle-phase chemicals) are efficiently removed by precipitation events (Bidleman, 1988). Dry deposition refers to the removal of gases and particles from the atmosphere.

In the Air Toxics "Hot Spots" program, deposition is quantified for particle-bound pollutants and not gases. Wet deposition of water-soluble gas phase chemicals is thus not considered. When calculating pollutant mass deposited to surfaces without including depletion of pollutant mass from the plume airborne concentrations remaining in the plume and deposition to surfaces can be overestimated, thereby resulting in overestimates of both the inhalation and multi-pathway risk estimates. However, neglecting deposition in the air dispersion model, while accounting for it in the multi-pathway health risk assessment, is a conservative, health protective approach (CAPCOA, 1987; Croes, 1988). Misapplication of plume depletion can also lead to possible underestimates of multi-pathway risk and for that reason no depletion is the default assumption. If plume depletion is incorporated, then some consideration for possible resuspension is warranted. An alternative modeling methodology accounting for plume depletion can be discussed with the Air District and used in an approved modeling protocol.

Although not generally used, several ~~Several~~ air dispersion models can provide downwind concentration estimates that take into account the upwind deposition of pollutants to surfaces and the consequential reduction of mass remaining in the plume ~~(e.g., ISCST3)~~. ~~Deposition algorithms are unavailable in the initial release of AERMOD. U.S. EPA is developing deposition algorithms for AERMOD. Check with U.S. EPA for availability.~~ Air dispersion models having deposition and plume depletion algorithms require particle distribution data that are not always readily available. These variables include particle size, mass fraction, and density for input to AERMOD. In addition, the meteorological fields need to include additional parameters including relative humidity, precipitation, cloud cover, and surface preasure. Consequently, depletion of pollutant mass from the plume often is not taken into account.

~~There are two types of deposition; wet deposition and dry deposition. Wet deposition is the incorporation of gases and particles into rain-, fog- or cloud water followed by a precipitation event and also rain scavenging of particles during a precipitation event. Wet deposition of gases is therefore more important for water soluble chemicals; particles (and hence particle-phase chemicals) are efficiently removed by precipitation events (Bidleman, 1988). Dry deposition refers to the removal of gases and particles from the atmosphere.~~

In conclusion, multipathway ~~Multipathway~~ risk assessment analyses normally incorporate deposition to surfaces in a screening mode, specifically by assigning a

default deposition velocity of 2 cm/s for controlled sources and 5 cm/s for uncontrolled sources in lieu of actual measured size distributions (ARB, 1989). For particles (and particle-phase chemicals), the deposition velocity depends on particle size and is minimal for particles of diameter approximately 0.1-1 micrometer; smaller and larger particles are removed more rapidly.

~~In the Air Toxics "Hot Spots" program, deposition is modeled for particle-bound pollutants and not gases. Wet deposition of water-soluble gas phase chemicals is thus not considered. When calculating pollutant mass deposited to surfaces without including depletion of pollutant mass from the plume, an inconsistency occurs in the way deposition is treated in the risk analysis, specifically, airborne concentrations remaining in the plume and deposition to surfaces can both be overestimated, thereby resulting in overestimates of both the inhalation and multi-pathway risk estimates. However, neglecting deposition in the air dispersion model, while accounting for it in the multi-pathway health risk assessment, is a conservative, health protective approach (CAPCOA, 1987; Croes, 1988). Misapplication of plume depletion can also lead to possible underestimates of multi-pathway risk and for that reason no depletion is the default assumption. If plume depletion is incorporated, then some consideration for possible resuspension is warranted. An alternative modeling methodology accounting for plume depletion can be discussed with the Air District and used in an approved modeling protocol.~~

2.12.3 Short Duration Emissions

Short-duration emissions (i.e., much less than an hour) require special consideration. In general, "puff models" provide a better characterization of the dispersion of pollutants having short-duration emissions. Continuous Gaussian plume models have traditionally been used for averaging periods as short as about 10 minutes and are not recommended for modeling sources having shorter continuous emission duration.

2.12.4 Fumigation

Fumigation occurs when a plume that was originally emitted into a stable layer in the atmosphere is mixed rapidly to ground-level when unstable air below the plume reaches plume level. Fumigation can cause very high ground-level concentrations. Typical situations in which fumigation occurs are:

- Breaking up of a nocturnal radiation inversion by solar warming of the ground surface (rising warm unstable air); note that the break-up of a nocturnal radiation inversion is a short-lived event and should be modeled accordingly.

- Shoreline fumigation caused by advection of pollutants from a stable marine environment to an unstable inland environment

- Advection of pollutants from a stable rural environment to a turbulent urban environment

SCREEN3 incorporates concentrations due to inversion break-up and shoreline fumigation and is limited to maximum hourly evaluations. The Offshore and Coastal Dispersion Model incorporates overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline – hourly meteorological data are needed from both offshore and onshore locations.

2.12.5 Raincap on Stack

The presence of a raincap or any obstacle at the top of the stack hinders the momentum of the exiting gas. The extent of the effect is a function of the distance from the stack exit to the obstruction and of the dimensions and shape of the obstruction.

On the conservative side, the stack could be modeled as having a non-zero, but negligible exiting velocity, effectively eliminating any momentum rise. Such an approach would result in final plume heights closer to the ground and therefore higher concentrations nearby. There are situations where such a procedure might lower the actual population-dose and a comparison with and without reduced exit velocity should be examined.

Plume buoyancy is not strongly reduced by the occurrence of a raincap. Therefore, if the plume rise is dominated by buoyancy, it is not necessary to adjust the stack conditions. (The air dispersion models determine plume rise by either buoyancy or momentum, whichever is greater.)

The stack conditions should be modified when the plume rise is dominated by momentum and in the presence of a raincap or a horizontal stack. Sensitivity studies with the SCREEN3 model, on a case-by-case basis, can be used to determine whether plume rise is dominated by buoyancy or momentum. The District should be consulted before applying these procedures.

- Set exit velocity to 0.001 m/sec
- Turn stack tip downwash off
- Reduce stack height by 3 times the stack diameter

Stack tip downwash is a function of stack diameter, exit velocity, and wind speed. The maximum stack tip downwash is limited to three times the stack diameter in the AERMOD air dispersion model. In the event of a horizontal stack, stack tip downwash should be turned off and no stack height adjustments should be made.

Note: This approach may not be valid for large (several meter) diameter stacks.

An alternative, more refined, approach could be considered for stack gas temperatures which are slightly above ambient (e.g., ten to twenty degrees Fahrenheit above

ambient). In this approach, the buoyancy and the volume of the plume remains constant and the momentum is minimized.

- Turn stack tip downwash off
- Reduce stack height by 3 times the stack diameter ($3D_o$)
- Set the stack diameter (D_b) to a large value (e.g., 10 meters)
- Set the stack velocity to $V_b = V_o (D_o/D_b)^2$

Where V_o and D_o are the original stack velocity and diameter and V_b and D_b are the alternative stack velocity and diameter for constant buoyancy. This approach is advantageous when $D_b >> D_o$ and $V_b << V_o$ and should only be used with District approval.

In the presence of building downwash and in the event that PRIME downwash is being utilized in AERMOD, an alternative approach is recommended. PRIME algorithms use the stack diameter to define initial plume radius and to solve conservation laws. The user should input the actual stack diameter and exit temperature but set the exit velocity to a nominally low value (e.g., 0.001 m/s). Also since PRIME does not explicitly consider stack-tip downwash, no adjustments to stack height should be made.

Currently US-EPA is BETA testing options for capped and horizontal releases in AERMOD. It is expected that these options will replace the above guidance when BETA testing is complete.

2.12.6 Landfill Sites

Landfills should be modeled as area sources. The possibility of non-uniform emission rates throughout the landfill area should be investigated. A potential cause of non-uniform emission rates would be the existence of cracks or fissures in the landfill cap (where emissions may be much larger). If non-uniform emissions exist, the landfill should be modeled with several smaller areas assigning an appropriate emission factor to each one of them, especially if there are nearby receptors (distances on the same order as the dimensions of the landfill).

2.13 Specialized Models

Some models have been developed for application to very specific conditions. Examples include models capable of simulating sources where both land and water surfaces affect the dispersion of pollutants and models designed to simulate emissions from specific industries.

2.13.1 Buoyant Line and Point Source Dispersion Model (BLP)

BLP is a Gaussian plume dispersion model designed for the unique modeling problems associated with aluminum reduction plants, and other industrial sources where plume rise and downwash effects from stationary line sources are important.

2.13.1.1 Regulatory Application

Regulatory application of BLP model requires the selection of the following options:

- rural (IRU=l) mixing height option;
- default (no selection) for all of the following: plume rise wind shear (LSHEAR), transitional point source plume rise (LTRANS), vertical potential temperature gradient (DTHTA), vertical wind speed power law profile exponents (PEXP), maximum variation in number of stability classes per hour (IDELS), pollutant decay (DECFAC), the constant in Briggs' stable plume rise equation (CONST2), constant in Briggs' neutral plume rise equation (CONST3), convergence criterion for the line source calculations (CRIT), and maximum iterations allowed for line source calculations (MAXIT); and
- terrain option (TERAN) set equal to 0.0, 0.0, 0.0, 0.0, 0.0, 0.0

For more information on the BLP model consult the user's guide (Schulman and Scire, 1980).

2.13.2 Offshore and Coastal Dispersion Model (OCD)

OCD (DiCristofaro and Hanna, 1989) is a straight-line Gaussian model developed to determine the impact of offshore emissions from point, area or line sources on the air quality of coastal regions. OCD incorporates "over-water" plume transport and dispersion as well as changes that occur as the plume crosses the shoreline. Hourly meteorological data are needed from both offshore and onshore locations. Additional data needed for OCD are water surface temperature, over-water air temperature, mixing height, and relative humidity.

Some of the key features include platform building downwash, partial plume penetration into elevated inversions, direct use of turbulence intensities for plume dispersion, interaction with the overland internal boundary layer, and continuous shoreline fumigation.

2.13.2.1 Regulatory Application

OCD has been recommended for use by the Minerals Management Service for emissions located on the Outer Continental Shelf (50 FR 12248; 28 March 1985). OCD is applicable for over-water sources where onshore receptors are below the lowest source height. Where onshore receptors are above the lowest source height, offshore plume transport and dispersion may be modeled on a case-by-case basis in consultation with the District.

2.13.3 Shoreline Dispersion Model (SDM)

SDM (PEI, 1988) is a hybrid multipoint Gaussian dispersion model that calculates source impact for those hours during the year when fumigation events are expected using a special fumigation algorithm and the MPTER regulatory model for the remaining hours.

SDM may be used on a case-by-case basis for the following applications:

- tall stationary point sources located at a shoreline of any large body of water;
- rural or urban areas;
- flat terrain;
- transport distances less than 50 km;
- 1-hour to 1-year averaging times.

2.14 Interaction with the District

The risk assessor must contact the District to determine if there are any specific requirements. Examples of such requirements may include: specific receptor location guidance, specific usage of meteorological data and specific report format (input and output).

2.14.1 Submittal of Modeling Protocol

It is strongly recommended that a modeling protocol be submitted to the District for review and approval prior to extensive analysis with an air dispersion model. The modeling protocol is a plan of the steps to be taken during the air dispersion modeling process. Following is an example of the format that may be followed in the preparation of the modeling protocol. Consult with the District to confirm format and content requirements or to determine the availability of District modeling guidelines before submitting the protocol.

Emissions

- Specify that emission estimates for all substances for which emissions were required to be quantified will be included in the risk assessment. This includes both annual average emissions and maximum one-hour emissions of each pollutant from each process.

- Specify the format in which the emissions information will be provided (consult with the District concerning format prior to submitting the protocol).

- Specify the basis for using emissions data, other than that included in the previously submitted emission inventory report, for the risk assessment (consult with the District concerning the use of updated emissions data prior to submitting the protocol).

- Specify the format for presenting release parameters (e.g., stack height and diameter, stack gas exit velocity, release temperature) for each process as part of the risk assessment (consult with the District concerning the format prior to submitting the protocol).

- A revised emission inventory report must be submitted to the District and forwarded by the District to the CARB if revised emission data are used.

Models

- Identify the model(s) to be used, including the version number.

- Identify any additional models to be run if receptors are found above stack height.

- Specify which model results will be used for receptors above stack height.

- Specify the format for presenting the model options selected for each run (consult with the District concerning the format prior to submitting the protocol).

Meteorological Data

- Specify type, source, and year (e.g., hourly surface data, upper air mixing height information).

- Evaluate whether the data are representative.

- Describe QA/QC procedures.

- Identify any gaps in the data; if so, describe how the data gaps are filled.

Deposition

- Specify method to calculate deposition (if applicable).

Receptors

- Identify the method to determine maximum exposed individual for residential and occupational areas for long-term exposures (e.g., a Cartesian grid at 20-meter grid increments).

- Identify whether spatially averaged supplemental results will be submitted in addition to the modeling results from the maximum concentration at the single location. Identify the spatial average grid receptor domain and resolution and procedure for centering the grid on the maximum concentration. For tilted spatial average fields, identify whether rectangular or polar fields will be used. This information should be

provided for each receptor type (e.g., PMI, MEIR, and MEIW) and any water body or pasture land that will use spataial averaging for determining multipathway disposition exposure.

- Identify method to determine maximum short-term impact.

- Identify the methods and data sources for population and land-use that will be used to evaluate cancer risk in the vicinity of the facility for purposes of calculating cancer burden or population exposure estimates (e.g., centroids of the census tracts in the area within the zone of impact).

- Specify that UTM coordinates and street addresses, where possible, will be provided for specified receptor locations.

Maps

- Specify which cancer risk isopleths will be plotted (e.g., 10^{-6}, 10^{-7}; see Section 2.6.1).

- Specify which hazard indices will be plotted for acute and chronic (e.g., 0.1, 1, 10).

2.15 Report Preparation

This section describes the information related to the air dispersion modeling process that needs to be reported in the risk assessment. The District may have specific requirements regarding format and content (see Section 2.14). Sample calculations should be provided at each step to indicate how reported emissions data were used. Reviewing agencies must receive input, output, and supporting files of various model analyses on computer-readable media (e.g., CD). See the Air Toxics Risk Assessment Guidance Manual on the ARB website (http://www.arb.ca.gov/toxics/harp/harp.htm) for information on which files that should be included with a HARP risk assessments.

2.15.1 Information on the Facility and its Surroundings

Report the following information regarding the facility and its surroundings:

- Facility Name
- Location (UTM coordinates and street address)
- Land use type (see Section 2.4)
- Local topography
- Facility plot plan identifying:

    - source locations
    - property line
    - horizontal scale
    - building heights
    - emission sources

2.15.2 Source and Emission Inventory Information†

Source Description and Release Parameters

Report the following information for each source in table format:

- Source identification number used by the facility
- Source name
- Source location using UTM coordinates
- Source height (m)
- Source dimensions (e.g., stack diameter, building dimensions, area size) (m)
- Exhaust gas exit velocity (m/s)
- Exhaust gas volumetric flow rate (ACFM)
- Exhaust gas exit temperature (K)

Source Operating Schedule

The operating schedule for each source should be reported in table form including the following information:

- Number of operating hours per day and per year (e.g., 0800-1700, 2700 hr/yr)
- Number of operating days per week (e.g., Mon-Sat)
- Number of operating days or weeks per year (e.g., 52 wk/yr excluding major holidays)

Emission Control Equipment and Efficiency

Report emission control equipment and efficiency by source and by substance

Emissions Data Grouped By Source

Report emission rates for each toxic substance, grouped by source (i.e., emitting device or process identified in Inventory Report), in table form including the following information:

- Source name
- Source identification number
- Substance name and CAS number (from Inventory Guidelines)
- Annual average emissions for each substance (lb/yr)
- Hourly maximum emissions for each substance (lb/hr)

Emissions Data Grouped by Substance

Report facility total emission rate by substance for all emitted substances listed in the Air Toxics "Hot Spots" Program including the following information:

- Substance name and CAS number (from Inventory Guidelines)
- Annual average emissions for each substance (lb/yr)
- Hourly maximum emissions for each substance (lb/hr)

Emission Estimation Methods

Report the methods used in obtaining the emissions data indicating whether emissions were measured or estimated. Clearly indicate any emission data that are not reflected in the previously submitted emission inventory report and submit a revised emission inventory report to the district. A reader should be able to reproduce the risk assessment without the need for clarification.

List of Substances

Include tables listing all "Hot Spots" Program substances which are emitted, plus any other substances required by the District. Indicate substances to be evaluated for cancer risks and noncancer effects.

2.15.3 Exposed Population and Receptor Location

- Report the following information regarding exposed population and receptor locations:

- Description of zone of impact including map showing the location of the facility, boundaries of zone of impact, census tracts, emission sources, sites of maximum exposure, and the location of all appropriate receptors. This should be a true map (one that shows roads, structures, etc.), drawn to scale, and not just a schematic drawing. USGS 7.5 minute maps or GIS based maps are usually the most appropriate choices. (If significant development has occurred since the user's survey, this should be indicated.)

- Separate maps for the cancer risk zone of impact and the hazard index (noncancer) zone of impact. The cancer zone of impact should include isopleths down to at least the 1/1,000,000 risk level. Because some districts use a level below 1/1,000,000 to define the zone of impact, the District should be consulted. Two separate isopleths (to represent both chronic and acute HI) should be created to define the zone of impact for the hazard index from both inhalation and noninhalation pathways greater than or equal to 0.5. The point of maximum impact (PMI), maximum exposed individual at a residential receptor (MEIR), and maximum exposed individual worker (MEIW) for both cancer and noncancer risks should be located on the maps.

- Tables identifying population units and sensitive receptors (UTM coordinates and street addresses of specified receptors)

- Heights or elevations of the receptor points

- For each receptor type (e.g., PMI, MEIR, and MEIW) that will utilize spatial averaging, the domain size and grid resolution must be clearly identified. If another domain or grid resolution other than 20 meters by 20 meters with 5-meter grid spacing will be used for a receptor, then care should be taken to determine the proper domain size and grid resolution that should be used. For a worker, the HRA shall support all assumptions used, including, but not limited to, documentation for all workers showing the area where each worker routinely performs their duties. The final domain size should not be greater than the smallest area of worker movement. Other considerations for determining domain size and grid spacing resolution may include an evaluation of the concentration gradients across the worker area. The grid spacing used within the domain should be sufficient in number and detail to obtain a representative concentration across the area of interest. When spatial averaging over the deposition area of a pasture or water body, care should be taken to determine the proper domain size to make sure it includes all reasonable areas of potential deposition. The size and shape of the pasture or water body of interest should be identified and used for the modeling domain. The grid spacing or resolution used within the domain should be sufficient in detail to obtain a representative deposition concentration across the area of interest. One way to determine the grid resolution is to include an evaluation of the concentration gradients across the deposition area. The HRA shall support all assumptions used, including, but not limited to, documentation of the deposition area (e.g., size and shape of the pasture or water body, maps, representative coordinates, grid resolution, concentration gradients, etc.). The use or spatial averaging is subject to approval by the reviewing authority. This includes the size of the domain and grid resolution that is used for spatial averaging of a worksite or multipathway deposition area.

2.15.4 Meteorological Data

If meteorological data were not obtained directly from the District, then the report must clearly indicate the data source and time period used. Meteorological data not obtained from the District must be submitted in electronic form along with justification for their use including information regarding representativeness and quality assurance.

The risk assessment should indicate if the District required the use of a specified meteorological data set. All memos indicating the District's approval of meteorological data should be attached in an appendix.

2.15.5 Model Selection and Modeling Rationale

The report should include an explanation of the model chosen to perform the analysis and any other decisions made during the modeling process. The report should clearly indicate the name of the models that were used, the level of detail (screening or refined analysis) and the rationale behind the selection.

Also report the following information for each air dispersion model used:

- version number
- selected options and parameters in table form

2.15.6 Air Dispersion Modeling Results

- Maximum hourly and annual average concentrations of chemicals at appropriate receptors such as the residential and worker MEI receptors

- Annual average and maximum one-hour (and 30-day average for lead only) concentrations of chemicals at appropriate receptors listed and referenced to computer printouts of model outputs

- Model printouts (numbered), annual concentrations, maximum hourly concentrations

- Disk with input/output files for air dispersion program (e.g., the AERMOD input file containing the regulatory options and emission parameters, receptor locations, meteorology, etc.)

- Include tables that summarize the annual average concentrations that are calculated for all the substances at each site. The use of tables that present the relative contribution of each emission point to the receptor concentration is recommended. (These tables should have clear reference to the computer model which generated the data. It should be made clear to any reader how data from the computer output was transferred to these tables.) [As an alternative, the above two tables could contain just the values for sites of maximum impact (i.e., PMI, MEIR and MEIW), and sensitive receptors, if required. All the values would be found in the Appendices.]

(†) Health and Safety Code section 44346 authorizes facility operators to designate certain "Hot Spots" information as trade secret. Section 44361(a) requires districts to make health risk assessments available for public review upon request. Section 44346 specifies procedures to be followed upon receipt of a request for the release of trade secret information. See also the Inventory Guidelines Report regarding the designation of trade secret information in the Inventory Reports.

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Chapter 3 Daily Breathing Rates

3.1 Introduction

This chapter presents age-specific breathing rates for use in health risk assessments for short-term exposure to maximum 1-hour facility emissions and for long-term daily average exposures resulting from continuous or 8-hour intermittent exposure. The specified age ranges of toxicological interest in the "Hot Spots" program are ages third trimester, 0<2, 2<9, 2<16, 16<30 and 16-70 years.

The term ventilation rate has been frequently used for the metric of volume of air inhaled per minute (i.e., mL/min) and is used in this document to describe short-term, one hour exposures. For chronic daily exposures, the term "breathing rate" is applied both to the metric of volume of air inhaled per day (L/day) and the volume of air inhaled per kg body weight per day (L/kg-day). The normalized daily breathing rate in L/kg-day is the preferred metric for use in the "Hot Spots" program.

The 8-hour breathing rates were developed for specialized exposure scenarios that involve exposures only during facility operations of about 8-12 hours/day. Eight-hour breathing rates reflect exposures to off-site workers or exposures that may occur in schools when class is in session. Ventilation rates for 1-hour exposure were developed to meet the SB-352 mandate for school districts to conduct a risk assessment at school sites located within 100 meters of a freeway or busy roadway. These ventilation rates were developed for exposures to 1-hour maximum facility emissions that may occur during passive activities such as sitting at a desk during class instruction or during higher intensity activities such as play during recess.

OEHHA recommends the breathing rates presented in Section 3.2. Various published methods for deriving daily breathing rates and their advantages and limitations are discussed in Sections 3.3 to 3.7. Where possible, the breathing rates from these reports were re-evaluated to correspond with the five specific age groups used in OEHHA's risk assessment guidelines.

At elevations above 5000 feet, the breathing rate will increase due to lower air pressure (NOLS, 2012). The respiratory rate at this elevation peaks at one week and then slowly decreases over the next few months, although it tends to remain higher than its normal rate at sea level. There have been a few facilities located at 5000 feet or higher that have been required to produce a Hot Spots risk assessment. However, long-term residents at high altitude will have breathing rates near what is found in residents at sea level. OEHHA does not anticipate any adjustments will be needed to the breathing rates at higher altitudes in California, although ~~T~~the Districts should consider this issue and adjust if needed for very high altitude facilities.

3.2 Breathing Rate Recommendations

[Note: this section was moved from the back to the front]

3.2.1 Long-Term Breathing Rates

The recommended long-term daily breathing rate point estimates in Table 3.1 are based on a mean of two different methods used to determine daily breathing rates, the doubly labeled water method and an energy intake approach based on food consumption data from the Continuing Survey of Food Intake of Individuals (CSFII). These methods are described in detail below. The recommended distributions for stochastic analysis are presented in Tables 3.2a-b. The breathings rates normalized to body weight are expressed in L/kg-day, and the non-body weight-normalized breathing rates are expressed in m^3/day. All values were rounded to two or three significant figures.

Table 3.1. Recommended Point Estimates for Long-Term Daily Breathing Rates

	3rd Trimester	**0<2 years**	**2<9 years**	**2<16 years**	**16<30 years**	**16<70 years**
		L/kg-day				
Mean	225	658	535	452	210	185
95th Percentile	361	1090	861	745	335	290
		m^3/day				
Mean	15.3	6.2	10.7	13.3	15.0	13.9
95th Percentile	23.4	11.2	16.4	22.6	23.5	22.9

OEHHA calculated mean and high breathing rates for the third trimester assuming the dose to the fetus during the third trimester was the same as that to the mother.

TABLE 3.2a. Recommended Breathing Rate Distributions (L/kg-day) by Age Group for Stochastic Analysis

	3rd Trimester	**0<2 years**	**2<9 years**	**2<16 years**	**16<30 years**	**16-70 years**
Distribution	Max extreme	Max extreme	Max extreme	Log-normal	Logistic	Logistic
Minimum	78	196	156	57	40	13
Maximum	491	2,584	1,713	1,692	635	860
Scale	59.31	568.09	125.59		40.92	36.19
Likeliest	191.50	152.12	462.61			
Location				-144.06		
Mean	225	658	535	452	210	185
Std Dev	72	217	168	172	75	67
Skewness	0.83	2.01	1.64	1.11	0.83	1.32
Kurtosis	3.68	10.61	7.88	6.02	5.17	10.83

Percentiles						
5%	127	416	328	216	96	86
10%	142	454	367	259	118	104
25%	179	525	427	331	161	141
50%	212	618	504	432	207	181
75%	260	723	602	545	252	222
80%	273	758	631	572	261	233
90%	333	934	732	659	307	262
95%	361	1090	861	745	335	290
99%	412	1430	1,140	996	432	361

TABLE 3.2b. Recommended Breathing Rate Distributions (M^3/day) by Age Group for Stochastic Analysis

	3rd Trimester	0<2 years	2<9 years	2<16 years	16<30 years	16-70 years
Distribution	Logistic	Log-normal	Log-normal	Log-normal	Logistic	Log-normal
Minimum	4.0	0.8	2.7	2.7	1.5	1.8
Maximum	29.0	20.1	31.7	52.3	75.4	75.4
Scale	2,403.72				2,992.97	
Location		-650.7	-1,072.82	598.92		-8,251.33
Mean	15.1	6.2	10.7	13.3	15.0	13.9
Std Dev	4.3	2.6	3.1	4.9	5.4	5.4
Skewness	0.48	1.06	0.912	1.39	1.16	1.42
Kurtosis	3.73	4.69	5.18	7.14	12.22	11.19
Percentiles						
5%	8.6	2.9	6.1	6.9	6.4	6.3
10%	10.4	3.3	6.9	8.1	8.5	7.6
25%	12.3	4.4	8.5	9.9	11.8	10.3
50%	15.1	5.8	10.4	12.3	14.7	13.6
75%	17.6	7.6	12.4	15.9	18.0	16.8
80%	18.2	8.1	13.0	16.7	18.9	17.6
90%	21.4	9.6	14.8	19.5	21.5	20.1
95%	23.4	11.2	16.4	22.6	23.5	22.9
99%	28.8	13.9	20.0	28.1	29.9	28.0

3.2.2. Eight-hour Breathing Rate Point Estimates

The 8-hour breathing rates are based on minute breathing rates derived by U.S. EPA (2009). The minute ventilation rates, presented in Section 3.6, were multiplied by 480 (60 min x 8) to generate 8-hour breathing rate point estimates shown in Table 3.3. The 8-hour breathing rates may be useful for cancer risk assessment for the off-site worker exposure scenario, and school exposures to facility emissions. They may also be useful for evaluating residential exposures where the facility operates non-continuously. The 8-hour breathing rates vary depending on the intensity of the activity. Exposed individuals may be engaged in work activities ranging from watching TV to desk work, which would reflect breathing rates of sedentary/passive or light activities, to yard work or farm worker activities, which would reflect breathing rates of moderate intensity or greater. Breathing rates resulting from high intensity activities generally cannot be sustained for an 8-hour period (see Section 3.6).

OEHHA recommends using point estimate 8-hour breathing rates in L/kg-8-hrs based on the mean and 95th percentile of moderate intensity activities, 170 and 230 L/kg-8-hrs, respectively, for screening level risk assessments. Point estimates for lower breathing rates of sedentary/passive and light intensity work activities may be used in site-specific scenarios (i.e., work in which activity is limited to desk jobs or similar work). Pregnant women will generally participate in lower intensity activities than non-pregnant women, but as shown in Tables 3.1 and 3.2, breathing rate normalized to body weight will be slightly greater than breathing rates of adult men and non-pregnant women combined. OEHHA recommends using the mean and 95th percentile 8-hour breathing rates based on moderate intensity activity for third trimester women.

Table 3.3a. Eight Hour Breathing Rate (L/kg-8 Hr) Point Estimates for ~~(~~Males and Females Combined~~)~~

	0<2 years	**2<9 years**	**2<16 years**	**16<30 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	200	100	80	30	30
95th Percentile	250	140	120	40	40
	Light Intensity Activities (1.5 < METs ≤ 3.0)				
Mean	490	250	200	80	80
95th Percentile	600	340	270	100	100
	Moderate Intensity Activities (3.0 < METs ≤ 6.0)				
Mean	890	470	380	170	170
95th Percentile	1200	640	520	240	230

Table 3.3b. Eight-Hour Breathing Rate (M^3/8-Hr) Point Estimates for ~~Estimating Breathing Rates During the School Day~~ , ~~(~~Males and females Combined~~)~~

	0<2 years	**2<9 years**	**2<16 years**	**16<30 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	1.86	2.24	2.37	2.33	2.53
95th Percentile	2.69	2.99	3.20	3.23	3.34
	Light Intensity Activities (1.5 < METs ≤ 3.0)				
Mean	4.61	5.44	5.66	5.72	6.03
95th Percentile	6.51	7.10	7.52	7.75	7.80
	Moderate Intensity Activities (3.0 < METs ≤ 6.0)				
Mean	8.50	10.20	10.84	12.52	12.94
95th Percentile	12.36	13.47	14.52	18.08	18.07

~~For facility emissions that occur only during waking hours, 8-hour breathing rates based on light activities (METs values exceeding 1.5 to ≤3.0) or moderate activities (METs values exceeding 3.0 to ≤6.0) should be used. Basing 8-hour breathing rates on high intensity activities (MET values >6.0) were not considered here because even at the 95th percentile, U.S. EPA (2009) showed that individuals spent only about 1 hour or less per day at this intensity. For moderate intensity activities, the 95th percentile was at or~~

~~near 8 hours/day for some age groups. For the most activities that occur around the home or workplace, such as outdoor chores around the house or farming/service/machinist jobs (as discussed below in Section 3.6), using the mean or 95th percentile minute breathing rate of moderate intensity activities is recommended. The 95th percentile for light activities may be chosen for such activities as reading, completing homework and administrative office work~~.

3.2.3. Short-term (1-Hour) Ventilation Rate Point Estimates

One-hour breathing rates (Tables 3.4a-b) were calculated from U.S. EPA (2009) minute ventilation rates (e.g., minute ventilation rate x 60) to meet the SB-352 mandate for school districts to conduct a risk assessment for school sites located within 100 M of a freeway or busy roadway. These breathing rates allow assessment of exposures to facility emissions during the course of the school day.

The age groups for children mostly deviate from those child age groupings designed for AB2588. The 1-hour age groups attempt to address specific school categories (e.g., kindergarten, grade school, high school) under SB-352. However, if 1-hr breathing rates are required that fit the AB2588 age groups, 1-hr breathing rates can be calculated from the 8-hr breathing rates shown in Tables 3.28a-b.

Table 3.4a. One-Hour Breathing Rates for SB352 School Sites in L/kg-60 min (Males and Females Combined)

	0<2 Years	**2<6 years**	**6<11 years**	**11<16 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	25	17	10	6	4
95th Percentile	31	23	14	8	5
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	61	41	23	14	10
95th Percentile	75	54	32	19	13
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	110	76	44	28	21
95th Percentile	140	100	62	39	29
	High Intensity Activities (METS ≥ 6.0)				
Mean	-	140	82	55	38
95th Percentile	-	190	110	80	56

Table 3.4b. One-Hour Breathing Rates for SB352 School Sites in M^3/60 min (Males and Females Combined)

	0<2 Years	**2<6 years**	**6<11 years**	**11<16 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	0.23	0.27	0.29	0.33	0.32
95th Percentile	0.34	0.36	0.39	0.45	0.42
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	0.58	0.68	0.68	0.76	0.75
95th Percentile	0.81	0.86	0.91	1.03	0.97
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	1.06	1.25	1.30	1.50	1.62
95th Percentile	1.54	1.63	1.73	2.05	2.26
	High Intensity Activities (METS ≥ 6.0)				
Mean	-	2.24	2.49	2.92	3.01
95th Percentile	-	2.98	3.51	4.18	4.39

For children at school, MET activity levels equivalent to sitting at a desk during instruction and outside at play can be used as guidance for determining 1-hour breathing rates. As shown in Table 3.26 below, sitting was assigned a MET of 1.5, while play outdoors, recess and physical education had mean MET values in the range of 4.5 to 5.0 (U.S. EPA, 2009). Thus, 1-hour breathing rates based on sedentary/passive or light activities to represent activities within the class room and moderate intensity activities to represent activities during recess and some physical education classes, are recommended.

U. S. EPA (2009) also determined ventilation rates for high intensity activities with MET values ≥ 6.0. The distributions generated by U.S. EPA for hrs/day spent at MET values ≥6.0 for infants (age 0<2 yrs) suggests that this level of activity is unlikely for this age group. However, there is a subgroup of children in the older child age groups that exercise at this level for at least one hr/day, although this level of activity may not happen all in one hour's time. OEHHA recommends using 1-hr high intensity breathing rates for after-school sports and training that require high energy output such as track, football, tennis etc. This MET category may also be used for demanding sports during physical education classes.

3.~~2~~3 ~~Methods Used to~~ Estimatione ~~of~~ Daily Breathing Rates

3.3.1 Inhalation Dose and Cancer Risk

The approach to estimating cancer risk from long-term inhalation exposure to carcinogens requires calculating a range of potential doses and multiplying by cancer potency factors in units of inverse dose to obtain a range of cancer risks. This range reflects variability in exposure rather than in the dose-response. In equation 3-1, the daily breathing rate (L/kg BW-day) is the variate which is varied for each age group.

The general algorithm for estimating dose via the inhalation route is as follows:

$$DOSEair = Cair \times [BR/BW] \times A \times EF \times (1 \times 10^{-6}) \quad \textbf{(Eq. 3-1)}$$

where:

DOSEair	= dose by inhalation (mg/kg BW-day)
Cair	= concentration in air (µg/m^3)
[BR/BW]	= daily breathing rate normalized to body weight (L/kg BW-day)
A	= inhalation absorption factor, if applicable (default = 1)
EF	= exposure frequency (days/365 days)
1×10^{-6}	= conversion factors (mg to µg, m^3 to L)

The inhalation absorption factor (A) is a unitless factor that is only used if the cancer potency factor itself includes a correction for absorption across the lung. It is inappropriate to adjust a dose for absorption if the cancer potency factor is based on applied rather than absorbed dose. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) to allow for a two week period away from home each year. (US EPA, (1991). Another factor may come into consideration in the inhalation dose equation, the fraction of time at home (FAH). See Chapter 11 for more details.

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (CPF), expressed in units of (mg/kg-day)$^{-1}$.

$$RISKair = DOSEair * CPF * ASF * ED/AT \quad \textbf{(Eq. 3-2)}$$

RISK is the predicted risk of cancer (unitless) over a lifetime as a result of the exposure, and is usually expressed as chances per million persons exposed (e.g., 5×10^{-6} would be 5 chances per million persons exposed).

The dose-response phase of a cancer risk assessment aims to characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. This is usually expressed as a cancer potency factor, or CPF, in the above equation. The CPF is the slope of the extrapolated dose-response curve and is expressed as units of inverse dose (mg/kg-d)$^{-1}$, or inverse concentration (µg/m^3)$^{-1}$.

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the DOSEair and ED are different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)

7 yrs for 2<9 age group (ASF = 3)
14 yrs for 2<16 age group (ASF = 3)
14 yrs for 16<30 age group (ASF = 1)
54 yrs for 16-70 age group (ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKair_{(lifetime)} = RISKair_{(3rdtri)} + RISKair_{(0<2\ yr)} + RISKair_{(2<16\ yr)} + RISKair_{(16\text{-}70yr)} \quad \textbf{(Eq. 3-3)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as follows:

$$RISKair_{(9\text{-}yr\ residency)} = RISKair_{(3rdtri)} + RISKair_{(0<2\ yr)} + RISKair_{(2<9\ yr)} \quad \textbf{(Eq. 3-4)}$$

For 30-year residential exposure scenario, the 2<16 and 16<30 age group RISKair would be added to the risk from exposures in the third trimester and ages 0<2yrs. For 70 year residency risk, Eq 3-3 would apply.

3.3.2 Methods for Estimating Daily Breathing Rates

Two basic techniques have been developed to indirectly estimate daily breathing rates: the time-activity-ventilation (TAV) approach and an energy expenditure derivation method. Ideally, daily breathing rates would be directly measured. However, the equipment for direct measurement is bulky and obtrusive and thus impractical for measuring breathing rates over an entire 24-hour period, especially on children performing their typical activities. Thus, ventilation measurements are typically taken for shorter time periods under specific conditions (e.g., running or walking on a treadmill).

The TAV approach relies on estimates or measurements of ventilation rates at varying physical activity levels, and estimates of time spent each day at those activity levels. An average daily breathing rate is generated by summing the products of ventilation rate (L/min) and time spent (min/day) at each activity level.

The second approach derives breathing rates based on daily energy expenditure and was first proposed by Layton (1993). Layton reasoned that breathing rate is primarily controlled by the amount of oxygen needed to metabolically convert food into energy the body can use. Because the volume of oxygen required to produce one kcal of energy and the ratio of the volume of oxygen consumed to the volume of air inhaled per unit time are both constant values, the amount of energy a person expends is directly proportional to the volume of air the person breathes. Layton (1993) developed an

equation that models this relationship and that can be used to derive breathing rates from energy expenditure data:

$$VE = H \times VQ \times EE \qquad \text{(Eq. 3-~~1~~5)}$$

where:

VE = the volume of air breathed per day (L/day),
H = the volume of oxygen consumed to produce 1 kcal of energy (L/kcal),
VQ = the ratio of the volume of air to the volume of oxygen breathed per unit time and is referred to as the breathing equivalent (unitless)
EE = energy (kcal) expended per day

Layton calculated an H value of 0.21 L/kcal for noninfant children. Arcus-Arth and Blaisdell (2007) calculated essentially the same H value of 0.22 L/kcal from data of non-breastfed infants based on food surveys. For VQ, Layton calculated a value of 27 from adult data. Children have different respiratory minute ventilation rates, as well as other respiratory parameter values, relative to adults. Therefore, children's VQ values can be different from those of adults. Arcus-Arth and Blaisdell (2007) calculated VQ values for children from which daily breathing rates can be derived (Table 3.~~1~~5).

Table 3.~~1~~5. Mean VQ Values Calculated for Children

	Weighted mean VQ	**Recommended VQ**
Infants 0-11 mo.	nd[a]	33.5
Boys & girls 1-3 yrs	nd[a]	33.5
Boys & girls 4-8 yrs	33.5	33.5
Boys 9-18 yrs	30.6	30.6
Girls 9-18 yrs	31.5	31.5

[a] Insufficient or no data

Three variations of estimating EE have been used based on conversion of metabolic energy to derive a breathing rate: (1) from the caloric content of daily food intake, (2) as the product of basal metabolic rate (BMR) and ratios of average daily energy expenditure to BMR, and (3) as time-weighted averages of energy expenditure (expressed as multiples of BMR) across different levels of physical activity during the course of a day. Published reports applying these variations in metabolic energy conversion to arrive at breathing rates using Layton's equation are summarized below.

In addition to using energy intake data with Layton's method to derive breathing rates, an approach called the doubly labeled water (DLW) technique has also been used to derive total energy expenditure and is summarized below. The DLW data have been shown to be quite accurate, but the approach has only been applied to specific sub-populations.

3.~~3~~4 Available Daily Breathing Rate Estimates

There are a number of sources of information on daily breathing rates for various age groups and other subpopulations that have been derived via the methods described above. Some sources have compiled breathing rates from other studies.

3.~~3~~4.1 Traditional Breathing Rate Estimation

The book Reference Man (Snyder et al., 1975), a report by the International Commission on Radiological Protection (ICRP), presents breathing rates based on about 10 limited studies. Using an assumption of 8 hour (hr) resting activity and 16 hr light activity and the breathing rates (see Table 3.6), ICRP recommended daily breathing rates of 23 m^3/day for adult males, 21 m^3/day for adult females, and 15 m^3/day for a 10 year old child ~~(Table 3.2)~~. In addition, assuming 10 hr resting and 14 hr light activity each day, ICRP recommends a daily breathing rate of 3.8 m^3/day for a 1 year old. Finally, assuming 23 hr resting and 1 hr light activity, ICRP recommends a daily breathing rate of 0.8 m^3/day for a newborn. The breathing rates estimated by the ICRP used sources that had a small sample size and were limited in scope. Table 3.~~2~~6 is the minute volume data upon which the daily breathing rates were based.

Table 3.~~2~~6. Minute Volumes from ICRP'S Reference Man [a]

	Resting L/min (m^3/hr)	Light Activity L/min (m^3/hr)
Adult male	7.5 (0.45)	20 (1.2)
Adult female	6.0 (0.36)	19 (1.14)
Child, 10 yr	4.8 (0.29)	13 (0.78)
Child, 1 yr	1.5 (0.09)	4.2 (0.25)
Newborn	0.5 (0.03)	1.5 (0.09)

[a] Data compiled from available studies measuring minute volume at various activities by age/sex categories

This report provided the approach used in traditional risk assessment, in that a single estimate of daily breathing was employed, often 20 m^3/day for a 70-kg person.

3.~~3~~4.2 Daily Breathing Rate Estimates Based on Time-Activity-Ventilation (TAV) Data

3.~~3~~4.2.1 Marty et al. (2002)

Marty et al. (2002) derived California-specific distributions of daily breathing rates using estimates and measurements of ventilation rates at varying physical activity levels, and estimates of time spent each day at those activity levels. Two activity pattern studies were conducted in which activities of a randomly sampled population of 1762 adults and 1200 children were recorded retrospectively for the previous 24 hours via telephone interview (Phillips et al., 1991; Wiley et al., 1991a; Wiley et al., 1991b; Jenkins et al., 1992). Measured breathing rates in people performing various laboratory and field protocols were conducted by Adams et al. (1993). The subjects in this study were 160 healthy individuals of both sexes, ranging in age from 6 to 77 years. An additional forty 6 to 12 year olds and twelve 3 to 5 year olds were recruited for specific protocols.

For adults, each activity was assigned to a resting, light, moderate, moderately heavy, or heavy activity category to reflect the ventilation rate that could reasonably be associated with that activity. For children there were only resting, light, moderate, and heavy activity categories. The ventilation rates were classified into similar levels (e.g., the lying down protocol was considered the resting category of ventilation rate). The measured ventilation for each individual in the lab and field protocols was divided by that person's body weight. For each individual, the time spent at each activity level was summed over the day. The mean ventilation rate for each category (resting, etc.) was then multiplied by the summed number of minutes per day in that category to derive the daily breathing rate for each category. The breathing rates were then summed over categories to give a total daily breathing rate. The moments and percentiles for the raw derived breathing rates as well as for the breathing rates fit to a gamma distribution are presented in Tables 3.~~3~~7 and 3.~~4~~8 for the combined group of adolescents and adults (i.e., >12 years age) and for children (<12 years age). OEHHA staff also derived distributions of breathing rates for the equivalent of a 63-kg adult and an 18-kg child. These breathing rates form the basis of the current risk assessment guidelines (OEHHA, 2000), which this document is revising.

Table 3.~~3~~ 7 Children's (<12 Years) Daily Breathing Rates (L/Kg-Day)

	Moments and Percentiles from Empirical Data	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing Rate Equivalent for a 18 kg Child, m^3/Day (Empirical Data)**
N	1200		
Mean	452	451	8.1
Std Dev	67.7	66.1	1.22
Skewness	0.957	0.9	
Kurtosis	1.19	4.32	
%TILES	**L/kg-day**		
1%	342.5	(not calculated)	6.17
5%	364.5	360.3	6.56
10%	375	374.9	6.75
25%	401.5	402.7	7.23
50%	441	440.7	7.94
75%	489.5	488.4	8.81
90%	540.5	537.9	9.73
95%	580.5	572.1	10.5
99%	663.3	(not calculated)	11.9
Sample Max	747.5		13.5

Table 3.~~4~~ 8 Adult/Adolescent (>12 Years) Breathing Rates (L/kg-Day)

	Moments and Percentiles from Empirical Data	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing Rate Equivalent for a 63 kg Adult, m^3/Day**
N	1579		
Mean	232	233	14.6
Std Dev	64.6	56.0	4.07
Skewness	2.07	1.63	
Kurtosis	6.41	6.89	
%TILES	**L/kg-day**		
1%	174	(Not calculated)	11.0
5%	179	172.3	11.3
10%	181	178.0	11.4
25%	187	192.4	11.8
50%	209	218.9	13.2
75%	254	257.9	16.0
90%	307	307.8	19.3
95%	381	342.8	24.0
99%	494.0	(Not calculated)	31.1
Sample Max	693		43.7

Advantages of these rates are that the activity pattern data were from a large randomly sampled population of California adults and children, and that ventilation rates were normalized by body weight for each individual in the ventilation rate study. However, body weight information was not available for the activity pattern subjects. Measured breathing rates during specified activities were also collected from California participants with the intention that the data would be used in conjunction with the activity pattern data to derive daily breathing rates.

Limitations include the use of one-day activity pattern survey data that may tend to overestimate long-term daily breathing rates because both intraindividual variability and interindividual variability are poorly characterized. However, intraindividual variability is believed to be small relative to interindividual variability, which would make the breathing rate distributions reasonably accurate for chronic exposure assessment. Despite these limitations, the derived breathing rates were reasonably similar to those measured by the doubly-labeled water method (described in (OEHHA, 2000)).

Because the time-weighted average method involves professional judgment in assigning a breathing rate measured during a specific activity to various other types of activities, some uncertainty is introduced into the resulting daily breathing rates. Lastly, there is a paucity of breathing rate data for specific activities in children in the 3 to 6

year age range, and no data for children and infants younger than 3 years old. Thus, only a broad age range (i.e., < 12 years old) could be used for estimating daily breathing rates in children. Daily breathing rates cannot be reliably estimated from this study for children and infants over narrow age ranges, such as the critical 0<2 year age group.

3.~~3~~4.2.2 Allan et al. (2008)

Allan et al. (2008) also estimated breathing rates for specified age groups by the TAV approach, but employed a greater number of time-activity data sets than that used by Marty et al. (2002). This study updated TAV inhalation rate distributions from a previous report by Allan and Richardson (1998) by incorporating supplemental minute volume and time-activity data, and by correlating minute volume with metabolic equivalents (METs) for performing the physical activities at the time of measurement. Published time-activity and minute volume data used by Marty et al. (2002) were also used by the authors to develop the distributions (Wiley et al., 1991a; Wiley et al., 1991b; Adams, 1993), but also a number of other reports primarily conducted in the USA and Canada.

Their TAV approach calculated mean expected breathing rates for five different activity levels (i.e., level 1 – resting; level 2 – very light activity; level 3 – light activity; level 4 – light to moderate activity, level 5 – moderate to heavy activity). For infants, only three levels of activity were defined (i.e., sleeping or napping, awake but not crying, and crying).

Probability density functions describing 24-hour inhalation rates were generated using Monte Carlo simulation and can be described with lognormal distributions. Table 3.~~5~~ 9 presents the estimated breathing rates in m^3/day for males and females (combined) by age groupings commonly used in Canada for risk assessment purposes. In their report, Allan et al. (2008) also provided breathing rates for males and females separately. However, breathing rate distributions adjusted for body weight (**m^3**/day-kg) were not included in the report.

Table 3.~~5~~9. Allan et al. (2008) TAV-Derived Daily Breathing Rates (m^3/Day) for Males And Females Combined

Age Category	**Males and Females Combined (m^3/day)**			
	Mean + SD	**50%-ile[a]**	**90%-ile[a]**	**95%-ile[a]**
Infants (0-6 mo)	2.18 ± 0.59	2.06	2.87	3.12
Toddlers (7 mo-4 yr)	8.31 ± 2.19	7.88	10.82	11.72
Children (5-11 yr)	14.52 ± 3.38	13.95	18.49	19.83
Teenagers (12-19 yr)	15.57 ± 4.00	14.80	20.09	21.69
Adults (20-59 yr)	16.57 ± 4.05	15.88	21.30	22.92
Seniors (60+ yr)	15.02 ± 3.94	14.35	19.72	21.36

[a] Percentiles provided courtesy of Allan (e-mail communication)

Allen et al. (2008) compared the breathing rate distribution derived by the DLW method (see below, Table 3.12) to their TAV breathing rate probability density function results and found that there appeared to be longer tails in the upper bounds for all age groups

except teenagers and infants for the TAV method, suggesting the TAV distribution gives a better representation of the more exposed members of the population such as athletes. For teenagers, the TAV and DLW distributions show considerable overlap. But for infants, lower breathing rates were observed by the TAV approach compared with the DLW approach. The authors could not explain this discrepancy. Unlike the Marty et al. (2002) study, daily breathing rates could be estimated in infants and toddlers. However, there is still a shortage of TAV data in children in the younger age groups relative to adults.

Uncertainty was reduced by grouping activities by expected METs. However, Allen et al. (2008) noted that there is still uncertainty about actual physical exertion at an activity level because of the way some source studies grouped activities (e.g., grouping walking with running). Uncertainty was also reduced by using, wherever possible, studies that documented all activities over a multi-day period rather than studies that considered only a few hours of behavior. Nevertheless, there is some uncertainty in combining data from disparate studies and in assigning ventilation rates to activities that are not described by energy expenditure levels. In particular, interpolations and extrapolations were used to fill in minute volume data gaps and may have resulted in overestimates or underestimates. For example, minute volume data for some activity levels in toddlers and children were considered insufficient to adequately characterize their minute volumes.

3.~~3~~4.3 Daily Breathing Rate Estimates Based on Energy Expenditure

As discussed above, Layton (1993) developed a mathematical equation to estimate daily breathing rates based on energy expenditure. The paper also presented examples of breathing rates that had been derived using this method.

3.~~3~~4.3.1 Layton (1993)

Layton took three approaches to estimating breathing rates from energy estimates. The first approach used the U.S.D.A.'s National Food Consumption Survey (1977-78) data to estimate energy (caloric) intake. The National Food Consumption Survey used a retrospective questionnaire to record three days of food consumption by individuals in households across the nation, and across all four seasons. Layton recognized that food intake is underreported for individuals 9 years of age and older in these surveys and therefore adjusted the reported caloric intake for these ages. These data are no longer the most current population based energy intake data available. Further, the breathing rates are not normalized to body weight.

The second approach to estimating breathing rates multiplied the BMR estimated for a given age-gender group by the estimated ratio of energy intake to basal metabolic rate (EFD/BMR) for that age-gender group. The BMR can be determined as a linear function of body weight, after accounting for gender and age. An activity multiplier can then be applied which is derived from previously reported ratios of daily food intake to

BMR. The advantages of this approach include linking breathing rates to BMR, which is valuable since breathing rates are considered to be determined primarily by BMR.

However, the BMR for each age-gender group was calculated from equations derived from empirical but non-representative data. Further, these data were collected using techniques that may be outdated (e.g., for the 0-3 year age group, 9 of the 11 studies were conducted between 1914 and 1952). These data may no longer be representative of the current population. The EFD/BMR ratios for males and females over 18 years of age were estimated from data collected over one year in one study while those for other age groups were estimated based on the consistency of the value in calculating energy expenditures similar to other studies. Average body weights do not capture the variability of body weights in the population. Thus the BMR values may not be as accurate as current technology can provide nor are they representative of the population.

Layton's third approach to calculate daily breathing rates involves the metabolic equivalent (MET) approach, which is a multiple of the BMR and reflects the proportional increase in BMR for a specific activity. For example, the MET for standing is 1.5 (i.e., 1.5*BMR), and the MET for cycling and swimming is 5.3. Layton categorized METs into 5 levels (from light activity with a MET = 1 to very strenuous activities with a MET = 10). MET levels were then assigned to each activity in a study that had categorized activities by energy expenditure level and recorded the time study participants spent at each activity. The energy expended at each activity was converted to a breathing rate and then summed over the day to give a daily breathing rate. However, the time-activity data used in this approach were only available for ages over 18 years.

The results of Layton's approaches are presented in Table 3.~~6~~10. Layton did not report statistical distributions of the breathing rates that he derived. Other limitations, for our purposes, are that the breathing rates in Table 3.6 are not representative of the current U.S. population, are not normalized to body weight, and were for broad age ranges. In addition, no distributions were reported in the paper.

Table 3.~~6~~10. Layton (1993) Estimates of Breathing Rate Based on Caloric and Energy Expenditure

Method	Breathing Rate – Men m^3/day	Breathing Rate – Women m^3/day
Time-weighted average lifetime breathing rates based on food intake	14	10
Average daily breathing rates based on the ratio of daily energy intake to BMR	13-17 (over 10 years of age)	9.9-12 (over 10 years of age)
Breathing rates based on average energy expenditure	18	13

Finley et al. (1994) presented probability distributions for several exposure factors, including inhalation rates. Based on the data Layton used to derive point estimates via his third approach (i.e., with energy expenditure equivalent to a multiple of BMR), Finley et al. (1994) expanded on Layton's results to develop a probability distribution for breathing rate for several age groups (Table 3.~~7~~11).

Table 3.~~7~~11. Selected Distribution Percentiles from Finley et al. (1994) for Breathing Rates by Age

Age Category (years)	Percentile (m^3/day)		
	50th	90th	95th
<3	4.7	6.2	6.7
3 -10	8.4	10.9	11.8
10 – 18	13.1	17.7	19.3
18 – 30	14.8	19.5	21.0
30 – 60	11.8	15.4	16.7
>60	11.9	15.6	16.7

Because Finley largely used the same data as Layton to develop breathing rate distributions, the same limitations apply.

3.~~3~~4.3.2 Arcus-Arth and Blaisdell (2007)

Arcus-Arth and Blaisdell (2007) derived daily breathing rates for narrow age ranges of children and characterized statistical distributions for these rates. The rates were derived using the metabolic conversion method of Layton (1993) and energy intake data (calories consumed per day) from the Continuing Survey of Food Intake of Individuals (CSFII) 1994–1996, 1998 conducted by the USDA (2000). The CSFII provided the most recent population based energy data at the time. The CSFII dataset consisted of two days of recorded food intake for each individual along with self-reported body weights. The individual data allowed for the assessment of interindividual variability. Because one-day intakes may be less typical of average daily intake, the two-day intakes were averaged to obtain a better estimate of typical intake available from these limited repeated measures. The CSFII energy intakes were weighted to represent the U.S. population. The rates were intended to be more representative of the current U.S. children's population than prior rates that had been derived using older or non-representative data.

The premise for Layton's equation is that breathing rate is proportional to the oxygen required for energy expenditure. While there are no energy expenditure data that are representative of the population, there are population representative energy intake data (i.e., calories consumed per day). Energy intake data can be used in Layton's equation when energy intake equals energy expenditure. Energy intake is equal to energy expended when the individual is neither gaining nor losing body weight (i.e., all energy intake is expended). Because the percentage of daily energy intake that is needed to result in a discernible change in body weight for adults is very small, it can be assumed that for adults energy intake equals energy expended. However, in young infants, a

significant portion of their daily energy intake is deposited in new tissue (e.g., adipose, bone and muscle). The deposited energy is referred to as the energy cost of deposition (ECD). Therefore, the daily energy intake needed for normal growth of infants is used both for energy expenditure (EE) and ECD (i.e., energy intake = EE + ECD). If the breathing rate is to be estimated by the caloric intake approach for growing infants, the ECD must be subtracted from the total daily energy intake in order to determine an accurate breathing rate.

Accounting for the ECD is primarily important for newborn infants (Butte et al., 1990; Butte et al., 2000). For example, at ages 3 and 6 months the energy cost for growth constituted 22 and 6%, respectively, of total energy requirements. In older children the energy cost is only 2-3% of total energy requirements. By the age of 25 years in males and 19 years in females, the ECD has essentially decreased to zero and remains at that level throughout adulthood (Brochu et al., 2006a).

Because Layton's equation requires only energy expenditure to derive the breathing rate, a small modification to Eq. 3-~~1~~ 5 is made when deriving the infant breathing rate using the caloric intake approach:

$$VE = H \times VQ \times (TDEI - ECD) \times 10^{-3} \qquad \text{(Eq. 3-~~2~~6)}$$

where:

TDEI = Total daily energy intake (kcal/day)
ECD = Daily energy cost of deposition (kcal/day)

Arcus-Arth and Blaisdell (2007) subtracted the ECD from the TDEI to give a more accurate estimate of energy expended. The ECD for each month of age for infants up to 11 months of age was estimated from Scrimshaw et al. (1996). Although there is typically a burst of growth just prior to and during adolescence, Arcus-Arth and Blaisdell did not subtract the ECD during adolescence because investigators considered it negligible relative to total energy intake (Spady, 1981; Butte et al., 1989).

Layton (1993) reported on the bias associated with underreporting of dietary intakes by older children. He calculated a correction factor for this bias (1.2) and multiplied the daily energy intake of each child nine years of age and older by 1.2. Arcus-Arth and Blaisdell, having evaluated the literature and finding Layton's adjustment to be reasonable, likewise multiplied daily energy intake of adolescent ages by 1.2.

Arcus-Arth and Blaisdell (2007) also evaluated the numerical values used by Layton for the VQ and H conversion factors in his metabolic equation. Their estimated value for the conversion factor H was similar to that found by Layton. However, they found data in the literature indicating that other values of VQ may be more specific to children than those used by Layton (see Table 3.~~1~~5). The VQ values Arcus-Arth and Blaisdell calculated were used to derive breathing rates.

Non-normalized (L/day) and normalized (L/kg-day) breathing rates shown in Tables 3.8a-e) were derived for both children and adults from the CSFII dataset using the methodology described in Arcus-Arth and Blaisdell (2007). Briefly, the CSFII used a multistage complex sampling design to select individuals to be surveyed from the population. The CSFII recommended using a Jacknife Replication (JK) statistical method (Gossett et al., 2002; Arcus-Arth and Blaisdell, 2007), which is a nonparametric technique that is preferred to analyze data from multistage complex surveys.

For each age group, the mean, standard error of the mean, percentiles (50th, 90th, and 95th) of nonnormalized and normalized breathing rates, derived as described, are presented in Tables 3.~~8~~ 12a and 3.~~9~~12b, respectively. Child breathing rates are for males and females combined, except for the 9-18 yr adolescent age group breathing rates shown at the bottom of the tables.

TABLE 3.~~8~~12a. Non-Normalized Daily Breathing Rates (L/Day) for Children and Adults Using CSFII Energy Intake and Layton's Equation

Age	Sample Size Nonweighted	Mean	SEM	50%-ile	90%-ile	95%-ile	SE of 95%-ile
Age (months)	**Infancy**						
0-2	182	3630	137	3299	5444 [1]	7104 [1]	643
3-5	294	4920	135	4561	6859	7720	481
6-8	261	6089	149	5666	8383	9760	856
9-11	283	7407	203	6959	10,212	11,772	**
0-11	1020	5703	98	5323	8740	9954	553
Age (years)	**Children**						
1	934	8770	75	8297	12,192	13,788	252
2	989	9758	100	9381	13,563	14,807	348
3	1644	10,642	97	10,277	14,586	16,032	269
4	1673	11,400	90	11,046	15,525	17,569	234
5	790	12,070	133	11,557	15,723	18,257	468
6	525	12,254	183	11,953	16,342	17,973	868
7	270	12,858	206	12,514	16,957	19,057	1269
8	253	13,045	251	12,423	17,462	19,019	1075
9	271	14,925	286	14,451	19,680	22,449 [1]	1345
10	234	15,373	354	15,186	20,873	22,898 [1]	1021
11	233	15,487	319	15,074	21,035	23,914 [1]	1615
12	170	17,586	541	17,112	25,070 [1]	29,166 [1]	1613
13	194	15,873	436	14,915	22,811 [1]	26,234 [1]	1106
14	193	17,871	615	15,896	25,748 [1]	29,447 [1]	4382
15	185	18,551	553	17,913	28,110 [1]	29,928 [1]	1787
16	201	18,340	536	17,370	27,555	31,012	2065
17	159	17,984	957	15,904	31,421 [1]	36,690 [1]	**
18	135	18,591	778	17,339	28,800 [1]	35,243 [1]	4244
0<2	1954	7502	75	7193	11,502	12,860	170
2<16	7624	14,090	120	13,128	20,993	23,879	498
	Adolescent Boys						
9-18	983	19,267	278	17,959	28,776	32,821	1388
	Adolescent Girls						
9-18	992	14,268	223	13,985	21,166	23,298	607

[1] Value may be less statistically reliable than other estimates due to small cell size

** Unable to calculate

Table 3.~~9~~12b. Normalized Daily Breathing Rates (L/kg-Day) for Children and Adults Using CSFII Energy Intake and Layton's Equation

Age	Sample Size Nonweighted	Mean	SEM	50%-ile	90%-ile	95%-ile	SE of 95%-ile
Age (months)	**Infancy**						
0-2	182	839	42	725	1305	1614	290
3-5	294	709	24	669	1031	1232	170
6-8	261	727	16	684	1017	1136	73
9-11	283	760	20	710	1137	1283	96
0-11	1020	751	11	694	1122	1304	36
Age (years)	**Children**						
1	934	752	7	716	1077	1210	33
2	989	698	9	670	986	1107	31
3	1644	680	6	648	966	1082	18
4	1673	645	5	614	904	1011	19
5	790	602	7	587	823	922	25
6	525	550	10	535	765	849	28
7	270	508	9	495	682	788	39
8	253	458	11	439	657	727	37
9	271	466	11	445	673	766 [1]	21
10	234	438	12	425	661	754 [1]	38
11	233	378	9	350	566	616 [1]	32
12	170	373	13	356	545 [1]	588 [1]	46
13	194	311	12	289	459 [1]	588 [1]	55
14	193	313	12	298	443 [1]	572 [1]	92
15	185	299	10	285	461 [1]	524 [1]	25
16	201	278	10	258	434	505	46
17	159	276	15	251	453 [1]	538 [1]	**
18	135	277	10	244	410 [1]	451 [1]	42
0<2	1954	752	6	706	1094	1241	24
2<16	7624	481	3	451	764	869	6
	Adolescent Boys						
9-18	983	367	5	343	567	647	14
	Adolescent Girls						
9-18	992	315	6	288	507	580	24

[1] Value may be less statistically reliable than other estimates due to small cell size
** Unable to calculate

Ideally, breathing rates and other variates used in risk assessment should be as representative as possible of the exposed population. Population representative daily energy (caloric) intake can be estimated from national food consumption surveys, such as the CSFII and the National Health and Nutrition Examination Survey (NHANES). These surveys can be analyzed to provide results that are representative of the nation

and of several subpopulations, including narrow age groups. The sample sizes are large with these surveys and thus provide relatively robust results, which is of particular concern for the tails of probability distributions.

Limitations for the CSFII energy intake-derived breathing rates include the underreporting of food intakes discussed above. Underestimation of energy intake leads to underestimation of breathing rates. Another limitation is that only two days of food intake data had been collected. Although collection of two consecutive days of food intake is an improvement over earlier collections of one day of food intake, the repeated measures in the survey were still too limited to reduce the impact of daily variations in food intake and would tend to overestimate the upper and lower percentiles. Typical intake is not captured by the caloric intake of two days, and breathing rate and dietary intake on any given day are not tightly coupled.

3.~~3~~4.3.3. US EPA (2009) Metabolic Equivalent-Derived Daily Breathing Rate Estimates

Similar to one of the approaches Layton (1993) used to estimate the breathing rate, U.S. EPA employed a metabolic equivalent (METS) approach for estimating breathing rates. This method determines daily time-weighted averages of energy expenditure (expressed as multipliers of the basal metabolic rate) across different levels of physical activity. METs provide a scale for comparing the physical intensities of different activities. Recent energy expenditure data including the 1999-2002 NHANES and U.S EPA's Consolidated Human Activity Database (CHAD) were used that considers variability due to age, gender, and activities. NHANES (CDC, 2000; 2002) was used as the source of body weight data, and CHAD (U.S. EPA, 2002) was the central source of information on activity patterns and METS values for individuals. The 4-year sampling weights assigned to the individuals within NHANES 1999-2002 were used to weight each individual's data values in the calculations of these statistics.

Data were grouped into age categories and a simulated 24-hour activity pattern was generated by randomly sampling activity patterns from the set of participants with the same gender and age. Each activity was assigned a METS value based on statistical sampling of the distribution assigned by CHAD to each activity code. Using statistical software, equations for METS based on normal, lognormal, exponential, triangular and uniform distributions were generated as needed for the various activity codes. The METS values were then translated into energy expenditure (EE) by multiplying the METS by the basal metabolic rate (BMR), which was calculated as a linear function of body weight. The VO2 was calculated by multiplying EE by H, the volume of oxygen consumed per unit energy.

The inhalation rate for each activity within the 24-hour simulated activity pattern for each individual was then estimated as a function of VO2, body weight, age, and gender. Following this, the average inhalation rate was calculated for each individual for the entire 24-hour period, as well as for four separate classes of activities based on METS value (sedentary/passive [METS less than or equal to 1.5], light intensity [METS greater

than 1.5 and less than or equal to 3.0], moderate intensity [METS greater than 3.0 and less than or equal to 6.0], and high intensity [METS greater than 6.0]. Data for individuals were then used to generate summary tables with distributional data based on gender and age categories (Tables 3.~~10~~ 13a and 3.~~11~~13b). No parametric distributional assumptions were placed on the observed data distributions before these statistics were calculated.

Table 3.~~10~~13a. US EPA (2009) Metabolically-Derived Daily Breathing Rate (m^3/Day in Males and Females Unadjusted For Body Weight

Age Category (years)	Means and Percentiles in m^3/day							
	Males				Females			
	Mean	**50th**	**90th**	**95th**	**Mean**	**50th**	**90th**	**95th**
Birth to <1	8.76	8.70	11.93	12.69	8.53	8.41	11.65	12.66
1	13.49	13.11	17.03	17.89	13.31	13.03	17.45	18.62
2	13.23	13.19	16.27	17.71	12.74	12.60	15.58	16.37
3 to <6	12.65	12.58	14.63	15.41	12.16	12.02	14.03	14.93
6 to <11	13.42	13.09	16.56	17.72	12.41	11.95	15.13	16.34
11 to <16	15.32	14.79	19.54	21.21	13.44	13.08	16.25	17.41
16 to <21	17.22	16.63	21.94	23.38	13.59	13.20	17.12	18.29
21 to <31	18.82	18.18	24.57	27.14	14.57	14.10	19.32	21.14
31 to <41	20.29	19.83	26.77	28.90	14.98	14.68	18.51	20.45
41 to <51	20.93	20.60	26.71	28.37	16.20	15.88	19.91	21.35
51 to <61	20.91	20.41	27.01	29.09	16.18	15.90	19.93	21.22
61 to <71	17.94	17.60	21.78	23.50	12.99	12.92	15.40	16.15

Table 3.~~11~~13b. US EPA (2009) Metabolically-Derived Daily Breathing Rate (m^3/Kg-Day) in Males and Females Adjusted for Body Weight

Age Category (years)	Means and Percentiles in m^3/kg-day							
	Males				Females			
	Mean	**50th**	**90th**	**95th**	**Mean**	**50th**	**90th**	**95th**
Birth to <1	1.09	1.09	1.26	1.29	1.14	1.13	1.33	1.38
1	1.19	1.17	1.37	1.48	1.20	1.18	1.41	1.46
2	0.95	0.94	1.09	1.13	0.95	0.96	1.07	1.11
3 to <6	0.70	0.69	0.87	0.92	0.69	0.68	0.88	0.92
6 to <11	0.44	0.43	0.55	0.58	0.43	0.43	0.55	0.58
11 to <16	0.28	0.28	0.36	0.38	0.25	0.24	0.31	0.34
16 to <21	0.23	0.23	0.28	0.30	0.21	0.21	0.27	0.28
21 to <31	0.23	0.22	0.30	0.32	0.21	0.20	0.26	0.28
31 to <41	0.24	0.23	0.31	0.34	0.21	0.20	0.27	0.30
41 to <51	0.24	0.23	0.32	0.34	0.22	0.21	0.28	0.31
51 to <61	0.24	0.24	0.30	0.34	0.22	0.21	0.28	0.30
61 to <71	0.21	0.20	0.24	0.25	0.18	0.17	0.21	0.22

US EPA (2009) described the strengths and weaknesses of their approach. The strengths of this metabolically-derived method include nationally representative data sets with a large sample size, even within the age and gender categories. This approach also yields an estimate of ventilation rate that is a function of VO2 rather than an indirect measure of oxygen consumption such as VQ as other researchers have used.

Another strength is that the breathing rates included a BMR component which had been derived from NHANES body weights and to which NHANES sampling weights were linked. The BMR component of the breathing rates was representative of the population because of the sampling weights. That is, the degree of association between body weight and breathing rate was incorporated into the distribution of breathing rate distributions.

However, the degree of association between breathing rate and other characteristics (e.g., race, geographic region) was not incorporated into the distributions (US EPA, 2009). These non-body weight characteristics can be highly associated with variability in activity patterns. Although BMR may contribute the greatest percent to the quantitative breathing rate value, the variability in breathing rates is most likely driven by differing levels of physical activity by different persons. Because the activity data was collected over a 24-hour period, day-to-day variability is not well characterized (US EPA, 2009; US EPA, 2011). The outcome is that the simulated 24-hour activity pattern assigned to an NHANES participant is likely to contain a greater variety of different types of activities than one person may typically experience in a day.

Furthermore, because the simulated activity profiles did not consider possible limits on the “maximum possible METS value” that would account for previous activities, ventilation rates may be overestimated (US EPA, 2009). This happens, in part, because the MET approach does not take into consideration correlations that may exist between body weight and activity patterns. For example, high physical activity levels can be associated with individuals of high body weight, leading to unrealistically high inhalation rates at the upper percentiles levels (US EPA 2011). The result is that the central tendency of the MET breathing rates may be fairly representative of the population, but the breathing rates may not appropriately capture the variability within the population. This limitation was probably most evident in children <3 years of age where the data used to calculate BMR values may be less representative of the current population. (US EPA, 2009).

3.~~3~~4.4. Daily Breathing Rate Estimates from Doubly Labeled Water Measurements

In another method used to quantify human energy expenditure, published doubly-labeled water (DLW) energy expenditure data can be used in conjunction with Layton’s equation to convert metabolic energy to daily inhalation rates (Brochu et al., 2006a; 2006b; Stifelman, 2007). In the DLW method, isotopically labeled water containing $^{2}H_2 0$ (i.e., heavy water) and $H_2{}^{18}0$ is given orally to the study participant.

The isotopes then distribute in the body and disappear from body water pools by dilution from new unlabeled water into the body, by the excretion of the labeled isotope from the body, or by the production of CO_2. The difference in disappearance rates between the two isotopes represents CO_2 production over an optimal period of 1–3 half-lives (7 to 21 days in most human subjects) of the labeled water. CO_2 production is an indirect measure of metabolic rate and can be converted into units of energy using knowledge of the chemical composition of the foods consumed.

A major advantage of the DLW method is that it provides an index of total energy expenditure over a period of 1 to 3 weeks, which is a more biologically meaningful period of time compared to the other methods, and can reduce the impact of daily variations in physical activity or food intake (IOM, 2005). In addition, the DLW method is non-invasive, requiring only that the subject drink the stable isotopes and provide at least three urine samples over the study period. Thus, measurements can be made in subjects leading their normal daily lives (i.e., free-living individuals). The DLW method is considered to be the most accurate method for determining the breathing rate of an individual (IOM, 2005).

A disadvantage is that the DLW method is expensive to undertake, and that essentially all the available studies investigated different age ranges but the subjects were not randomly selected to be representative of populations. However, measurements are available in a substantial number of men, women and children whose ages, body weights, heights and physical activities varied over wide ranges.

DLW measurements of total daily energy expenditures (TDEE) include basal metabolism, physical activity level, thermogenesis, and the synthetic cost of growth (Butte et al., 2000). The synthetic cost of growth is the energy that is expended to synthesize the molecules that will be stored. This is different from the energy deposited for growth (ECD), which is the energy intake that is deposited in the body for new tissue. The ECD is an important factor in newborn infants and is not accounted for in DLW measurements. Thus, the derivation of breathing rates using Layton's equation does not require an adjustment to subtract out the ECD to determine TDEE, as was necessary for deriving the breathing rates of infants by the caloric intake approach (Section 3.~~4~~5.3.2).

3.~~3~~4.4.1. Brochu et al. (2006a,b)

Brochu et al. (2006a) calculated daily inhalation rates for 2210 individuals aged 3 weeks to 96 years using DLW energy expenditure data mainly from the IOM (2005). The IOM database is a compilation of DLW-derived energy expenditure results and other raw data from individuals collected from numerous studies. Breathing rates were estimated for different groups of individuals including healthy normal-weight males and females with normal active lifestyles (n=1252), overweight/obese individuals with normal active lifestyles (n=679), individuals from less affluent societies (n=59), underweight adults (n=34), and individuals during various extreme physical activities (n=170). Normal weight adults age 20 yrs and above were categorized as having BMIs between 18.5 and

25 kg/m^2. Overweight/obese adults had BMIs above 25 kg/m^2. For children and teenagers aged 4 to 19 yrs, BMIs corresponding to the 85th percentile or below were considered normal. The breathing rate data were presented as 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 99th percentile values as well as mean and SEM values for the derived inhalation rates for narrow age groups ranging from 1 month to 96 years. A partial listing of the breathing rate percentiles for normal weight individuals by age group are shown in Tables 3.~~12~~ 14a and 3.~~13~~14b.

Table 3.~~12~~14a. Means and Percentiles of Daily Breathing Rates (in m^3/Day) for Free-Living Normal-Weight Males and Females Derived from DLW Measurements by Brochu et al. (2006a)

Age Category (years)	Means and Percentiles in m^3/day									
	Males[a]					Females[a]				
	N	Mean	50th	90th	95th	N	Mean	50th	90th	95th
0.22 to <0.5	32	3.38	3.38	4.30	4.57	53	3.26	3.26	4.11	4.36
0.5 to <1	40	4.22	4.22	5.23	5.51	63	3.96	3.96	4.88	5.14
1 to <2	35	5.12	5.12	6.25	6.56	66	4.78	4.78	6.01	6.36
2 to <5	25	7.60	7.60	9.25	9.71	36	7.06	7.06	8.54	8.97
5 to <7	96	8.64	8.64	10.21	10.66	102	8.22	8.22	9.90	10.38
7 to <11	38	10.59	10.59	13.14	13.87	161	9.84	9.84	12.00	12.61
11 to <23	30	17.23	17.23	21.93	23.26	87	13.28	13.28	16.61	17.56
23 to <30	34	17.48	17.48	21.08	22.11	68	13.67	13.67	16.59	17.42
30 to <40	41	16.88	16.88	20.09	21.00	59	13.68	13.68	15.94	16.58
40 to <65	33	16.24	16.24	19.67	20.64	58	12.31	12.31	14.96	15.71
65 to <96	50	12.96	12.96	16.13	17.03	45	9.80	9.80	12.58	13.37

[a] Percentiles based on a normal distribution assumption for all age groups

Table 3.~~13~~14b. Means and Percentiles of Daily Breathing Rates (in m^3/kg-Day) for Free-Living Normal-Weight Males and Females Derived from DLW Measurements by Brochu et al. (2006a)

Age Category (years)	Mean and Percentiles in m^3/kg-day									
	Males[a]					Females[a]				
	N	Mean	50th	90th	95th	N	Mean	50th	90th	95th
0.22 to <0.5	32	0.509	0.509	0.627	0.661	53	0.504	0.504	0.623	0.657
0.5 to <1	40	0.479	0.479	0.570	0.595	63	0.463	0.463	0.545	0.568
1 to <2	35	0.480	0.480	0.556	0.578	66	0.451	0.451	0.549	0.577
2 to <5	25	0.444	0.444	0.497	0.512	36	0.441	0.441	0.532	0.559
5 to <7	96	0.415	0.415	0.475	0.492	102	0.395	0.395	0.457	0.474
7 to <11	38	0.372	0.372	0.451	0.474	161	0.352	0.352	0.431	0.453
11 to <23	30	0.300	0.300	0.360	0.377	87	0.269	0.269	0.331	0.349
23 to <30	34	0.247	0.247	0.297	0.311	68	0.233	0.233	0.287	0.302
30 to <40	41	0.237	0.237	0.281	0.293	59	0.235	0.235	0.279	0.292
40 to <65	33	0.230	0.230	0.284	0.299	58	0.211	0.211	0.257	0.270
65 to <96	50	0.188	0.188	0.228	0.239	45	0.172	0.172	0.220	0.233

[a] Percentiles based on a normal distribution assumption for all age groups

Comparing the largest subgroups (i.e., overweight/obese individuals vs. normal-weight individuals), Brochu et al. observed that overweight/obese individuals inhaled between 0.8 to 3.0 m^3 more air per day than normal-weight individuals, but their physiological daily breathing rates are 6 to 21% lower than that of their leaner counterparts when expressed in m^3/kg-day. Also of interest is that the daily inhalation rates (in m^3/kg-day) of newborns and normal-weight infants aged 2.6 to less than 6 months are 2.1 to 5.1 times higher than those of normal-weight and overweight/obese adults aged 18 to 96 years with normal lifestyles.

Besides the lack of randomly selected individuals representative of a population for estimating energy expenditure, much of the DLW data used to derive the breathing rate percentiles relied heavily on adults with sedentary lifestyles (Black et al., 1996). Occupations of many participants included professionals, white collar workers or other sedentary occupations, and almost no participants were in manual labor occupations that are known to result in higher breathing rates. Although a small group of athletic individuals appear to be included in the DLW database by Brochu et al. (2006a), it was suggested by Black et al. (1996) that not enough participants involved in manual labor are represented in the DLW database. This may result in breathing rate percentiles that are lower than what might be obtained from a population-based study. Nevertheless, as noted above, the DLW method provides an index of total energy expenditure over a period of 1 to 3 weeks, which is a better determinant of long-term breathing rate than other methods described that rely on 1 to 2 days of energy intake or expenditure to estimate long-term breathing rates. Thus, the DLW method is considered to be the most accurate method for determining an average daily breathing rate of a free-living individual.

3.~~3~~4.4.2 Stifelman (2007)

Using energy expenditure data based on extensive DLW measurements from two sources (FAO, 2004a; 2004b; IOM, 2005), Stifelman (2007) calculated inhalation rates with Layton's equation for long-term physical activity levels categorized as active to very active individuals. The breathing rate data are presented in Table 3.~~14~~ 15 in one year age groupings for infants and children and in three age groupings for adults up to age 70.

TABLE 3.~~14~~15. Equivalent Breathing Rates Based on Institute of Medicine Energy Expenditure Recommendations for Active and Very Active People

Age (Years)	Inhalation rate – males active – very active (m^3/day)	Inhalation rate – females active – very active (m^3/day)
<1	3.4	3.4
1	4.9	4.9
2	5.9	5.5
3	8.4 – 9.5	7.9 – 9.3
4	8.8 – 10.1	8.3 – 9.9
5	9.4 – 10.7	8.8 – 10.5
6	9.8 – 11.3	9.3 – 11.1
7	10.4 – 11.9	9.7 – 11.6
8	10.9 – 12.6	10.2 – 12.3
9	11.5 – 13.3	10.7 – 12.8
10	12.1 – 14.0	11.1 – 13.4
11	12.9 – 14.9	11.7 – 14.1
12	13.7 – 15.9	12.3 – 14.9
13	14.8 – 17.2	12.9 – 15.6
14	16.0 – 18.5	13.2 – 16.0
15	17.0 – 19.8	13.3 – 16.2
16	17.8 – 20.7	13.4 – 16.3
17	18.2 – 21.2	13.3 – 16.2
18	18.6 – 21.5	13.2 – 16.1
19-30	17.0 – 19.7	13.4 – 15.2
31-50	16.2 – 18.9	12.8 – 14.5
51-70	15.1 – 17.8	12.0 – 13.8

Physical activity levels (PALs) were categorized into four levels of activity by the IOM, two of which were the active and very active levels. A PAL is the ratio of total energy expended (TEE) divided by the basal metabolic rate, defined as the minimum level of energy needed to support essential physiologic functions in free-living people. Stifelman (2007) also calculated the breathing rate associated with each level, as shown in Table 3.~~15~~16. It is believed unlikely that the PAL "very active" category (i.e., PAL range 1.9-2.5) would be exceeded over a duration of years. PALs exceeding the IOM and FAO ranges are generally not sustainable over long periods of time, but can be quite high for limited periods of time (Westerterp, 2001). For example, highly trained athletes during periods of high-intensity training competition, including cross-country skiers and Tour de France bicycle racers, can reach a PAL of 3.5-5.5.

The IOM and FAO PALs describe a range of 1.4-2.5 in accord with ranges of sustainable PALs described by others, including people actively engaged in non-mechanized agriculture, deployed military personnel, and long-distance runners (Stifleman, 2007; Westerterp, 2001; Westerterp, 1998; Black et a., 1996; Haggerty et al., 1994). Individuals among the general population exceeding PALs of 2-2.5 for long periods of time are expected to experience negative energy balance (i.e., weight loss) mainly because an important limit to sustainable metabolic rate is the energy intake (Westerterp 1998; Westerterp, 2001).

TABLE 3.~~15~~16. IOM Physical Activity Categories, Associated Breathing Rates and Equivalent Walking Distance

PAL Category	PAL midpoint value (range)	Breathing rate midpoint value	Equivalent walking distance (km /day)[a]
Sedentary	1.25 (1.0-1.39)	14.4 m^3/day	0
Low active	1.5 (1.4-1.59)	15.7 m^3/day	3.5
Active	1.75 (1.6-1.89)	17.3 m^3/day	11.7
Very active	2.2 (1.9-2.5)	19.4 m^3/day	26.9

[a] Equivalent walking distance in addition to energy expended during normal daily life, based on a 70 kg adult walking 5-6 km per hour. Adapted from Stifelman (2007) and Brooks et al. (2004)

Based on the DLW data, Stifelman's analysis indicates that human energy expenditure occurs within a fairly narrow range of activity levels (PAL in the range of 1.4-2.5), and that for breathing rates estimated by the DLW method, a breathing rate of 19.4 m^3/day (equivalent to a PAL of 2.2) is near the maximum energy expenditure that can be sustained for long periods of time in adults. This finding supports the idea that the traditional 20 m^3/day is an upper end breathing rate (Snyder et al. (1975).

The narrow range in breathing rates was found to be consistent with the daily energy expenditure estimated from the adult breathing rate distribution in Marty et al. (2002) where the range is slightly over 2-fold between the 5th and 95th percentile in Table 3.4~~7~~. A roughly 2-fold range in between the 5th and 95th percentiles is also exhibited in the MET-derived breathing rates by US EPA (2009).

3.~~3~~4.4.3 Limits of Sustainable Breathing Rates Derived from PALs

As noted above, DLW studies have shown that a PAL of approximately 2 to 2.5 in the general population of adults is the limit of sustainable energy expenditure for long periods of time (Westerterp, 2001; IOM, 2005; Stifelman, 2007). The PAL of novice athletes training for endurance runs and soldiers during field training falls within this range (Westerterp, 1998; 2001). The PAL has been found to be twice the upper limit (PALs = 3.5 to 5.5) in professional endurance athletes in the most demanding sports (cross-country skiing and cycling) during training and competition. The PALs of these professional athletes are in the right tail of the breathing rate distribution of the general

population (Westerterp, 2001). However, the high PALs are not expected to be sustained at these high levels when averaged over years.

Knowing the average basal energy expenditure (BEE) for adults and the upper range of daily energy expenditure, the upper limit of long-term daily breathing rates for the general population can be estimated from Layton's equation (eq. 3.1). Marty et al. (2002) observed that the 95th percentile breathing rate should be found within this PAL range of 2 to 2.5. Thus, it might be reasonable to compare the 95th percentile adult breathing rate calculated by other methods to the breathing rates derived from an upper limit PAL range of 2 to 2.5.

Table 3.~~16~~ 17 show the expected breathing rates of adults in a PAL range of 2.0 to 2.5. The mean BEE in kcal/day for the adult age groups is obtained from Brooks et al. (2004). Mean weights for the adult age groups were also obtained from this reference in order to convert breathing rates in L/day to L/kg-day. The results from the DLW-derived energy expenditure data suggest that for normal weight adults (i.e., adults with BMIs within the healthy range of 18.5 to 25), the upper limit of breathing rates for males and females combined would be 16,629 to 20,787 L/day, or 256 to 320 L/kg-day.

Table 3.~~16~~17. Description of the Normative Adult DLW Data from Brooks et al. (2004) for Persons with a Healthy BMI, and the Resulting Calculations of Breathing Rate Within the Sustainable PAL Range of 2.0 to 2.5

	Age years	**n**	**Mean BEE kcal/d**	**TEE limits[a] kcal/d**	**Breathing rate L/d**	**Mean weight kg**	**Breathing rate L/kg-d**
Males	19-30	48	1769	3538 - 4423	20,060 - 25,078	71.0	283 - 353
	31-50	59	1675	3350 - 4188	18,995 - 23,746	71.4	266 - 333
	51-70	24	1524	3048 - 3810	17,282 - 21,603	70.0	247 - 309
	19-70[b]	-	-	-	18,582 - 23,229	-	263 - 328
Females	19-30	82	1361	2722 - 3403	15,434 - 19,295	59.3	260 - 325
	31-50	61	1322	2644 - 3305	14,991 - 18,739	58.6	256 - 320
	51-70	71	1226	2452 - 3065	13,903 - 17,379	59.1	235 - 294
	19-70[b]	-	-	-	14,675 - 18,344	-	249 - 311
Males/ females[c]	19-70	-	-	-	16,629 - 20,787	-	256 - 320

[a] Sustainable PAL range (2.0 to 2.5) multiplied by mean BEE equals the daily total energy expenditure (TEE) that can be sustained over long periods of time.
[b] 19-70 yr breathing rates calculated as a weighted average from the three smaller age groupings
[c] Average breathing rates of males and females combined, assuming each gender represents 50% of the population.

Although the PAL limits were estimated for adults, it might also be useful to estimate high-end sustainable breathing rates for adolescents using the same assumption that a PAL of 2 to 2.5 represents the limit of sustainable energy expenditure over a long-term

period. Some of the highest daily breathing rates in L/day were calculated for adolescents from the CSFII caloric intake data (Arcus-Arth and Blaisdell, 2007).

For deriving adolescent breathing rates from the mean BEE in Brooks et al. (2004) for 14-18 year olds, an upper limit of sustainable energy expenditure would be in the range of 3458-4323 kcal/d for males, and 2722-3403 kcal/d for females. Using Layton's equation to derive the breathing rates from these daily energy expenditures, sustainable upper limit breathing rates of 22,221-27,780 L/day for adolescent males, and 18,006-22,511 L/day for adolescent females were calculated. After normalizing for weight using the mean weights for the 14-18 year age groups in Brooks et al. (2004), upper range daily breathing rates of 378-472 L/kg-day for males and 332-513 L/kg-day for females were calculated.

3.~~3~~4.5. Compilations of Breathing Rate Data

In the US EPA (2011) Exposure Factors Handbook, ranges of measured breathing rate values were compiled for infants, children and adults by age and sex. Table 3.~~17~~ 18 presents the recommended breathing rate values for males and females combined for specific age groups up to age ≥81 yrs based on the average of the inhalation rate data from four recent key studies: Brochu et al. (2006a); U.S. EPA, (2009); Arcus-Arth and Blaisdell, (2007); and Stifelman (2007). The Table represents the unweighted means and 95th percentiles for each age group from the key studies. U.S. EPA noted that there is a high degree of uncertainty associated with the upper percentiles, including the 95th percentile shown in Table 3.~~17~~18, thus they should be used with caution. The upper percentiles represent unusually high inhalation rates for long-term exposures, but were included in the handbook to provide exposure assessors a sense of the possible range of inhalation rates for children.

Table 3.~~17~~18. US EPA (2011) Recommended Long-Term Exposure (More than 30 Days) Breathing Rate Values for Infants and Children (Males and Females Combined) Averaged From Four Key Studies

Age Group	Mean m^3/day	Sources Used for Means	95th Percentile m^3/day	Sources Used for 95th-ile
Birth to <1 month	3.6	a	7.1	a
1 to <3 months	3.5	a,b	5.8	a,b
3 to <6 months	4.1	a,b	6.1	a,b
6 to <12 months Birth to <1 year	5.4 5.4	a,b a,b,c,d	8.0 9.2	a,b a,b,c
1 to <2 years	8.0	a,b,c,d,	12.8	a,b,c
2 to <3 years	8.9	a,b,c,d	13.7	a,b,c
3 to <6 years	10.1	a,b,c,d	13.8	a,b,c
6 to <11 years	12.0	a,b,c,d	16.6	a,b,c
11 to <16 years	15.2	a,b,c,d	21.9	a,b,c
16 to <21 years	16.3	a,b,c,d	24.6	a,b,c
21 to <31 years	15.7	b,c,d	21.3	b,c
31 to <41 years	16.0	b,c,d	21.4	b,c
41 to <51 years	16.0	b,c,d	21.2	b,c
51 to <61 years	15.7	b,c,d	21.3	b,c
61 to <71 years	15.7	b,c,d	18.1	b,c
71 to <81 years	14.2	b,c	16.6	b,c
≥91 years	12.2	b,c	15.7	b,c

a Arcus-Arth and Blaisdell, 2007;
b Brochu et al. 2006a;
c U.S. EPA, (2009)
d Stifelman 2007

3.~~4~~5 OEHHA-Derived Breathing Rate Distributions for the Required Age Groupings Using Existing Data.

The summarized published reports provide breathing rate distributions by month/year of age or in specific age groups, but seldom in age groups applicable to OEHHA's age groupings for cancer risk assessment. However, individual data were obtainable from the CSFII food intake study and the DLW database in the IOM (2005) report, from which breathing rate distributions could be derived in the specific age groups of third trimester, 0<2, 2<9, 2<16, 16<30, and 16-70 years. In addition, The U.S. EPA's breathing rate distributions based on the MET approach, shown in Tables 3.~~10~~ 13a and 3.~~11~~13b, can be merged to obtain the necessary age group breathing rates.

3.~~4~~5.1 OEHHA-derived breathing rates based on CSFII energy intake data

In Tables 3.~~18a~~19a-e, non-normalized (L/day) and normalized (L/kg-day) breathing rates for the specific OEHHA age groups were derived for both children and adults from

the CSFII dataset using the Jacknife Replication statistical method (Arcus-Arth and Blaisdell, 2007). Breathing rates for pregnant women, for determination of third trimester breathing rates, are presented in Section 3.5.4.

In addition, each age group was also fit to a lognormal distribution using Crystal Ball® (Oracle Corp., Redwood Shores, CA, 2009). Crystal Ball® was also used to determine the best parametric model fit for the distribution of breathing rates for each age group. The Anderson-Darling test was chosen over other goodness-of-fit tests available in Crystal Ball® because this test specifically gives greater weight to the tails than to the center of the distribution. OEHHA is interested in the tails since the right tail represents the high-end (e.g., 95th percentile) breathing rates.

Tables 3.~~18a~~19a-e. Breathing Rate Distributions by Age Group (Males and Females Combined) Derived from CSFII Food Intake Data Using Jacknife Methodology and Parameter Estimates of Log-Normally and Best Fit Distributions

Table 3.~~18a~~19a. Breathing Rate Distributions for the 0<2 Year Age Group

	Jacknife Approach		**Lognormal Parametric Model**		**Best Fit Parametric Model**	
					Max Extreme	Lognormal
N (sample)	1954	1954	-	-	-	-
Skewness	na[a]	na	0.74	0.77	1.47	0.77
Kurtosis	na	na	3.96	4.34	7.81	4.34
%-ile or mean	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
Sample Min	43	79	-	-	-	-
Mean (SE)[b]	752 (9)	7502 (91)	752 (1)	7568 (13)	752 (1)	7568 (13)
50%-ile (SE)	706 (7)	7193 (91)	720	7282	706	7282
75%-ile (SE)	870 (11)	9128 (91)	909	9201	871	9201
90%-ile (SE)	1094 (19)	11,502 (120)	1107	11,523	1094	11,523
95%-ile (SE)	1241 (24)	12,860 (170)	1241	12,895	1241	12,895
Sample Max	2584	24,411	-	-	-	-

[a] Not applicable
[b] SE = Standard error

Table 3.~~18b~~19b. Breathing Rate Distributions For the 2<9 Year Age Group

	Jacknife Approach		**Lognormal Parametric Model**		**Best Fit Parametric Model**	
					Log-normal	Lognormal
N (sample)	6144	6144	-	-	-	-
Skewness	na[a]	na	0.95	0.86	0.95	0.86
Kurtosis	na	na	4.63	4.96	4.63	4.96
%-ile or mean	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
Sample Min	144	2661	-	-	-	-
Mean (SE)[b]	595 (4)	11,684 (82)	595 (1)	11,680 (16)	595 (1)	11,680 (16)
50%-ile (SE)	567 (5)	11,303 (70)	567	11,303	567	11,303
75%-ile (SE)	702 (5)	13,611 (110)	702	13,606	702	13,606
90%-ile (SE)	857 (7)	16,010 (170)	857	16,012	857	16,012
95%-ile (SE)	975 (9)	17,760 (229)	975	17,758	975	17,758
Sample Max	1713	31,739	-	-	-	-

[a] Not applicable
[b] SE = Standard error

Table 3.~~18c~~19c. Breathing Rate Distributions for the 2<16 Year Age Group

	Jacknife Approach		**Lognormal Parametric Model**		**Best Fit Parametric Model**	
					Gamma	Max Extreme
N (sample)	7624	7624	-	-	-	-
Skewness	na[a]	na	0.74	0.75	0.91	1.46
Kurtosis	na	na	3.97	4.02	4.38	7.26
%-ile or mean	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
Sample Min	57	2661	-	-	-	-
Mean (SE)[b]	481 (5)	14,090 (135)	481 (1)	14,094 (24)	481 (1)	14,095 (24)
50%-ile (SE)	450 (5)	13,128 (110)	456	13,465	451	13,131
75%-ile (SE)	603 (4)	16,644 (189)	606	17,239	603	16,655
90%-ile (SE)	764 (6)	20,993 (361)	763	21,214	763	20,993
95%-ile (SE)	869 (6)	23,879 (498)	868	23,870	868	23,886
Sample Max	1713	53,295	-	-	-	-

[a] Not applicable
[b] SE = Standard error

Table 3.~~18d~~19d. Breathing Rate Distributions for the 16<30 Year Age Group

	Jacknife Approach		**Lognormal Parametric Model**		**Best Fit Parametric Model**	
					Max Extreme	Lognormal
N (sample)	2155	2155	-	-	-	-
Skewness	na[a]	na	0.69	1.90	1.69	1.90
Kurtosis	na	na	3.75	11.15	8.94	11.15
%-ile or mean	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
Sample Min	23	1029	-	-	-	-
Mean (SE)[b]	197 (3)	13,759 (204)	200 (<1)	13,899 (31)	200 (<1)	13,899 (31)
50%-ile (SE)	180 (3)	12,473 (125)	190	12,494	182	12,494
75%-ile (SE)	238 (4)	16,975 (245)	259	17,192	242	17,192
90%-ile (SE)	320 (4)	21,749 (305)	331	22,136	323	22,136
95%-ile (SE)	373 (11)	26,014 (634)	378	26,481	377	26,481
Sample Max	976	75,392	-	-	-	-

[a] Not applicable
[b] SE = Standard error

Table 3.~~18e~~19e. Breathing Rate Distributions for the 16-70 Year Age Group

	Jacknife Approach		**Lognormal Parametric Model**		**Best Fit Parametric Model**	
					Max Extreme	Lognormal
N (sample)	8512	8512	-	-	-	-
Skewness	na[a]	na	0.67	2.05	1.87	2.05
Kurtosis	na	na	3.74	12.35	10.67	12.35
%-ile or mean	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
Sample Min	13	740	-	-	-	-
Mean (SE)[b]	165 (2)	12,078 (134)	165 (<1)	12,074 (26)	165 (<1)	12,074 (26)
50%-ile (SE)	152 (1)	10,951 (86)	157	10,951	152	10,951
75%-ile (SE)	200 (1)	14,687 (141)	212	14,685	200	14,685
90%-ile (SE)	257 (3)	18,838 (173)	269	18,834	257	18,834
95%-ile (SE)	307 (4)	21,812 (371)	307	21,831	307	21,831
Sample Max	975	75,392	-	-		

[a] Not applicable
[b] SE = Standard error

3.~~4~~5.2 OEHHA-derived breathing rates based on the IOM DLW Database

The Institute of Medicine (IOM) 2005 dietary reference report includes an extensive database that is a compilation of DLW-derived energy expenditure results and other raw

data for individuals collected from numerous studies. An advantage of this dataset over the U.S. EPA MET approach and the TAV approaches is that individual data on energy expenditure are matched with the weight and age of the individuals. The disadvantage is that the data are not necessarily representative of a random sample of a population~~, with the possible exception of the infant energy expenditure data~~.

When breathing rates were calculated from the energy expenditure data, it became apparent that there were some extreme individual breathing rates that did not appear physically possible. Using the results from the PAL limits (Section 3.~~3~~4.4.3), breathing rates with a PAL greater than 2.5 were removed. Additionally, some breathing rates were below the expected BMR for an individual. Based on evidence that energy expenditure during sleep is 5 to 10% lower than the BMR, derived breathing rates that were 10% or more below the expected BMR were also removed (Brooks et al., 2004). However, relatively few individuals were removed due to an extreme breathing rate; <1 to 6% of the values were removed from any one age group.

Rather than assume a normal distribution for the age groupings as Brochu et al. (2006a) had done, OEHHA arranged the data to be more representative of a population by weighting the energy expenditure data by age and gender. The modeled populations were weighted towards an equal number of persons per year of age and the assumption was used that males and females in a population are at a ratio of 50:50. In addition, the IOM database separated individuals by weight, or more specifically, by body mass index (BMI). Children 3 to 18 years of age are considered at risk of overweight when their BMI is greater than the 85th percentile, and overweight when their BMI is greater than the 95th percentile (Kuczmarski et al., 2000). Thus, the IOM (2005) placed overweight/obese children in a separate dataset. For the modeled populations, an 85:15 weighting for normal:overweight children in the 2<9 and 2<16 age groups was used. Adults (>19 years of age) were placed in the overweight/obese dataset if they had BMIs of 25 kg/m^2 and higher by the IOM. The results from USDA's 1994-96 Diet and Health Knowledge Survey (Tippett and Clevelend, 2001) found that 54.6% of the U.S. population have a BMI of 25 kg/m^2 or greater (n=5530). Thus, for the adult age groups (16<30 and 16-70 yrs), 45:55 weighting for normal:overweight adults was used to model the populations.

For infants, the source of the raw data in the IOM (2005) database was from Butte et al. (2000), a DLW study conducted at the Children's Nutrition Research Center in Houston, TX. Butte et al. (2000) monitored energy expenditure in 76 healthy infants by the DLW method up to six times during the study, at 3, 6, 9, 12, 18, and 24 months of age, generating a total of 351 measurements that fell within the OEHHA-specified 0<2 year age group. Thus, many of the infants were tested more than once during the study period. Following each administration of DLW by mouth, urine samples were collected over 10 days and analyzed for the hydrogen and oxygen isotopes to calculate energy expenditure.

The percentage of breast-fed infants at ages 3, 6, 9, 12, 18, and 24 months were 100%, 80%, 58%, 38%, 15%, and 5%, respectively in the Butte et al. (2000) study. The racial

distribution by maternal lineage was 55 white, 7 African American, 11 Hispanic, and 3 Asian infants. The NCHS growth reference (Hamill et al., 1979) was used to evaluate the adequacy of growth in these infants. The growth performance of these infants was comparable with that of other breast-fed and formula-fed infant populations in whom socioeconomic and environmental constraints would not be expected to limit growth. Relative to the NCHS reference and compared with other breast-fed and formula-fed study populations, the growth of the children was considered satisfactory by the researchers.

Although the study did not choose subjects representative of any particular population, the range of activities that individuals of this age engage in is not as variable as the range of activities engaged in by older children and adults. In addition, even though many of the infants were tested more than once during the study period, repeated measures on the same individuals can reduce the amount of intraindividual variability in the distribution of measurements because a better estimate of typical energy expenditure is captured. Considering the limitations, the study results were judged by OEHHA to be similar enough to a randomly sampled population to calculate distributional statistics for breathing rate.

An additional observation from Butte et al. (2000) was that total energy expenditure measurements differed by age and by feeding group, but not by sex, when adjusted for weight. As expected, PAL increased significantly with age from 1.2 at 3 months to 1.4 at 24 months.

Breathing rates determined by the DLW method for women in their third trimester of pregnancy are presented separately in Section 3.5.4.

To obtain the daily breathing rate distributions for all age groups shown in Table 3.~~19a~~20a-e, OEHHA fit the data to a lognormal distribution using Crystal Ball® and sampled 250,000 times using Latin-Hypercube. The lognormal distribution is commonly used in stochastic risk assessment and has been found to be a reasonable parametric model for a variety of exposure parameters, including breathing rate. Latin-Hypercube analysis in Crystal Ball® was also used to determine the best parametric model fit for the distribution of breathing rates. The Anderson-Darling statistic was used for the goodness-of-fit test because it gives greater weight to the tails than to the center of the distribution.

Tables 3.~~19a~~20a-e. Breathing Rate Distributions by Age Group (Males and Females Combined) Derived from IOM (2005) DLW Database Using Parameter Estimates of Lognormal and Best Fit Distributions

Table 3.~~19a~~20a. 0<2 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Empirical Data		**Moments and Percentiles, Lognormal Parametric Model**		**Moments and Percentiles, Best Fit Parametric Model**	
N	281	281				
Skewness	-0.044	0.28	-0.001	0.44	-0.044	0.28
Kurtosis	2.10	2.59	3.00	3.35	2.10	2.59
	L/kg-day	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
					Beta	Beta
Sample Min	357	2228	-	-	-	-
Mean (SE)	567	5031	567	5031	567	5031
50%-ile	562	4967	567	4925	568	4943
80%-ile	657	6323	644	6232	655	6325
90%-ile	689	6889	685	6981	691	7042
95%-ile	713	7595	718	7638	714	7607
Sample Max	752	9210	-	-	-	-

Table 3.~~19b~~20b. 2<9 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Empirical Data		**Moments and Percentiles, Lognormal Parametric Model**		**Moments and Percentiles, Best Fit Parametric Model**	
N	810	810				
Skewness	0.0759	0.4676	0.0796	0.4763	0.0796	0.0290
Kurtosis	2.93	3.62	3.00	3.40	3.00	3.50
	L/kg-day	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
					Log-normal	Stu-dent's T
Sample Min	240	5085	-	-	-	-
Mean (SE)	482	9708	482	9708	482	9711
50%-ile	479	9637	481	9521	481	9708
80%-ile	551	11,478	555	11,650	555	11,641
90%-ile	597	12,629	595	12,880	595	12,704
95%-ile	631	13,626	628	13,962	628	13,632
Sample Max	703	21,152	-	-	-	-

Table 3.~~19c~~20c. 2<16 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Empirical Data		**Moments and Percentiles, Lognormal Parametric Model**		**Moments and Percentiles, Best Fit Parametric Model**	
N	1227	1237				
Skewness	0.2729	0.8705	0.4613	1.12	0.2729	1.14
Kurtosis	2.45	3.70	3.38	5.32	2.45	5.43
	L/kg-day	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
					Beta	Max Ext.
Sample Min	168	5328	-	-	-	-
Mean (SE)	423	12,695	423	12,700	423	12,695
50%-ile	411	11,829	414	12,000	416	11,988
80%-ile	529	16,184	517	15,833	527	15,788
90%-ile	580	18,944	576	18,328	583	18,303
95%-ile	623	20,630	628	20,694	626	20,716
Sample Max	737	27,803	-	-	-	-

Table 3.~~19d~~20d. 16<30 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Empirical Data		**Moments and Percentiles, Lognormal Parametric Model**		**Moments and Percentiles, Best Fit Parametric Model**	
N	245	245				
Skewness	0.3471	0.4786	0.4008	0.6962	0.4008	0.6962
Kurtosis	3.03	3.11	3.28	3.88	3.28	3.88
	L/kg-day	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
					Log-normal	Log-normal
Sample Min	135	7246	-	-	-	-
Mean (SE)	222	16,458	222	16,464	222	16,464
50%-ile	220	16,148	219	16,053	219	16,053
80%-ile	256	19,468	259	19,395	259	19,395
90%-ile	282	21,954	282	21,410	282	21,410
95%-ile	308	23,295	302	23,231	302	23,231
Sample Max	387	26,670	-	-	-	-

Table 3.~~19e~~20e. 16-70 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Empirical Data		**Moments and Percentiles, Lognormal Parametric Model**		**Moments and Percentiles, Best Fit Parametric Model**	
N	842	846				
Skewness	0.4264	0.6323	0.4506	0.7346	0.4506	0.7346
Kurtosis	3.18	3.32	3.36	3.98	3.36	3.98
	L/kg-day	**L/day**	**L/kg-day**	**L/day**	**L/kg-day**	**L/day**
					Log-normal	Log-normal
Sample Min	95	7235	-	-	-	-
Mean (SE)	206	15,713	206	15,715	206	15,715
50%-ile	204	15,313	203	15,282	203	15,282
80%-ile	241	18,773	243	18,664	243	18,664
90%-ile	268	20,612	266	20,687	266	20,687
95%-ile	286	22,889	286	22,541	286	22,541
Sample Max	387	29,136	-	-	-	-

3.~~4~~5.3 OEHHA Age Group Breathing Rate Distributions Derived From U.S. EPA (2009) MET Approach

In Tables 3.~~20a~~21a-e, non-normalized (L/day) and normalized (L/kg-day) breathing rates for the specific OEHHA age groups were derived for both children and adults from the data included in the U.S. EPA (2009) report and presented above. Values for males and females were combined by taking weighted averages for each age range provided, assuming that the numbers of males and females in the population are equal. Ages were combined by the same means to create the age ranges of toxicological interest to the "Hot Spots" program.

The breathing rates used in preparation of the U.S. EPA report were derived by selecting an activity pattern set from a compilation of daily activity pattern sets (CHAD) and assigning them to a person in NHANES of the same sex and age group, although the age groups are fairly narrow for the very young (i.e., 3-month or 1-year intervals), the older age groups consist of broad age categories (i.e., 3 to 5 year intervals). These broad age groups include periods, for example 3 to <6 years, when activity can vary greatly by year of age. In addition, NHANES calculates a "sampling weight" for each participant, which represents the number of individuals in the population with the same set of these characteristics. When an individual in CHAD is matched to an individual in NHANES only on sex and age group, the set of characteristics that belonged to the CHAD individual are ignored, which could result in significantly different weighting. Thus the derived breathing rates cannot be considered representative of the population.

For these reasons and other limitations of the EPA data, as stated in Section 3.3.3.3, OEHHA chose to fit a selected set of parametric distributions to the percentile data given by U.S. EPA, rather than attempting to use the raw data to determine the best fit parametric model. A gamma distribution was fit to each age group using Crystal Ball®, which is usually one of the better fitting distributions for the right-skewed distributions typical of intake variability. The gamma distribution is a three parameter distribution with fewer shape constraints than two parameter distributions such as a lognormal distribution.

Table 3.~~20a~~21a-e. Normalized and Non-Normalized Breathing Rate Distributions by Age Group (Males and Females Combined) Derived From U.S. EPA (2009) Breathing Rates Using a Gamma Parameter Estimate Distribution

Table 3.~~20a~~21a. 0<2 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Gamma Parametric Model	
N	1601	1601
	L/kg-day	**L/day**
Mean	1125	10,711
50%-ile	1104	10,489
75%-ile	1199	12,301
90%-ile	1302	14,104
95%-ile	1372	15,271

Table 3.~~20b~~21b. 2<9 Year Age Group Breathing Rate Distribution[a]

	Moments and Percentiles, Gamma Parametric Model	
N	4396	4396
	L/kg-day	**L/day**
Mean	597	12,758
50%-ile	591	12,518
75%-ile	662	13,911
90%-ile	732	15,375
95%-ile	776	16,176

[a] Breathing rate data for this age range were actually available for 2<11 years of age

Table 3.~~20c~~21c. 2<16 Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Gamma Parametric Model	
N	7657	7657
	L/kg-day	**L/day**
Mean	449	13,365
50%-ile	440	13,106
75%-ile	496	14,694
90%-ile	555	16,426
95%-ile	595	17,609

Table 3.~~20d~~21d. 16<30 Year Age Group Breathing Rate Distribution[a]

	Moments and Percentiles, Gamma Parametric Model	
N	6111	6111
	L/kg-day	**L/day**
Mean	221	16,005
50%-ile	215	15,469
75%-ile	244	17,984
90%-ile	275	20,699
95%-ile	296	22,535

[a] Breathing rate data for this age range were actually available for 16<31 years of age

Table 3.~~20e~~21e. 16-70[a] Year Age Group Breathing Rate Distribution

	Moments and Percentiles, Gamma Parametric Model	
N	16,651	16,651
	L/kg-day	**L/day**
Mean	219	16,937
50%-ile	214	16,515
75%-ile	245	18,924
90%-ile	278	21,443
95%-ile	299	23,128

[a] Breathing rate data for this age range were given as 16<71 years of age

A limitation in calculating these breathing rates is that equal weighting by year of age was assumed when merging the U.S. EPA breathing rates into larger age groups used by OEHHA. However, this may not be a significant factor for the smaller age groups (i.e., 3rd trimester, 0<2, 2<9, 2<16, 16<30 yr old age groups), but could affect the

breathing rate estimate for the 16-70 year olds. This is because a random sample of the population would find proportionally fewer adults in the 61 to 70 year age range, for example, compared to 21 to 30 year age range.

Another limitation is that merging the U.S. EPA age groups into the OEHHA age groupings does not yield the precise age range for 2<9 and 16 to <30 year olds. The actual age range in the US EPA data used to get the 16 to <30 year olds is 16 to <31, which we do not consider a significant deviation. However, the actual age range in the US EPA data used to get the 2 to <9 year olds is 2 to <11 years. The addition of 9 and 10 year olds would slightly reduce the normalized breathing rate in L/kg-day because younger children (i.e., 2<9 year olds) have higher normalized breathing rates than older children (i.e., 9-10 year olds). Alternatively, addition of 9 and 10 year olds to the 2<9 year age group would slightly increase the absolute breathing rate in L/day due to higher volumes of air breathed per day by 9 and 10 year olds compared to younger children.

3.5.4 OEHHA-Derived Third Trimester Breathing Rates

For third trimester exposure, OEHHA calculated breathing rates using the assumption that the dose to the fetus during the third trimester was the same as that to the mother. Both the CSFII and DLW data sets included data from pregnant women that could be used to calculate breathing rates (Table 3.22). The DLW data included a code for trimester of pregnancy, while the CSFII data did not. Thus, breathing rates by the CSFII method was estimated using data for women in all stages of pregnancy with no means for separation by stage of pregnancy. OEHHA believes this would not underestimate the third trimester breathing rates, since the CSFII breathing rate data tend to overestimate the breathing rate in the upper (e.g., 95th percentile) and lower percentiles for the reasons cited in Section 3.4.3.2. Since breathing rate increases over the course of pregnancy, we felt that we could successfully combine these data with the DLW data and produce a reasonable set of point estimates for the third trimester.

In order to create a set of breathing rate data suitable for use in a stochastic risk assessment for third trimester pregnant women, we selected 1,000 observations from each set of data, normalized and non-normalized, using a Monte Carlo simulation in Crystal Ball®. Because the data sets from the two sources were similar in size, a relatively small set of simulated data was sufficient. We combined these data to create two sets of pooled data (see Section 3.2 above). We then fit a parametric distribution to each of the pooled samples, using Crystal Ball® and the Anderson-Darling goodness-of-fit test.

Table 3.22. Normalized and Non-Normalized Breathing Rate Distributions for Women in Their Third Trimester of Pregnancy: OEHHA-Derived Values from Doubly-Labeled Water (DLW) and Continuing Survey of Food Intake of Individuals (CSFII) Databases

	DLW L/kg BW-day	CSFII L/kg BW-day	DLW L/day	CSFII L/day
Distribution	Lognormal	Gamma	Lognormal	Gamma
Minimum	150	78	10,316	4,025
Maximum	348	491	23,932	29,041
Mean	220	232	15,610	14,830
Median	210	216	15,196	14,311
Std Dev	46	92	3,118	5,326
Skewness	1.19	0.5575	0.7744	0.4393
Kurtosis	4.04	2.57	3.57	3.02
Percentiles				
1%	150	84	10,316	4,025
5%	161	104	10,809	7,714
10%	174	127	11,846	8,201
25%	192	155	13,750	11,010
50%	210	216	15,196	14,311
75%	241	302	17,343	18,153
80%	246	323	17,832	19,114
90%	280	363	18,552	21,799
95%	322	392	22,763	24,349
99%	348	490	23,932	28,848

3.5.5 Summary of Long-Term Daily Breathing Rate Distributions

Table 3.23 presents a summary of the long-term daily mean and high end (i.e., 95th percentile) breathing rates derived by OEHHA from different sets of energy expenditure data. The breathing rate distributions for women in their third trimester of pregnancy are presented separately in Table 3.22 above. The MET- (non-normalized only), CSFII- and DLW-derived breathing rates in Table 3.22 are based on the best fit parametric models for each age group, although little variation in the breathing rate was observed between models within each breathing rate method. Also included are data from TAV studies that estimated breathing rates in age groupings reasonably similar to that used by OEHHA.

As noted in Table 3.23, some of the age groupings for the MET-derived breathing rates, and all age groups in the TAV-derived breathing rates do not precisely reflect the age ranges used in the "Hot Spots" program. This was primarily due to methodological differences in data collection which did not allow individual breathing rates matched with the age of the individual. However, the differences in the age ranges were small

enough in many cases to allow a rough comparison among the various breathing rate estimation methods, so they were included in the table.

TABLE 3.23. Summary of Breathing Rate by Study and Age Group

	0<2 yrs L/kg-day		**2<9 yrs L/kg-day**		**2<16 yrs L/kg-day**		**16<30 yrs L/kg-day**		**16-70 yrs L/kg-day**	
	mean	**95th**	**mean**	**95th**	**mean**	**95th**	**mean**	**95th**	**mean**	**95th**
MET[a]	1125	1372	597[b]	776[b]	449	595	221[c]	296[c]	219	299
CSFII[d]	752	1241	595	975	481	868	200	377	165	307
DLW[e]	567	713	482	628	423	626	222	302	206	286
TAV[f]										
Marty et al.	-	-	-	-	452[g]	580.5[g]	-	-	232[h]	381[h]
Allan et al.	-	-	-	-	-	-	-	-	201[e]	280[e]
	0<2 yrs L/day		**2<9 yrs L/day**		**2<16 yrs L/day**		**16<30 yrs L/day**		**16-70 yrs L/day**	
	mean	**95th**	**mean**	**95th**	**mean**	**95th**	**mean**	**95th**	**mean**	**95th**
MET[a]	10,711	15,271	12,758	16,176	13,365	17,609	16,005	22,535	16,937	23,128
CSFII[d]	7568	12,895	11,680	17,758	14,095	23,886	13,899	26,481	12,074	21,831
DLW[e]	5031	7595	9711	13,632	12,695	20,716	16,464	23,231	15,715	22,541
TAV[f]										
Marty et al.	-	-	-	-	8,100[g]	10,500[g]	-	-	14,600[h]	24,000[h]
Allan et al.	-	-	-	-	-	-	-	-	16,160[i]	22,480[i]

[a] U.S. EPA metabolic equivalent (MET) approach breathing rate point estimates shown were derived using the best fit parametric model from Tables 3.20a-e.
[b] All MET-derived breathing rates for the 2<9 yr age group actually represent 2<11 yr olds.
[c] All MET-derived breathing rates for the 16<30 yr age group actually represent 16<31 yr olds.
[d] CSFII food intake-derived breathing rate point estimates shown were derived using the best fit parametric model as presented in Tables 3.18a-e.
[e] Doubly-labeled water-derived (DLW) breathing rate point estimates shown were derived using the best fit parametric model as shown in Tables 3.19a-e.
[f] Time-activity-ventilation (TAV) breathing rate point estimates are from Table 3.3 (Marty et al. 2002) and Table 3.5 (Allan et al., 2008).
[g] The breathing rate point estimates from Table 3.3 actually represent an age range of about 3 to <12 yrs old. The non-normalized breathing rate point estimates in L/day is the equivalent for an 18 kg child.
[h] The breathing rate point estimates from Table 3.4 actually represent an age range of 12 to 70 years old. Non-normalized breathing rate point estimates in L/day are the equivalent for a 63 kg adult.
[i] Breathing rate point estimates were derived from Table 3.5 and represent an age range of 12 to 60+ years. The point estimates were calculated assuming equal weighting for each age group (12-19 yrs, 20-59 yrs, 60+ yrs) and combined. Breathing rates in Table 3.5 were available only in L/day, so the non normalized point estimates were both divided by the mean body weight for the 16-70 age group (80.3 kg) to generate breathing rates in L/kg-day.

The DLW energy expenditure data likely result in daily breathing rates that are slightly lower in some cases than what would be expected in a random population sample, particularly for adults (Black et al., 1996). On the other hand, U.S. EPA (2008) observed that the upper percentile breathing rates for the MET and CSFII approaches are unusually high for long-term daily exposures. Based on the limits of sustainable daily breathing rates for adolescents and adults discussed in Section 3.4.4.3, the 95th percentile breathing rates in Table 3.22 appear to be above sustainable limits for some age groups. For example, the CSFII-generated upper percentile breathing rates are

highest in the age groups containing older adolescents. The 16<30 year age group upper percentile breathing rate from the CSFII study is 377 L/kg-d. This breathing rate is above the sustainable breathing rate (based on PAL) of 283-353 L/kg-d for males 19-30 years of age shown in Table 3.16 (but is not above the sustainable breathing rates for the subgroup of males and females 14-18 yrs of age with a breathing rate of 332-513 L/kg-d).

A limitation of the estimated PALs for daily breathing rates determined in Tables 3.15 and 3.17 is that the participants used in the study may not reflect a random sample of the population. Nevertheless, the observed PAL of novice athletes training for endurance runs and soldiers during field training falls within this range of 2.0-2.5 (Westerterp, 1998; 2001). Thus, the breathing rates based on physical activity limits should be accurate for the general population, with the exception of professional endurance athletes in the most demanding sports (cross-country skiing and cycling) during training and competition.

With the advantages and disadvantages of the breathing rate datasets described in Section 3.2, OEHHA recommends using a daily breathing rate point estimates based on a mean of the DLW and CSFII approaches. The main benefit is the use of individual data from these two datasets, including individual body weights, which can be combined into one distribution. In order to create a set of breathing rate data suitable for use in a stochastic risk assessment of long-term daily average exposures, OEHHA combined data for each age range within the two sources of breathing rate data, CSFII and DLW. We selected an equal number of observations from each source for the five age ranges, normalized and non-normalized, using a Monte Carlo simulation in Crystal Ball® to create pooled data for each group. We then fit a parametric distribution to each of the pooled samples, using Crystal Ball® and the Anderson-Darling goodness-of-fit test.

For infants 0<2 yrs of age, OEHHA used the DLW data by Butte et al. (2000) for combining with CSFII study 0<2 yr data. This longitudinal study followed a group of about 40 infants collecting urine every 3 months after DLW administration from age 3 months to two years of age. The sample size was not considered large enough to use this data exclusively for determining the 0<2 yr breathing rates, so was combined with CSFII data of infants in the same age range.

3.~~5~~6 8-Hour Breathing Rates

Specialized exposure scenarios for estimating cancer risk to offsite workers, neighborhood residents, and school children may involve evaluating exposure in the 8-12 hour range~~, and emissions may occur at times when exposed off-site individuals are either largely sleeping (e.g., facility emissions occurring only at night) or awake (e.g., facility emissions occurring during the day)~~. Therefore, 8-hour breathing rates were estimated for exposed individuals engaged in activities that bracket the range of breathing rates including minimal inhalation exposure~~,~~ such as ~~during sleeping/napping~~reading a book and desk work, and high breathing rates such as farm work or yard work, that can be reasonably sustained for an 8-hour period.

As part of the development of average daily breathing rates, U.S. EPA (2009) used existing data on minute ventilation rates (in ml/min or ml/kg-min) for a range of activities and assigned MET values depending on the intensity level of activity:

- Sedentary/Passive Activities: Activities with MET values no higher than 1.5
- Light Intensity Activities: Activities with MET values exceeding 1.5 to ≤3.0
- Moderate Intensity Activities: Activities with MET values exceeding 3.0 to ≤6.0
- High Intensity Activities: Activities with MET values exceeding 6.0

An additional ventilation rate distribution was developed for sleeping/napping only, although the sedentary/passive activity category (MET values ≤1.5) also includes sleeping and napping. Table 3.~~21~~ 23 shows selected MET values for various workplace activities and activities in the home or neighborhood that were used to calculate daily breathing rates by U.S. EPA (2009).

Table 3.~~21~~23. METS Distributions for Workplace and Home Activities

Activity Description	Mean	Median	SD	Min	Max
Workplace Activities					
Administrative office work	1.7	1.7	0.3	1.4	2.7
Sales work	2.9	2.7	1.0	1.2	5.6
Professional	2.9	2.7	1.0	1.2	5.6
Precision/production/craft/repair	3.3	3.3	0.4	2.5	4.5
Technicians	3.3	3.3	0.4	2.5	4.5
Private household work	3.6	3.5	0.8	2.5	6.0
Service	5.2	5.3	1.4	1.6	8.4
Machinists	5.3	5.3	0.7	4.0	6.5
Farming activities	7.5	7.0	3.0	3.6	17.0
Work breaks	1.8	1.8	0.4	1.0	2.5
Household/Neighborhood Activities					
Sleep or nap	0.9	0.9	0.1	0.8	1.1
Watch TV	1.0	1.0	-	1.0	1.0
General reading	1.3	1.3	0.2	1.0	1.6
Eat	1.8	1.8	0.1	1.5	2.0
Do homework	1.8	1.8	-	1.8	1.8
General personal needs and care	2.0	2.0	0.6	1.0	3.0
Indoor chores	3.4	3.0	1.4	2.0	5.0
Care of plants	3.5	3.5	0.9	2.0	5.0
Clean house	4.1	3.5	1.9	2.2	5.0
Home repairs	4.7	4.5	0.7	4.0	6.0
General household chores	4.7	4.6	1.3	1.5	8.0
Outdoor chores	5.0	5.0	1.0	2.0	7.0
Walk/bike/jog (not in transit) age 20	5.8	5.5	1.8	1.8	11.3
Walk/bike/jog (not in transit) age 30	5.7	5.7	1.2	2.1	9.3
Walk/bike/jog (not in transit) age 40	4.7	4.7	1.8	2.3	7.1

MET values and hr/day spent at these various activities were used by U.S. EPA (2009) to calculate selected minute ventilation rates shown in Table 3.~~22a~~24a-b.

Table 3.~~22a~~24a. Descriptive Statistics for Minute Ventilation Rates (L/min-kg) While Performing Activities Within the Specified Activity Category (US EPA, 2009)

Age Category (years)	Males				Females			
	Mean	50th	90th	95th	Mean	50th	90th	95th
	Sedentary & Passive Activities[a] (METS ≤ 1.5)							
Birth to <1	0.40	0.39	0.47	0.50	0.40	0.40	0.48	0.52
1	0.41	0.40	0.49	0.52	0.43	0.42	0.51	0.54
2	0.34	0.34	0.41	0.45	0.36	0.35	0.42	0.44
3 to <6	0.25	0.25	0.33	0.35	0.25	0.25	0.33	0.36
6 to <11	0.16	0.16	0.21	0.22	0.16	0.16	0.21	0.23
11 to <16	0.10	0.10	0.13	0.14	0.10	0.09	0.12	0.13
16 to <21	0.08	0.08	0.09	0.10	0.07	0.07	0.10	0.10
21 to <31	0.06	0.06	0.08	0.08	0.06	0.06	0.07	0.08
31 to <41	0.07	0.07	0.08	0.09	0.06	0.06	0.08	0.08
41 to <51	0.07	0.07	0.09	0.09	0.06	0.06	0.08	0.09
51 to <61	0.07	0.07	0.09	0.09	0.07	0.07	0.08	0.09
61 to <71	0.08	0.08	0.09	0.09	0.07	0.07	0.08	0.08
	Light Intensity Activities (1.5 < METS ≤ 3.0)							
Birth to <1	0.99	0.97	1.17	1.20	0.98	0.96	1.18	1.23
1	1.02	1.01	1.22	1.30	1.05	1.04	1.25	1.27
2	0.84	0.83	1.00	1.03	0.90	0.89	1.04	1.10
3 to <6	0.63	0.63	0.79	0.87	0.62	0.60	0.78	0.83
6 to <11	0.38	0.38	0.49	0.53	0.38	0.38	0.50	0.54
11 to <16	0.25	0.24	0.31	0.33	0.23	0.22	0.28	0.31
16 to <21	0.18	0.18	0.22	0.23	0.17	0.17	0.21	0.22
21 to <31	0.16	0.15	0.19	0.21	0.15	0.15	0.18	0.19
31 to <41	0.16	0.16	0.20	0.21	0.15	0.15	0.19	0.20
41 to <51	0.17	0.16	0.20	0.21	0.16	0.16	0.20	0.22
51 to <61	0.17	0.16	0.20	0.22	0.16	0.16	0.20	0.21
61 to <71	0.16	0.16	0.19	0.20	0.15	0.14	0.17	0.18
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)							
Birth to <1	1.80	1.78	2.18	2.28	1.87	1.85	2.25	2.40
1	1.88	1.82	2.33	2.53	1.90	1.87	2.24	2.37
2	1.55	1.54	1.84	2.02	1.60	1.58	1.92	2.02
3 to <6	1.17	1.12	1.56	1.68	1.14	1.11	1.45	1.56
6 to <11	0.74	0.71	0.96	1.04	0.72	0.71	0.94	1.01
11 to <16	0.49	0.47	0.64	0.68	0.44	0.43	0.55	0.61
16 to <21	0.39	0.38	0.49	0.52	0.36	0.35	0.46	0.49
21 to <31	0.36	0.34	0.47	0.51	0.33	0.32	0.42	0.45
31 to <41	0.36	0.34	0.47	0.52	0.32	0.30	0.41	0.46
41 to <51	0.37	0.35	0.47	0.52	0.33	0.32	0.44	0.49
51 to <61	0.38	0.37	0.48	0.55	0.34	0.33	0.44	0.49
61 to <71	0.34	0.34	0.40	0.42	0.29	0.28	0.35	0.37

[a] Sedentary and passive activities includes sleeping and napping

Table 3.~~22b~~24b. Descriptive Statistics for Minute Ventilation Rates (L/min) While Performing Activities Within the Specified Activity Category (US EPA, 2009)

Age Category (years)	Males				Females			
	Mean	50th	90th	95th	Mean	50th	90th	95th
	Sedentary & Passive Activities[a] (METS ≤ 1.5)							
Birth to <1	3.18	3.80	4.40	4.88	3.00	2.97	4.11	4.44
1	4.62	5.03	5.95	6.44	4.71	4.73	5.95	6.63
2	4.79	5.35	6.05	6.71	4.73	4.67	5.75	6.22
3 to <6	4.58	5.03	5.58	5.82	4.40	4.34	5.29	5.73
6 to <11	4.87	5.40	6.03	6.58	4.64	4.51	5.88	6.28
11 to <16	5.64	6.26	7.20	7.87	5.21	5.09	6.53	7.06
16 to <21	5.76	6.43	7.15	7.76	4.76	4.69	6.05	6.60
21 to <31	5.11	5.64	6.42	6.98	4.19	4.00	5.38	6.02
31 to <41	5.57	6.17	6.99	7.43	4.33	4.24	5.33	5.79
41 to <51	6.11	6.65	7.46	7.77	4.75	4.65	5.74	6.26
51 to <61	6.27	6.89	7.60	8.14	4.96	4.87	6.06	6.44
61 to <71	6.54	7.12	7.87	8.22	4.89	4.81	5.86	6.29
	Light Intensity Activities (1.5 < METS ≤ 3.0)							
Birth to <1	7.94	7.95	10.76	11.90	7.32	7.19	9.82	10.80
1	11.56	11.42	14.39	15.76	11.62	11.20	15.17	15.80
2	11.67	11.37	14.66	15.31	11.99	11.69	15.63	16.34
3 to <6	11.36	11.12	13.40	14.00	10.92	10.69	12.85	13.81
6 to <11	11.64	11.26	14.60	15.60	11.07	10.79	13.47	14.67
11 to <16	13.22	12.84	16.42	18.65	12.02	11.76	14.66	15.82
16 to <21	13.41	12.95	16.95	18.00	11.08	10.76	13.80	14.92
21 to <31	12.97	12.42	16.46	17.74	10.55	10.24	13.40	14.26
31 to <41	13.64	13.33	16.46	18.10	11.07	10.94	13.11	13.87
41 to <51	14.38	14.11	17.39	18.25	11.78	11.61	13.85	14.54
51 to <61	14.56	14.35	17.96	19.37	12.02	11.79	14.23	14.87
61 to <71	14.12	13.87	16.91	17.97	10.82	10.64	12.62	13.21
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)							
Birth to <1	14.49	14.35	20.08	22.50	13.98	13.53	19.41	22.30
1	21.35	20.62	26.94	28.90	20.98	20.14	27.09	29.25
2	21.54	20.82	26.87	29.68	21.34	21.45	27.61	28.76
3 to <6	21.03	20.55	25.60	27.06	20.01	19.76	23.83	25.89
6 to <11	22.28	21.64	27.59	29.50	21.00	20.39	26.06	28.08
11 to <16	26.40	25.41	33.77	36.93	23.55	23.04	28.42	31.41
16 to <21	29.02	27.97	38.15	42.14	23.22	22.39	30.28	31.98
21 to <31	29.19	27.92	38.79	43.11	22.93	21.94	30.02	32.84
31 to <41	30.30	29.09	39.60	43.48	22.70	21.95	28.94	31.10
41 to <51	31.58	30.44	40.28	44.97	24.49	23.94	30.79	33.58
51 to <61	32.71	31.40	41.66	45.77	25.24	24.30	31.87	35.02
61 to <71	29.76	29.22	36.93	39.98	21.42	20.86	25.72	27.32

[a] Sedentary and passive activities includes sleeping and napping

In order to obtain minute ventilation rates that represent age ranges used in risk assessment for the "Hot Spots" program, age groups in Tables 3.~~23a~~25a-b were weighted equally by year of age and combined by OEHHA. The male and female data were also merged assuming 50:50 ratio in the California population. Two of the age groups combined from the U.S. EPA MET data do not exactly reflect the age ranges used by OEHHA, but they were judged reasonably close enough to use (i.e., combined MET ages 2 to <11 yrs represents OEHHA's 2<9 yr age group; combined MET ages 16 to <31 yrs represents OEHHA's 16<30 yr age group).

Table 3.~~23a~~25a. Minute Ventilation Rates for OEHHA Age Groups in L/kg-min (Males and Females Combined)

	0<2 years	**2<9 years**	**2<16 years**	**16<30 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	0.41	0.21	0.17	0.07	0.07
95th Percentile	0.52	0.29	0.24	0.09	0.09
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	1.01	0.52	0.42	0.16	0.16
95th Percentile	1.25	0.70	0.56	0.21	0.21
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	1.86	0.97	0.79	0.36	0.35
95th Percentile	2.40	1.33	1.09	0.49	0.48

Table 3.~~23b~~25b. Minute Ventilation Rates for OEHHA Age Groups in L/min (Males and Females Combined)

	0<2 years	**2<9 years**	**2<16 years**	**16<30 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	3.88	4.67	4.94	4.85	5.27
95th Percentile	5.60	6.22	6.66	6.73	6.96
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	9.61	11.34	11.79	11.92	12.56
95th Percentile	13.57	14.80	15.67	16.15	16.24
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	17.70	21.25	22.58	26.08	26.95
95th Percentile	25.74	28.07	30.25	37.67	37.65

From these tables, the 8-hour breathing rates were calculated by OEHHA based on age groupings used in the Hot Spots program and are presented in Section 3.2~~7 2 below~~. Eight-hour breathing rates based on high intensity activities (MET values >6.0) were not considered here because even at the 95th percentile, U.S. EPA (2009) showed that individuals spent only about 1 hour or less per day at this intensity. For moderate intensity activities, the 95th percentile was at or near 8 hours/day for some age groups.

For women in their third trimester of pregnancy, we are recommending using breathing rates based on moderate intensity activities.

3.~~6~~7 Short-term (1-Hour) Ventilation Rates

SB-352 mandates school districts to conduct a risk assessment for school sites located within 100 meters of a freeway or busy roadway, and also mandates that the AB-2588 risk assessment guidance be used in the risk assessment. Assessing cancer risks due to exposure at a school site requires less than 24 hour breathing rates. OEHHA recommends breathing rates derived from the USEPA (2009) age-specific ventilation rates for these purposes.

The U.S. EPA ventilation rates were developed for various levels of activities and can be used to estimate inhalation cancer risk from short-term maximal emissions from facilities. Breathing rates for children at school can range from sedentary in the classroom to active on the playground or sports field. OEHHA assumes that in some cases, a day care facility will be present on the school site where children may be as young as 0<2 years of age. The age ranges that U.S. EPA (2009) presents are useful for estimating the impact of early-in-life exposure for school-age children. Classroom instructors (i.e., adults) are also considered under SB-352. If the soil ingestion or dermal pathways need to be assessed, OEHHA recommends the exposure variates presented elsewhere in this document. The public health protective approach is to assume that all daily dermal and soil ingestion exposure occurs at school.

As discussed in Section 3.~~5~~ 6 above, U.S. EPA (2009) used existing data of ventilation rates (in ml/min or ml/kg-min) from a range of activities and assigned MET values depending on the intensity level of activity. Table 3.~~24~~ 26 shows MET values various school-related activities collected from the CHAD database (U.S. EPA, 2009).

~~(activities with METs values exceeding 3.0 to ≤ 6.0) were used to represent the typical range of children at play during recess.~~

Table 3.~~24~~26. METS Distributions for School-Related Activities

Activity Description	Mean	Median	SD	Min	Max
Passive sitting	1.5	1.5	0.2	1.2	1.8
Use of computers	1.6	1.6	0.2	1.2	2.0
Do homework	1.8	1.8	-	1.8	1.8
Use library	2.3	2.3	0.4	1.5	3.0
Attending day-care	2.3	2.3	0.4	1.5	3.0
Attending K-12 schools	2.1	2.1	0.4	1.4	2.8
Play indoors	2.8	2.8	0.1	2.5	3.0
Play outdoors	4.5	4.5	0.3	4.0	5.0
Recess and physical education	5.0	5.0	1.7	2.0	8.0

For OEHHA's purposes, the minute ventilation rates of males and females from Tables 3.~~22a~~24a-b were combined assuming a 50:50 proportional population distribution, and some age groups were combined assuming equal number of individuals in the population per year of age (Table 3.~~24a~~27a-b). For the SB-352, the child age groups were 0<2 years (infants), 2<6 years (preschool, kindergarten), 6<11 years (grade

school), 11<16 (junior high and high school). From these minute ventilation rates, 1-hour breathing rates are derived and presented in Section 3.~~7.1~~2.

Table 3.~~24a~~27a. Minute Ventilation Rates for SB352 School Sites in L/kg-min (Males and Females Combined)

	0<2 years	**2<6 years**	**6<11 years**	**11<16 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	0.41	0.28	0.16	0.10	0.07
95th Percentile	0.52	0.38	0.23	0.14	0.09
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	1.01	0.69	0.38	0.24	0.16
95th Percentile	1.25	0.90	0.54	0.32	0.21
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	1.86	1.26	0.73	0.47	0.35
95th Percentile	2.40	1.72	1.03	0.65	0.48
	High Intensity Activities (METS ≥ 6.0)				
Mean	-	2.27	1.37	0.92	0.64
95th Percentile	-	3.12	1.87	1.34	0.93

Table 3.~~24b~~25b. Minute Ventilation Rates for SB352 School Sites in L/min (Males and Females Combined)

	0<2 years	**2<6 years**	**6<11 years**	**11<16 years**	**16-70 years**
	Sedentary & Passive Activities (METS ≤ 1.5)				
Mean	3.88	4.56	4.76	5.43	5.27
95th Percentile	5.60	5.95	6.43	7.47	6.96
	Light Intensity Activities (1.5 < METS ≤ 3.0)				
Mean	9.61	11.31	11.36	12.62	12.56
95th Percentile	13.57	14.38	15.14	17.24	16.24
	Moderate Intensity Activities (3.0 < METS ≤ 6.0)				
Mean	17.70	20.75	21.64	24.98	26.95
95th Percentile	25.74	27.16	28.79	34.17	37.66
	High Intensity Activities (METS ≥ 6.0)				
Mean	-	37.34	41.51	48.69	50.10
95th Percentile	-	49.66	58.50	69.62	73.23

No high intensity minute ventilation rates are included in Tables 3.~~24a~~25a-b for infants age 0<2 yrs. The distributions generated by U.S. EPA (2009) for hrs/day spent at MET values ≥6.0 for infants (age 0<2 yrs) suggest that this level of activity for a 1-hr duration is unlikely for this age group.

SB-352 is also designed to protect adults working at the schools, including pregnant women. For women in their third trimester of pregnancy, OEHHA is recommending

using breathing rates of moderate intensity activities based on the same reasoning cited above in Section 3.6.

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4. SOIL INGESTION

4.1 Introduction

There is general consensus that hand-to-mouth activity results in incidental soil ingestion, and children ingest more soil than adults. Soil ingestion rates vary depending on the age of the individual, frequency of hand-to-mouth contact, seasonal climate, amount and type of outdoor activity, the surface on which that activity occurs, and personal hygiene practices. The specified age ranges of toxicological interest in the "Hot Spots" program are ages third trimester<2, 0<2, 2<9, 2<16, 16<30 and 16-70 years.

At present, the knowledge of soil ingestion patterns within the United States is limited. A few researchers in the U.S. have attempted to quantify soil ingestion patterns in children, and have performed studies in a few locales mainly in the northern parts of the United States. The limited information shows that children may ingest fairly substantial amounts of soil on a per-kilogram-body-weight basis, and their soil ingestion pattern is important in understanding and estimating their overall exposures to environmental toxicants from contaminated soil.

The Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (ATSDR) has developed definitions for soil ingestion, soil-pica, and geophagy, to distinguish aspects of soil ingestion patterns that are important from a research perspective (ATSDR, 2001):

- ***Soil ingestion*** is defined as the intentional or unintentional consumption of soil. This may result from various behaviors including, but not limited to, mouthing, contacting dirty hands, eating dropped food, or consuming soil directly.

- ***Soil-pica*** is a form of intentional or unintentional soil ingestion of unusually high amounts of soil (i.e., on the order of 1,000 - 5,000 milligrams per day).

- ***Geophagy*** is a form of soil ingestion defined as the intentional ingestion of earths usually associated with cultural practices.

The "soil" ingested could be from outdoor soil, containerized soil for indoor plants, or a combination of both. ~~Children could ingest soil from outside as well as from soil in indoor potted plants.~~ The soil ingestion recommendations in this document represent ingestion of combined "soil" and outdoor settled dust. Outdoor settled dust is derived from particles that deposited or settled on outdoor objects and surfaces. It is not possible to differentiate between soil and outdoor settled dust. The "dust" found indoors includes soil tracked inside the building or blown indoors through opened windows and doors, particles from building

materials or consumer products, human and animal dander, and particles drawn in by the house's heating and air conditioning system.
The source of "dust" in indoor environments can be quite variable. Many studies provided dust or soil ingestion estimates on pollutants that have both indoor and outdoor sources. For some pollutants it is often difficult to determine the percentage which each of these sources contributed to the amount of soil or dust ingested. Many pollutants emitted from stationary outdoor sources can also come from important indoor sources. For example, lead from lead paint is probably the major source of lead found in indoor dust. The contribution of lead emitted from stationary sources to indoor dust is probably minor compared to that from lead paint but is difficult to pinpoint. Thus, pollutants found in indoor dust from many studies may ~~overestimate~~ misinterprete the amount contributed from stationary sources.

Soil ingestion has been documented in U.S. children and adults in several studies that use a "tracer element" methodology. The tracer element methodology attempts to quantify amounts of soil ingested by analyzing samples of soil from residences, and by analyzing samples of excreta (feces, and sometimes also urine). The soil, fecal, and urine samples are analyzed for the presence and quantity of tracer elements - typically, aluminum, silicon, titanium, and yttrium, and other elements. Because these metals/metalloids are not metabolized or absorbed to an appreciable extent in the gut, their presence in feces and urine can be used to estimate the quantity of soil ingested.

However, there is some evidence that tracer elements such as aluminum and silicon can be absorbed in small amounts from the digestive tract (Davis and Mirick, 2006). None of the studies using this methodology attempt to quantify amounts excreted in perspiration, tears, glandular secretions, shed skin, hair or nails. Entry into the body via the dermal and inhalation routes was not examined. Early studies usually did not account for the contribution of tracer elements from non-soil substances (food, medications, and non-food sources such as toothpaste) that children might swallow. Some studies adjusted the soil ingestion estimates to account for the potential contribution of tracer elements found in household dust as well as soil.

The amount of soil ingested is calculated from the quantity of the tracer element measured in the feces and urine minus that present in the food and medicine consumed. This number is then divided by the soil concentration of the tracer element to yield an estimate of ingested soil. Most of the studies assumed a lag time of 24 to 28 hours between ingestion and resulting fecal and urine output. Thus, the previous day's food, medications and non-food quantity of the tracer element is subtracted from that found in the current day's feces and urine excreted. An estimation of the amount of soil ingested daily can be obtained by dividing the total amount of soil ingested by the number of days in which the feces and urine were collected.

In the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008), U.S. EPA includes the "biokinetic model comparison" and "survey response" methods in the document to assess soil and dust ingestion in children. The biokinetic model methodology is used mainly to estimate children's exposure to lead. This model compares lead exposure and uptake to predict children's blood lead levels with biomarker blood measurements.

The model predictions are made using assumptions about ingested soil and dust amounts that are based on the tracer element methodology. The survey response method uses the responses to survey questions regarding soil and dust ingestion. This method includes questions about children's soil and dust ingestion behaviors, frequency, and sometimes the quantity ingested. The respondents are the children themselves, or their caregivers.

4.2 Soil Ingestion Recommendations [This section was moved from the back of the chapter to the front of the chapter.]

4.2.1 Incidental Soil Ingestion

Before 1997, the U.S. EPA (1989, 1991) used 200 mg/day as a soil ingestion rate for children one through six years of age. In 1997, in the *Exposure Factors Handbook*, U.S. EPA recommends 100 mg/day as a mean for children under six, but indicates 200 mg could be used as a conservative estimate of the mean as it is consistent with the data.

U.S. EPA (2008) in the *Child-Specific Exposure Factors Handbook* recommended values (central tendency, mg/d) for soil, and soil and dust combined of 30, 60 (age 6 to <12 months), 50, 100 (age 1 to <6 years), and 50, 100 (age 6 to <21 years), respectively. The 90th and 95th percentile values from the key studies were used together with other data to derive a number for pica soil ingestion (above 1000 mg/d). We think that it is not appropriate to assume that the 90th and 95th percentile values in the children's studies are due to pica behavior as in any group of children there will be those that will consume more soil than the average.

OEHHA supports the U.S. EPA (2008) recommendations of 100 mg/day as the central tendency of the combined soil and dust ingestion rate for children aged 1 to <6 years. This number was rounded down from the actual number of 110 mg/d. Using 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (Table 4-13), and assuming this group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Figure 4-17), soil and dust ingestion in other age groups are estimated (Table 4-18 and Table 4-19).

OEHHA calculated mean and 95th percentile soil and dust ingestions estimates (mg/kg BW-day) for the 3rd trimester < 2 by assuming that the soil and dust ingestions rate in mg/kg-day for the fetus was the same as for the mother (ages 16<30) and doing a time weighted average for the third trimester and ages 0 < 2.

OEHHA recommends the following point estimate soil and dust ingestion rates for children of various age groups and adults. Due to insufficient data, OEHHA has not developed distributions of soil ingestion data. Thus, this pathway is evaluated through the point estimate approach only.

Table 4.1 Recommended Soil Ingestion Estimates for Adults and Children (mg/kg-day)*

Age Groups (years)	**Mean (mg/kg-day)**	**95th % (mg/kg-day)**
3rd Trimester[a]	0.7	3
0 < 2	20	40
2<9	5	20
2<16	3	10
9<16[b]	2	7
16<30	0.7	3
16to70	0.6	3
PICA children[c]	200	-
PICA adult	NR	-

The mean weights for various age groups (with exceptions, see below) are from Chapter 10, Table 10.8

[a] Assumed to be the mother's soil ingestion rate (adult age 16 <30)

[b] Estimated mean body weight for this age group 55 kg

[c] Estimated mean body weight used for the PICA children 30 kg

* Soil includes outdoor settled dust

4.3 Algorithm for Dose from Soil Ingestion

4.3.1 Inadvertent Soil Ingestion by Adults and Children

The dose from inadvertent soil ingestion by adults can be estimated using the following general equation:

$$DOSEsoil = Csoil \times GRAF \times SIR \times EF \times (1 \times 10^{-9}) \quad \text{(Eq. 4-312)}$$

~~AT~~

where:

DOSEsoil = dose from soil ingestion (mg/kg body weight-day)

1×10^{-9} = conversion factor (μg to mg of contaminant, and kg to mg soil)
Csoil = concentration of contaminant in soil (μg/~~Kg~~ kg soil)
GRAF = gastrointestinal relative absorption fraction, unitless
SIR = soil ingestion rate (mg/kg BW-day)
EF = exposure frequency (days/year), EF = 350 d/yr (allows 2 weeks vacation away from residence)

~~ED = exposure duration (years)~~
~~AT = averaging time, period of time over which exposure is averaged (days); for noncancer endpoints, AT = ED × 365 d/yr; for cancer risk estimates, AT = 70 yr × 365 d/yr = 25,550 d~~

The annual average soil concentration in the Hot Spots model is determined by air dispersion models and the half life of the chemical in the soil. The term GRAF, or gastrointestinal relative absorption factor, is defined as the fraction of contaminant absorbed by the GI tract relative to the fraction of contaminant absorbed from the matrix (feed, water, other) used in the study(ies) that is the basis of either the cancer potency factor (CPF) or the reference exposure level (REL). If no data are available to distinguish absorption in the toxicity study from absorption from the environmental matrix in question, soil in this case, then the default assumption is that the GRAF = 1. The GRAF allows for adjustment for absorption from a soil matrix if it is known to be different from absorption across the GI tract in the study used to calculate the CPF or REL. At present that information is available only for polychlorinated dibenzo-p-dioxins and dibenzofurans. The GRAF for those compounds is 0.43. All others have a GRAF of 1.

The exposure frequency (EF) is the fraction of time spent at a residence or offsite work place, and is set at 350 days per year (i.e., per 365 days) to allow for two weeks per year away from home ~~following~~ (US EPA, ~~(~~1991).

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (POTENCY):

RISKsoil = DOSEsoil *POTENCY*ASF*ED/AT **(Eq. 4-2)**

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (see OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the DOSEsoil and ED are different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = exposure duration (yrs):
0.25 yrs for third trimester (ASF = 10)

	2 yrs for 0<2 age group	(ASF = 10)
	7 yrs for 2<9 age group	(ASF = 3)
	14 yrs for 2<16 age group	(ASF = 3)
	14 yrs for 16<30 age group	(ASF = 1)
	54 yrs for 16-70 age group	)ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKsoil_{(lifetime)} = RISKsoil_{(3rdtri)} + RISKsoil_{(0<2\ yr)} + RISKsoil_{(2<16\ yr)} + RISKsoil_{(16\text{-}70yr)} \quad \textbf{(Eq. 4-3)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential exposure scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$RISKsoil_{(9\text{-}yr\ residency)} = RISKsoil_{(3rdtri)} + RISKsoil_{(0<2\ yr)} + RISKsoil_{(2<9\ yr)} \quad \textbf{(Eq. 4-4)}$$

For 30-year residential exposure scenario, the 2<16 and 16<30 age group RISKsoil would be added to the risks for third trimester and age 0<2.~~.~~ For 70 year residential risk, Eq 4-3 would apply.

~~4.32.2 Inadvertent Soil Ingestion by Children~~

As described earlier, children have been divided into the following age groups with respect to soil ingestion rate: 0 to <2 years, 2 to <9 years, and 2 to <16 years of age. In addition, soil ingestion estimates are calculated for the adult age groups, 16 to < 30 years, and 16 to 70 years of age. In Section 4.7, OEHHA recommends soil ingestion rates for the 9, 30 and 70 year exposure duration scenarios.

The exposure duration scenarios evaluate the first 9, 30 and 70 years of an individual's life. The evaluation of the 9, 30 and 70 year exposure durations represent central tendency, 90th- 95th and lifetime of residency time. The evaluation of the 0 to <2 years, 2 to <9 years, 9 < 16 years, 16 to < 30 years, and 30 to 70 years age groupings are needed in order to properly estimate cancer risk for the age ranges as specified in *The Technical Support Document for Cancer Potency Factors: Methodologies for Derivation, Listing of Available Values, and Adjustments to Allow for Early Life Stage Exposures* (OEHHA, 2009).

For children, OEHHA is recommending that 9.7, 21.9, and 37.0 kg be used for the body weight for the 0 to <2, 2 to <9 and 2 to <16 year-old groups, respectively, for exposure duration determination of dose from soil ingestion (Chapter 10). For the 16 to <30 and 16 to70 year exposure duration scenarios, OEHHA recommends that 75.9 and 80.0 kg body weight, respectively, be used for the body weight term (Chapter 10). These body weights have been incorporated into the recommended soil consumption rates (mg/kg body weight-day). Care should be taken in using the appropriate ED and EF values for each sub-age grouping as well as the appropriate AT. Pica children are analyzed separately as described in Section 4.6.

4.3.~~3~~2 Inadvertent Soil Ingestion by Offsite Workers

The impact zone of a facility may include offsite workplaces. Risk estimates for those offsite workers include exposure from incidental soil ingestion for multi-pathway chemicals. Equation 4-3~~2~~ can be used, but the exposure is adjusted for the time at work by multiplying by 5/7 days, 50/52 weeks, and 46/70 years (a total adjustment of 0.15). This adjustment is meant to account for soil ingestion occurring while at work. The assumption inherent in the exposure adjustment is that one third of the daily soil ingestion occurs at work. For those who work outdoors this assumption may underestimate exposure, and could be an overestimation for those who work mainly indoors.

4.4~~3~~ SOIL INTAKE - KEY CHILDREN STUDIES

4.4~~3~~.1 Davis and Co-workers Studies

4.4~~3~~.1.1 Davis et al. (1990)

In this study, 104 toilet-trained children between the ages of 2 and 7 years were randomly recruited from a three-city area in southeastern Washington State. The study was conducted over a seven day period, primarily during the summer. A mass-balance/tracer technique was used to estimate soil ingestion. Daily soil ingestion was evaluated by analyzing soil and house dust, feces, urine, and duplicate food samples for aluminum, silicon, and titanium. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil intake rates among children. The soil intake rates were corrected for the amount of tracer in vitamins and medications.

Soil ingestion rates were highly variable, especially those based on titanium. Mean daily soil ingestion estimates were 39 mg/day for aluminum, 82 mg/day for silicon and 246 mg/day for titanium (Table 4-~~1~~2). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. The differences in concentrations of the tracer elements in house dust and yard soil were adjusted to estimate soil ingestion rates.

Table 4.2~~1~~ Soil Ingestion Values From Davis et al. (1990)

Tracer Element[a]	Mean (mg/d)	Median (mg/d)	Standard Error of the Mean (mg/d)	Range (mg/d)[b]
Aluminum	38.9	25.3	14.4	279.0 to 904.5
Silicon	82.4	59.4	12.2	-404.0 to 534.6
Titanium	245.5	81.3	119.7	-5,820.8 to 6,182.2

a Excludes three children who did not provide any samples (n=101).
b Negative values occurred as a result of correction for non-soil sources of the tracer elements.

The adjusted mean soil/dust intake rates were 65 mg/day for aluminum, 160 mg/day for silicon, and 268 mg/day for titanium. Adjusted median soil/dust intake rates were: 52 mg/day for aluminum, 112 mg/day for silicon, and 117 mg/day for titanium.

The soil ingestion range includes negative numbers, which is indicative of a basic difficulty in estimating soil ingestion rates using the mass balance approach. If fecal output does not correspond to the food/medicines sampled due to factors such as the variation in transit time in the gut, then the calculated soil ingestion rate will be inaccurate. Overcorrecting for the presence of tracer elements in foods and medicines can bias the soil ingestion estimates downward, producing negative soil ingestion estimates which are obviously impossible. Likewise, if the food that was digested to produce the fecal sample contained more tracer elements than the food that was sampled, the soil ingestion rate can be biased in the positive.

In addition, the following demographic characteristics were found to be associated with high soil intake rates: male sex, racial groups other than white, low income, operator/laborer as the principal occupation of the parent, and city of residence. However, none of these factors were predictive of soil intake rates when tested using multiple linear regression.

Although a relatively large sample population was surveyed, these children were all from a single area of the U.S. and may not be representative of the U.S. population as a whole. The study was conducted over a one-week period during the summer and may not be representative of long term (i.e., annual) or seasonal patterns of soil intake.

4.4~~3~~.1.2 Davis and Mirick, 2006

The study used a subset of the 104 families who participated in the soil ingestion study by Davis *et al.* (1990). The data for this study were collected one year prior to the Davis *et al.* (1990) study. Nineteen families were selected in this study.

Each family consisted of one child participant between the age of 3 and 7, and one female and one male parent or guardian living in the same house. Samples were collected for 11 consecutive days of all food items consumed, all feces excreted, twice-daily urine, and soil/house dust. Tracer elements for this study included aluminum, silicon and titanium. In addition, parents completed a daily diary of the activities for 4 consecutive days for themselves and the participant child during the study period.

For children, the mean and median estimates for all three tracers ranged from 36.7 to 206.9 mg/day and 26.4 to 46.7 mg/day, respectively, and fall within the range of those reported by Davis *et al.* (1990). Adult soil ingestion estimates ranged from 23.2 to 624.9 mg/day for mean values and from 0 to 259.5 mg/day for median values, and were more variable than for the children in the study regardless of the tracer element used. The authors believed that this higher variability in adult soil ingestion rates may be attributed to occupational exposure in some, but not all, of the adults. Similar to the Davis *et al.* (1990) study, the soil ingestion estimates were the highest for titanium.

Various behaviors were found to be associated with increased soil ingestion in this study such as reported eating of dirt (for children), occupational contact with soil (for adults), and hand washing before meals (for both children and adults). Within the same family, a child's soil ingestion was not found to be associated with the parent's soil ingestion, nor did the mother and father's soil ingestion appear to be correlated. Although toothpaste is a known source of titanium, the titanium content of the toothpaste used by study participants was not determined.

An advantage of this study is that it examines soil ingestion among children and adults in the same family. However, the sample population was small and the families were a subset of those in a previous study, chosen for their high compliance to the study protocol. Thus, the uncertainties from the previous study still exist.

Table 4.3~~2~~ Soil Ingestion Values From Davis and Mirick (2006)

Participant	Tracer Element	Estimated Soil Ingestion (mg/day)			
		Mean	Median	Standard Deviation	Maximum
Child[b]	Aluminum	36.7	33.3	35.4	107.9
	Silicon	38.1	26.4	31.4	95.0
	Titanium	206.9	46.7	277.5	808.3
Mother[c]	Aluminum	92.1	0	218.3	813.6
	Silicon	23.2	5.2	37.0	138.1
	Titanium	359.0	259.5	421.5	1394.3
Father[d]	Aluminum	68.4	23.2	129.9	537.4
	Silicon	26.1	0.2	49.0	196.8
	Titanium	624.9	198.7	835.0	2899.1

[a] For some study participants, estimated soil ingestion resulted in a negative value. These estimates have been set to 0 mg/day for tabulation and analysis.
[b] Results based on 12 children with complete food, excreta, and soil data.
[c] Results based on 16 mothers with complete food, excreta, and soil data.
[d] Results based on 17 fathers with complete food, excreta, and soil data.

4.4~~3~~.2 Binder and Co-workers Study

4.4~~3~~.2.1 Binder et al. (1986)

Binder *et al.* (1986) used a tracer technique modified from a method previously used to measure soil ingestion among grazing animals to study the ingestion of soil among children. The children were studied during the summer of 1984 as part of a larger study of residents living near a lead smelter in East Helena, Montana.

Binder *et al.* (1986) measured tracer elements in feces to estimate soil ingestion by young children 1 to 3 years of age who wore diapers. Soiled diapers collected over a three day period from 65 children (42 males and 23 females), and composite samples of soil obtained from 59 of these children's yards were

analyzed for aluminum, silicon, and titanium. It was assumed that the soil ingested by these children originated largely from their own yards. The soil tracer elements were assumed to be minimally absorbed in the GI tract and minimally present in the children's diet. Soil ingestion by each child was estimated based on an assumed fecal dry weight of 15 g/day. Tracer elements were assumed to be neither lost nor introduced during sampling.

Daily soil ingestion rates based on aluminum, silicon and titanium are presented in Table 4.4~~3~~. The minimum soil ingestion presented in the table is based on the lowest of three estimates of soil ingestion in each subject. The minimum is presented because of the failure to account for the presence of the three tracers in ingested foods, medicines, and other sources such as toothpaste. Estimates from aluminum and silicon were comparable. However, much higher soil ingestion estimates were obtained using titanium as a tracer suggesting that there may be an unrecognized source of titanium that the children were ingesting or the tracer element was introduced during the laboratory processing of stool samples.

Table 4.4~~3~~ Soil Ingestion Rates (mg/day) From Binder et al. (1986)

Tracer:	Aluminum	Silicon	Titanium
Mean	181	184	1834
Standard deviation	203	175	3091
Range	25-1324	31-799	4-17,076
Median	121	136	618
95th percentile	584	578	9590
Geometric mean	128	130	401

The advantages of this study are that a relatively large number of children were studied and tracer elements were used to estimate soil ingestion. However, there were several methodological difficulties with the protocol pointed out by the investigators. The tracers ingested in foods and medicines were not accounted for which leads to overestimation of soil ingestion rates. Rather than using measured fecal weights, the investigators assumed a dry fecal weight of 15 g/day for each child. This may lead to either over- or underestimation of soil ingestion rates. Measuring fecal weights was difficult because the entire diaper (including urine) was collected, and as much stool as possible recovered from the diaper.

This was a short-term study and, as with all the studies on soil ingestion rates, the data may not be entirely representative of longer-term soil ingestion rates. Finally, the children may not be a representative sample of the U.S. population.

4.4.3 Calabrese and Co-workers Studies

a. Amherst, Massachusetts Studies

4.4~~3~~.3.1 Calabrese et al. (1989)

Sixty-four children between one and four years old in the Amherst, Massachusetts area were studied. Soil ingestion rate was based on measurements of eight tracer elements: aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium, and a method similar to Binder *et al.* (1986) but including a mass balance approach was used. Duplicate meal samples, including vitamins and medicines, were collected for all children from Monday through Wednesday of two consecutive weeks, while fecal and urine samples were collected over four 24-hour periods from noon Monday through noon Friday in the corresponding weeks.

Soil and dust samples were collected from each child's home and play areas. Children were given toothpaste, diaper rash ointment and other hygiene products that contained trace to no levels of the tracer elements. Blanks of diaper and commode specimens using distilled water were collected to control for introduced tracer. Waste samples from a single 24-hour period were pooled as were soil samples which represented composite samples from the three areas in which the child played the most.

In addition, these investigators also provided a validation study in six adult volunteers, age 25-41, for three consecutive days (Monday to Wednesday, breakfast and dinner) for three weeks. The volunteers ingested empty gelatin capsules in week one, gel capsules containing 50 mg sterilized soil in week two, and gel capsules containing 250 mg soil in week three. Duplicate food samples were collected as in the children's study and total excretion was collected Monday through Friday for the three study weeks. Soil was determined to be non-contaminated in terms of priority pollutants and contained enough of each tracer element to be detectable in the excreta.

The adult validation study indicated that study methodology could adequately detect soil ingestion at rates expected by children. The ingestion of soil in the second week was accompanied by a marked increase in fecal excretion of tracer that could not be accounted for by variability of tracer in food. Recovery data from the adult study indicated that aluminum, silicon, yttrium, and zirconium had the best recoveries (closest to 100%) while barium and manganese grossly exceeded 100% recovery. Both these elements were deemed unreliable due to their relatively higher concentrations in food relative to soil. Zirconium as a tracer was highly variable and titanium was not reliable in the adult studies. The investigators conclude that aluminum, silicon, and yttrium are the most reliable tracers for soil ingestion. Also see description of Calabrese *et al.* (1990).

The results of the soil ingestion calculations for children based on excretory tracer levels minus food tracer levels (Table 4.5~~4~~) indicate a median value between 9 mg/day for yttrium and 96 mg/day for vanadium. There was a large

degree of interindividual variation, with one or two extreme outliers. The mean estimates were considerably higher than the median in most cases.

Table 4.5~~4~~ Soil Ingestion Results (mg/day) For Children Aged 1 To 4 Years From Calabrese et al. (1989)

Tracer:	Aluminum	Silicon	Titanium	Vanadium	Yttrium	Zirconium
Mean	153	154	218	459	85	21
Median	29	40	55	96	9	16
SD	852	693	1150	1037	890	209
95th %	223	276	1432	1903	106	110
Max	6837	5549	6707	5676	6736	1391

One child in this study exhibited pica behavior. The high soil ingestion rates for this child may or may not be applicable to other soil pica children or, over time, even to this one child. However, it is interesting to note that this study did pick up a child with this behavior.

There are a number of methodological difficulties in attempting to quantify soil ingestion using the tracer methodology. Food (including vitamins and medicines), soil, and fecal material are analyzed for specific tracer elements in a mass balance approach to estimate soil ingestion. The assumption is that the tracer elements measured in the feces are exclusively from the food and medicines analyzed. However, transit time through the gut varies widely. The fecal sample may not represent the food/medicine sample input. This input-output misalignment can underestimate soil ingestion and could result in negative soil ingestion estimates.

The other main type of error in tracer studies for estimating soil ingestion is source error. Source error occurs when an unknown or unaccounted for source of the tracer element is ingested by the study subjects. The soil ingestion estimate can be inflated since it is assumed that soil is the source of tracer.

However, this study is useful in several ways. The mass balance approach attempts to correct for ingestion of tracer such as titanium in foods, medicines, and toothpaste. The validation regimen in adults points out the most reliable tracers and validates the overall methodology. The complete sample collection of urine and feces in this study obviates the need to assume a fecal weight for calculating soil ingestion estimates. A relatively large population was studied, but it may not be entirely representative of the U.S. population because it was selected from a single location. The results presented in this paper have been superseded by more refined analyses of the same data by the authors (Stanek and Calabrese, 1995a and 1995b).

4.4~~3~~.3.2 Calabrese and Stanek (1992)

This study estimated the amount of outdoor soil in indoor dust using statistical modeling. Data from 60 homes in the Calabrese *et al.* (1989) study were used to develop scatter plots of each tracer concentration in soil (outdoor) versus dust (indoor) for the subject population. The scatter plots show little evidence of a consistent relationship between outdoor soil and indoor dust concentrations.

The assumption is that 50% of excess fecal tracers were from indoor origin. Multiplying this by the model prediction that 31.3% of indoor dust came from outdoor soil resulted in an estimate that 15% of excess fecal tracers were from soil material present in indoor dust. These analyses indicate that approximately 65% of the total fecal tracer was of soil origin and the estimates of median outdoor soil ingestion presented in the earlier study should be reduced by 35%. The revised soil ingestion estimates are reduced from 29 to19 mg/d based on aluminum, 40 to 26 mg/d based on silicon, and 9 to 6 mg/d based on yttrium.

The model uses several simplifying assumptions: a) the amount of dust produced every day from both indoor and outdoor sources in a house is constant for all houses, b) the proportion of indoor dust due to outdoor soil is constant for all houses, and c) the concentration of the tracer element in dust produced from indoor sources is constant for all houses. The validity of these assumptions cannot be evaluated and subsequent papers by the authors did not make use of this adjustment.

4.4~~3~~.3.3 Stanek and Calabrese (1995a)

Stanek and Calabrese (1995a) reanalyzed the soil ingestion study by Calabrese *et al.* (1989). The individual daily soil ingestion estimates (64 subjects for 8 days) were used to develop distributions of values for 365 days for each subject using an assumed lognormal distribution. All soil ingested was assumed to come from outdoors and food intake was directly linked with fecal output. Daily soil ingestion estimates were made for each element and each study subject. The study links the food samples with the fecal samples in an attempt to more accurately estimate soil ingestion rates. In addition, the tracers were ranked according to their usefulness, and criteria for excluding certain soil ingestion estimates were incorporated into the reanalysis.

Negative estimates were replaced with a value of 1 mg/day. For each day and subject, medians, and lower and upper bounds of soil ingestion rate were calculated for the eight tracers. The lower and upper bounds functioned as exclusion criteria. If a soil ingestion rate estimate fell outside the bounds, it was assumed to be invalid and discarded. The investigators took estimates of the means and medians of the subjects' daily soil ingestion and constructed their cumulative distributions.

The results indicate that mean soil ingestion estimates over the study period of four to eight days were 45 mg/day or less for 50% of the children and

208 mg/day or less for 95% of the children. The median daily soil ingestion estimates were 13 mg/day or less for 50% of the children studied, and 138 mg/day or less for 95% of the children studied.

The median of the distribution of average daily soil ingestion extrapolated over 365 days is 75 mg, while the 95th percentile is 1751 mg/day. The median of the distribution of median soil ingestion estimates is 14 mg/day while the 95th percentile is 252 mg/day. The range of upper 95th percentiles of the median soil ingestion rate estimates for 63 kids (exclusive of the one pica child) is 1 to 5623 mg/day.

Stanek and Calabrese (1995a) also evaluated the presence of soil pica using their distribution methodology. They estimated that on 35-40 days of the year, 16% of children would ingest more than 1 gram/d of soil and 1.6% would ingest more than 10 grams/d.

Table 4.6~~5~~ Estimates of Children (%) Exceeding Certain Soil Ingestion Rates from Stanek and Calabrese (1995a)

Soil Ingestion Rate	Days per year of excessive soil ingestion		
	1-2	7-10	35-40
> 1 gram	63%	41%	16%
> 5 grams	42%	20%	1.6%
>10 grams	33%	9%	1.6%

There are many limitations to the study, one of which is the assumption of lognormal distributions to estimate daily soil ingestion over 365 days. There is little empirical evidence to support its use. The number of samples needed to capture typical intake over a year would be considerably more and seasonal variability would need to be taken into account. There are methodological difficulties in quantifying the distribution of soil ingestion rates such as assuming that the transit time in the gut was the same for all subjects and did not vary within subjects. The correction used is unlikely to be adequate to account for the input-output misalignment error, probably resulting in the negative soil ingestion estimates as obtained in Calabrese *et al.* (1989).

There are large discrepancies between trace elements estimates of soil ingestion for the same subject on the same day. The outlier criterion was used to correct for the likelihood that ingestion of some tracers occurred from other sources than food or soil. The exclusion methodology (using the median as a reference point rather than the mean) did not indicate how many data points were excluded or what those data points were. However, the effect of these exclusions is probably small as indicated by comparing the distributions of the mean estimates (where three or fewer elements are used following exclusion) with the distribution of the mean estimates (where no elements are excluded).

Short term studies are often all that are available to extrapolate to long term intakes needed for risk assessment. However, the limitations need to be acknowledged and the data available must be sufficient to perform the quantification.

4.4~~3~~.3.4 Stanek and Calabrese (1995b)

Stanek and Calabrese (1995b) reanalyzed the data from their 1989 study with data from Davis *et al.* (1990) using a different methodology from that used in Stanek and Calabrese (1995a). The Best Tracer Method (BTM), based on the food to soil ratio, is designed to overcome inter-tracer inconsistencies in the estimation of soil ingestion rates. It is assumed that tracers with a low food to soil ratio lead to more precise soil ingestion estimates because confounding from the tracer content of food is decreased.

The combined data from the two studies (Calabrese *et al.* 1989 and Davis *et al.* 1990) were used to construct estimates of the food to soil (F/S) ratio for each trace element for each subject/week. The F/S ratio was calculated by dividing the average daily amount of a trace element ingested from food by the soil trace element concentration per gram soil. For each subject/week, these ratios were ranked lowest to highest. The F/S ratio is small when the tracer concentration in food is almost zero compared to the tracer concentration in soil. A small F/S ratio is desirable because it lessens the impact of transit time error. This error occurs when fecal output does not reflect food ingestion, due to fluctuation in gastrointestinal transit time. Distributions of soil ingestion estimates are presented based on the various ranked tracers for both children (Calabrese *et al.* 1989; Davis *et al.* 1990) and adults (Calabrese *et al.* 1990).

In contrast to the Stanek and Calabrese (1995a) study, negative values for soil ingestion estimates were included in the distributions. This would shift the distribution towards lower ingestion estimates. While it is valuable to eliminate source error as much as possible by utilizing elements with low F/S ratios, the presence of negative soil ingestion estimates is indicative that there still is a problem with input-output misalignment. Negative soil ingestion estimates are biologically meaningless, and incorporating these values into a distribution is problematic. Distributions of soil ingestion estimates from the combined studies for children are presented in Table 4.~~6~~7.

Table 4.7~~6~~ Distributions of Soil Ingestion Estimates (mg/d) in Children from Stanek and Calabrese (1995b)

Studies	Percentiles						Mean ± SD	Min	Max
	10th	25th	50th	90th	95th	99th			
A[a]	-6	9	33	110	154	226	132 ± 1006	-97	11,415
B[b]	-52	-15	44	210	246	535	69 ± 146	-404	905
A and B	-12	10	37	156	217	535	104 ± 758	-404	11,415

Table based on element groupings formed by ranked food:soil ratios.
[a] Study A: data from Calabrese et al., 1989
[b] Study B: data from Davis et al., 1990

Based on the 64 children in the Calabrese *et al.* (1989) study and using the median soil ingestion estimates from the best four tracers, the mean soil ingestion rate was 132 mg/day and the median soil ingestion rate was 33 mg/day. The 95th percentile value was 154 mg/day. For the 101 children in the Davis *et al.* (1990) study, the mean soil ingestion rate was 69 mg/day and the median soil ingestion rate was 44 mg/day. The 95th percentile estimate was 246 mg/day. When the Calabrese *et al.* (1989) and Davis *et al.* (1990) studies were combined, soil ingestion rates for children were estimated to be 104 mg/day (mean), 37 mg/day (median) and 217 mg/day (95th percentile), using the BTM. When the adult data from the Calabrese *et al.* (1990) study were reevaluated, soil ingestion rates were estimated to be 64 mg/day (mean), 87 mg/day (median), and 142 mg/day (95th percentile), using the BTM.

This study combines data from two studies of children, one from southwestern Washington and one from Massachusetts, thus increasing the number of observations. It also corrects for some differences associated with tracer metabolism. The limitations associated with the data used in this study are the same as the limitations described earlier in the summaries of the Calabrese *et al.* (1989), Davis *et al.* (1990) and Calabrese *et al.* (1990) studies.

b. Anaconda, Montana Studies

4.4~~3~~.3.5 Calabrese et al. (1997)

Sixty-four children ages 1-3 years and predominantly from two-parent households living on a Superfund site in Anaconda, Montana were selected for this study. Thirty-six of the 64 children were male, and the children ranged in age from 1 to 3 years with approximately an equal number of children in each age group. The study was conducted for seven consecutive days during a two week period in the month of September.

Duplicate samples of meals, beverages, and over- the-counter medicines and vitamins were collected over the seven day period, along with fecal samples. In addition, soil and dust samples were collected from the children's home and play areas. Toothpaste containing non-detectable levels of the tracer elements, with the exception of silica, was provided to all of the children. Infants were provided with baby cornstarch, diaper rash cream, and soap which were found to contain low levels of the tracer elements. The mass-balance methodology similar to that in Calabrese *et al.* (1989) was used.

As in Calabrese *et al.* (1989), an additional study was conducted in which the mass-balance methodology was used on adults in order to validate that soil ingestion could be detected. Known amounts of soil were administered to ten adults (5 males, 5 females) from Western Massachusetts over a period of 28 days. Each adult ingested for 7 consecutive days: a) no soil during Week 1, b) 20 mg of sterilized soil during Week 2, c) 100 mg of sterilized soil during Week 3, and d) 500 mg of sterilized soil during Week 4. Duplicate food and fecal samples were collected every day during each study week and analyzed for the eight tracer elements (aluminum, silicon, titanium, cerium, lanthanum, neodymium, yttrium, and zirconium). The authors determined that a soil ingestion of 200 to 500 mg/day could be detected in a reliable manner.

Soil ingestion by each tracer element was estimated using the Best Tracer Method (BTM), which allows for the selection of the most recoverable tracer for a group of subjects (Stanek and Calabrese, 1995b). The median soil ingestion estimates for the four best trace elements based on food:soil ratios for the 64 children are presented in Table 4-8~~7~~. The best estimate was calculated by taking the median of these four trace elements. Based on the soil ingestion estimate for the best tracer, the mean soil ingestion rate was 66 mg/day and the median was 20 mg/day. The 95th percentile value was 283 mg/day. Using the median of the 4 tracers, the mean was 7 mg/day and the 95th percentile was 160 mg/day.

These results are lower than the soil ingestion estimates obtained by Stanek and Calabrese (1995a). The investigators believed that families, who participated in this study, were aware that they lived on an EPA Superfund site and this knowledge might have resulted in reduced exposure. There was no statistically significant difference found in soil ingestion estimates by gender or age, by housing or yard characteristics (i.e., porch, deck, door mat, etc.), or between children with or without pets.

The advantages of this study were a consecutive seven day study period rather than two periods of 3 and 4 days (Stanek and Calabrese, 1995a), the use of the BTM, and the use of a dietary education program to reduce food tracer input and variability.

Table 4.8~~7~~ Soil Ingestion Estimates for 64 Anaconda Children (mg/day) Based on Food:Soil Ratios for Aluminum, Silicon, Titanium, Yttrium, and Zirconium[b]

Tracer	Soil Ingestion (mg/day)[a]										
	Percentile							Min	Max	Mean	SD
	5th	10th	25th	50th	75th	90th	95th				
Median[b]	-91.0	-53.8	-38.0	-2.4	26.8	73.1	159.8	-101.3	380.2	6.8	74.5
Best	-24.4	-14.4	2.2	20.1	68.9	223.6	282.4	-53.4	609.9	65.5	120.3
2nd best	-62.1	-48.6	-26.6	1.5	38.4	119.5	262.3	-115.9	928.5	33.2	144.8
3rd best	-88.9	-67.0	-52.0	-18.8	25.6	154.7	376.1	-170.5	1293.5	31.2	199.6
4th best	-171.0	-131.9	-74.7	-29.3	0.2	74.8	116.8	-298.3	139.1	-34.6	79.7

[a] Negative values occurred as a result of calculating child-specific estimates for multiple days. For example, negative estimates of soil ingestion occurred when an individual child had low, but positive, soil ingestion, but the standard deviation was large.
[b] Median value of best four tracers

Table 4.9~~8~~ Dust Ingestion Estimates for 64 Anaconda Children (mg/day) Based on Food/Dust Ratios for Aluminum, Silicon, Titanium, Yttrium, and Zirconium[b]

Tracer	Dust Ingestion (mg/day)[a]										
	Percentile							Min	Max	Mean	SD
	5th	10th	25th	50th	75th	90th	95th				
Median[b]	-186.2	-152.7	-69.5	-5.5	62.8	209.2	353.0	-261.5	683.9	16.5	160.9
Best	-193.8	-91.0	-20.8	26.81	198.1	558.6	613.6	-377.0	1499.4	127.2	299.1
2nd best	-147.2	-137.1	-59.1	7.6	153.1	356.4	409.5	-239.8	1685.1	82.7	283.6
3rd best	-247.5	-203.1	-81.7	-14.4	49.4	406.5	500.5	-375.7	913.2	25.5	235.9
4th best	-365.6	-277.7	-161.5	-55.1	52.4	277.3	248.8	-542.7	6120.5	81.8	840.3

[a] Negative values occurred as a result of calculating child-specific estimates for multiple days. For example, negative estimates of dust ingestion occurred when an individual child had low, but positive, dust ingestion, but the standard deviation was large.
[b] Median value of best four tracers.

However, the data presented in this study are from a single seven-day period during September which may not reflect soil ingestion rates for longer time-periods or other seasonal months. The net residual negative error indicates probably an underestimation in the soil ingestion rates. The investigators estimated that this error is unlikely to affect the median value by more than 40 mg/day. Since the data from half of the distribution are negative, it is difficult to place a lot of confidence in the soil and dust ingestion estimates obtained.

4.4~~3~~.3.6 Calabrese et al. (1996)

In this study Calabrese *et al.*, (1996) examined the hypothesis that differences in soil tracer concentrations could be related to soil particle size. Soil that was used

by Calabrese *et al.* (1997) from Anaconda, Montana was reanalyzed for the tracer concentration after it had been sieved to a particle size of <250 µm in diameter (<2 mm soil particle size in the original study). The smaller particle size was examined based on the assumption that children and adults principally ingest soil of small particle size adhering to fingertips and under fingernails.

Soil concentration was not changed by particle size for five of the tracers used in the original study (aluminum, silicon, titanium, yttrium, and zirconium). However, the soil concentrations of three tracers (cerium, lanthanum and neodymium) were increased two- to four-fold at the smaller soil particle size. Soil ingestion estimates for these three tracers were decreased by approximately 60% at the 95th ~~95th~~ percentile, when the effect of particle size on tracer concentration is taken into account.

4.4~~3~~.3.7 Stanek et al. (1999)

Stanek *et al.* (1999) extended the findings from their earlier study (Calabrese *et al.* 1996) by quantifying trace element concentrations in soil of different particle sizes. The soil was sieved to particle sizes of 100 to 250 µm and to particle sizes of 53 to < 100 µm. This study used the data from soil concentrations from the Anaconda, Montana site reported by Calabrese *et al.* (1997).

Results of the study indicated that soil concentrations of aluminum, silicon, and titanium did not increase at the two finer particle size ranges measured. However, soil concentrations of cerium, lanthanum and neodymium increased by a factor of 2.5 to 4.0 in the 100-250 µm particle size range when compared with the 0 to 2 µm particle size range. There was not a significant increase in concentration in the 53 to 100 µm particle size range. The importance of this study and that published in 1996 is that they provide further insights regarding the selection of tracers for soil ingestion studies.

4.4~~3~~.3.8 Stanek and Calabrese (2000)

In this study the soil ingestion data from the Anaconda, Montana study were reanalyzed, assuming a lognormal distribution for the soil ingestion estimates. Average soil ingestion for children was predicted over time periods of 7 days, 30 days, 90 days, and 365 days. The 95th percentile soil ingestion values predicted were 133 mg/day over 7 days, 112 mg/day over 30 days, 108 mg/day over 90 days, and 106 mg/day over 365 days. Based on this analysis, estimates of the distribution of longer term average soil ingestion are expected to be narrower, with the 95th percentile estimates being as much as 25% lower. The limitations to this analysis were similar to that discussed in Stanek and Calabrese (1995a) in Section 4.4~~3~~.3.4~~3~~.

4.4~~3~~.4 Clausing and Co-workers Studies

4.4~~3~~.4.1 Clausing et al. (1987)

This soil ingestion study was conducted with Dutch children using the Limiting Tracer Method (LTM). Aluminum, titanium, and acid-insoluble residue (AIR) contents were determined for fecal samples from children aged 2 to 4 years attending a nursery school and for samples of playground dirt at that school.

Twenty seven daily fecal samples were obtained over a 5-day period for the 18 children examined. Using the average soil concentrations present at the school, and assuming a standard fecal dry weight of 10 g/day, soil ingestion was estimated for each tracer. Eight daily fecal samples were also collected from six hospitalized, bedridden children. These children served as a control group, representing children who had little access to soil. The average quantity of soil ingested by the school children in this study was 230 mg/day (range 23 to 979 mg/day) for aluminum; 129 mg/day (range 48 to 362 mg/day) for AIR; and 1,430 mg/day (range 64 to 11,620 mg/day) for titanium. As in the Binder et al. (1986) study, a fraction of the children (6/19) showed titanium values well above 1,000 mg/day.

Table 4.10~~9~~ Soil Ingestion Results (mg/day) From Clausing et al. (1987)

	School Children	Hospitalized Children	Difference
Mean	105	49	56
Standard Deviation	67	22	
Range	23-362	26-84	
Geometric Mean	90	45	

Mean soil intake for the school children was estimated to be 105 mg/day with a standard deviation of 67 mg/day (range 23 to 362 mg/day). Geometric mean soil intake was estimated to be 90 mg/day. The soil intake for this group of children was much higher when compared to the hospitalized children used as the control group (mean 49 mg/day, standard deviation 22 mg/day).

Mean (arithmetic) soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum. For titanium, three of these children had estimates well in excess of 1,000 mg/day, with the remaining three children in the range of 28 to 58 mg/day. The mean soil ingestion rate was estimated to be 49 mg/day with a population standard deviation of 22 mg/day (range 26 to 84 mg/day). The geometric mean soil intake rate was 45 mg/day (Table 4-10~~9~~).

The data on hospitalized children suggest a non-soil source of titanium and aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered. Assuming that soil ingestion rates observed in hospitalized children actually represent background tracer intake from dietary and other non-soil sources, mean soil ingestion by nursery school children was estimated to be

56 mg/day (i.e., 105 mg/day for nursery school children minus 49 mg/day for hospitalized children).

The advantages of this study are that the investigators evaluated soil ingestion among children that had differences in access to soil and soil intake rates were corrected based on background estimates derived from the hospitalized group. However, the number of children used in this study was small. Tracer elements in foods or medicines were not evaluated. Also, the study was a short-term study and the intake rates may not be representative of soil intake over the long-term. The children's activities were not monitored. For example, hand washing frequency could impact soil ingestion.

4.4~~3~~.4.2 Van Wijnen et al. (1990)

In this study soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using the tracer element methodology (LTM) used by Clausing *et al.* (1987). Three tracers (titanium, aluminum, and acid insoluble residue (AIR)) were measured in soil and feces and soil ingestion was estimated from the measurements. An average daily feces dry weight of 15 g was assumed. A total of 292 children attending daycare centers were sampled during the first sampling period and 187 children were sampled in the second. A total of 78 children were sampled at campgrounds. Samples taken from 15 hospitalized children were used as controls.

The mean soil ingestion values for these groups were: 162 mg/day for children in daycare centers, 213 mg/day for campers and 93 mg/day for hospitalized children. Geometric means were estimated to be 111 mg/day for children in daycare centers, 174 mg/day for children vacationing at campgrounds and 74 mg/day for hospitalized children (70-120 mg/day based on the 95th percent confidence limits of the mean) (Table 4-1~~0~~1). AIR was the limiting tracer in about 80 percent of the samples. Among children attending daycare centers, soil intake was also found to be higher when the weather was good.

The investigators used the mean value (93 mg/day) for hospitalized children as the background intake of tracers. Using the mean value to correct the soil intake rates, corrected soil intake rates were 69 mg/day for daycare children and 120 mg/day for campers. Corrected geometric mean soil intake was estimated to range from 0 to 90 mg/day with a 90th percentile value of 190 mg/day for the various age categories within the daycare group and 30 to 200 mg/day with a 90th percentile value of 300 mg/day for the various age categories within the camping group.

The major limitation of this study is that tracer concentrations in food and medicine were not evaluated. Although the population of children studied was relatively large, it may not be representative of the U.S. population. This study was conducted over a relatively short time period and estimated intake rates may

not reflect long-term patterns, especially at the high-end of the distribution. Another limitation of this study is that values were not reported element-by-element, and the children's daily activities such as hand washing frequency were not monitored.

Table 4.11~~0~~ Soil Ingestion Values Using the LTM Methodology for Children at Daycare Centers and Campgrounds

Age (Years)	Sex	Daycare centers			Campgrounds		
		N	Geometric Mean (mg/d)	Geometric Standard Deviation (mg/d)	N	Geometric Mean (mg/d)	Geometric Standard Deviation (mg/d)
birth to <1	**Girls** **Boys**	3 1	81 75	1.09 -	- -	- -	- -
1 to <2	**Girls** **Boys**	20 17	124 114	1.87 1.47	3 5	207 312	1.99 2.58
2 to <3	**Girls** **Boys**	34 17	118 96	1.74 1.53	4 8	367 232	2.44 2.15
3 to <4	**Girls** **Boys**	26 29	111 110	1.57 1.32	6 8	164 148	1.27 1.42
4 to <5	**Girls** **Boys**	1 4	180 99	- 1.62	19 18	164 136	1.48 1.30
Combined All ages	**Girls** **Boys**	86 72	117 104	1.70 1.46	36 42	179 169	1.67 1.79
Total		162[a]	111	1.60	78[b]	174	1.73

[a] Age and/or sex not registered for eight children.
[b] Age not registered for seven children.

4.4~~3~~.5 Other Relevant Studies and Analyses

4.4~~3~~.5.1 Thompson and Burmaster (1991)

Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the key study data collected by Binder *et al.* (1986). In the original Binder *et al.* (1986) study, an assumed dry fecal weight of 15 g/day was used. Thompson and Burmaster re-estimated the soil ingestion rates from the Binder *et al.* (1986) study using the actual stool weights of the study participants instead of the assumed stool weights. Because the actual stool weights averaged only 7.5 g/day, the soil ingestion estimates presented by Thompson and Burmaster (1991) are approximately one-half of those reported by Binder *et al.* (1986).

The mean soil intake rates were 97 mg/day for aluminum, 85 mg/day for silicon, and 1,004 mg/day for titanium. The 90th percentile estimates were 197 mg/day for aluminum, 166 mg/day for silicon, and 2,105 mg/day for titanium. Based on the arithmetic average of aluminum and silicon for each child, mean soil intake was estimated to be 91 mg/day and 90th percentile intake was estimated to be 143 mg/day (Table 4-12~~1~~).

Table 4.12~~1~~ Distribution of Soil Ingestion Estimates For Children by Thompson and Burmaster (1991)

	Soil Intake (mg/d)			
	Aluminum	**Silicon**	**Titanium**	**Mean[a]**
Mean	97	85	1004	91
Median	45	60	293	59
90th %	197	166	2105	143

[a] Arithmetic average of soil ingestion based on aluminum and silicon

Thompson and Burmaster (1991) also adjusted Binder *et al.* (1986) data for aluminum, and silicon for lognormal distribution. No adjustment was made for titanium because titanium may be present in high concentrations in food and the Binder *et al.* (1986) study did not correct for food sources of titanium. Statistical tests indicated that only silicon and the average of the silicon and aluminum tracers were lognormally distributed.

The advantages of this study are that it provides percentile data and defines the shape of soil intake distributions. However, the number of data points used to fit the distribution was limited. This analysis is based on a study that did not correct for tracer intake from food or medicine and the methodological difficulties encountered in the original Binder *et al.* study still exist including difficulty in obtaining the entire fecal sample from a diaper.

4.4~~3~~.5.2 Sedman and Mahmood (1994)

The data of two previous studies, Calabrese *et al.* 1989 and Davis *et al.* 1990, were used to obtain estimates of the average daily soil ingestion in young children. The soil ingestion in these children was determined by dividing the excess tracer intake (the quantity of tracer recovered in the feces in excess of the measured intake) by the average concentration of tracer in soil samples from each child's dwelling.

The mean estimates of soil ingestion in children for each tracer were adjusted from both studies to reflect that of a 2-year old child. The mean of the adjusted levels of soil ingestion for a two year old child was 220 mg/kg for the Calabrese *et al.* (1989) study and 170 mg/kg for the Davis *et al.* (1990) study. Based on a normal distribution of means, the mean estimate for a 2-year old child was 195 mg/day. Based on uncertainties associated with the method employed, the authors recommended a conservative estimate of soil ingestion in young children

of 250 mg/day. Based on the 250 mg/day ingestion rate in a 2-year old child, a lifetime intake was estimated to be 70 mg/day.

4.4~~3~~.5.3 Calabrese and Stanek (1995)

Calabrese and Stanek (1995) examined the various sources and magnitude of positive and negative errors in soil ingestion estimates for children.
Possible sources of positive errors include:

a) ingestion of high levels of tracer elements before the start of the study and low ingestion during the study period, and
b) ingestion of tracer elements from a non-food or non-soil source during the study period.

Possible sources of negative bias include:

a) ingestion of tracer elements in food, but they are not captured in the fecal sample either due to slow lag time or not having a fecal sample available on the final study day, and
b) diminished detection of tracer element levels in fecal, but not in soil samples.

The data of Calabrese *et al.* (1989) were quantified to reduce the magnitude of error in the individual trace element ingestion estimates. A lag period of 28 hours was assumed for the passage of tracers ingested in food to the feces. A daily soil ingestion rate was estimated for each tracer for each 24-hr day fecal sample. Daily soil ingestion rates for tracers that fell beyond the upper and lower ranges were excluded from subsequent calculations, and the median soil ingestion rates of the remaining tracer elements were considered the best estimate for that particular day.

The positive and negative errors for six tracer elements from the 1989 Calabrese *et al.* study were estimated. The original mean soil ingestion rates ranged from a low of 21 mg/day based on zirconium to a high of 459 mg/day based on titanium. The adjusted mean soil ingestion rate after correcting for negative and positive errors ranged from 97 mg/day based on yttrium to 208 mg/day based on titanium.

The authors concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion. However, this approach is based on the hypothesis that the median tracer value is the most accurate estimate of soil ingestion, and the validity of this assumption depends on the specific set of tracers used in the study. The estimation of daily tracer intake is the same as in Stanek and Calabrese (1995a), and the same limitations mentioned earlier in Calabrese *et al.*(1989) still exist.

4.4~~3~~.5.5 Stanek et al. (2001)

The authors developed a simulation model to identify and evaluate biasing factors for soil ingestion estimates from data taken from Calabrese *et al.* (1989),

Davis *et al.* (1990), and Calabrese *et al.* (1997). Only the data from the aluminum and silicon trace element estimates were used.

Study duration has the most positive bias in all the biasing factors explored, with a bias of more than 100% for the 95th percentile estimates in the 4-day mass balance study. A smaller bias was observed for the impact of absorption of trace elements from food. Although the trace elements selected for use in the mass balance studies are believed to have low absorption, the amount unaccounted for will result in an underestimation of the soil ingestion distribution. In these simulations, the absorption of trace elements from food of up to 30% was shown to negatively bias the estimated soil ingestion distribution by less than 20 mg/day.

4.4~~3~~.5.6 Zartarian et al. (2005)

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates using data from several studies as input for the Stochastic Human Exposure and Dose Simulation (SHEDS) model for the U.S. EPA. Data from Calabrese's Amherst and Anaconda studies (Calabrese *et al.* 1989, 1997) were used to fit distributions of soil/dust ingestion rates. The statistical distributions relied upon two tracers only, aluminum and silicon, in estimating the parameters of the lognormal variability and uncertainty distributions.

Using a Monte-Carlo sampling method, values from the fitted distribution were separated into those values under 500 mg/day and values that exceeded 500 mg/day. Soil ingestion values that exceed 500 mg/day are assumed to represent pica behavior. Using the SHEDS model, the soil ingestion rate distribution for non-pica behavior children has a mean of 61, standard deviation of 81, median of 30, 95th percentile of 236, and 99th percentile of 402 (mg/day). For children exhibiting pica behavior, the mean is 962, standard deviation 758, median 735, 95th percentile 2130, and 99th percentile 3852 (mg/day).

A limitation of this analysis is that pica children and incidental ingestion were simulated separately. The distribution for incidental soil ingestion does not take into account that children may have days where they ingest unusually high levels of soil, which may not be indicative of long-term pica behavior.

4.4~~3~~.5.7 Hogan et al. (1998)

Hogan *et al.* (1998) published a paper that compares observed and predicted children's blood lead levels as applied to the Integrated Exposure and Uptake Biokinetic (IEUBK) model for lead in children. The IEUBK model is being used by the U.S. EPA and state regulatory agencies as a model for lead uptake from environmental media for risk assessments. The model functions primarily to estimate the risk and probability of children having blood lead concentrations exceeding a specific level of concern. It predicts children's blood levels by using

measurements of lead in house dust, soil, drinking water, food and air together with default inputs such as child-specific estimates of intake for each exposure medium.

One of the parameters that the IEUBK model uses to estimate child blood lead concentration is the ingestion of soil and household dust. Young children are primarily exposed to lead through fine particles of surface soil and household dust that adhere to their hands and are incidentally ingested during normal hand-to-mouth activities. The age-specific default soil and dust ingestion rates recommended for use in the IEUBK model (version 0.99d) are 50 and 60 mg/day (averaged over children ages 1 through 6), respectively. The combined soil and dust ingestion is 110 mg/day. The default soil ingestion values used in the IEUBK model are based on several observational studies by Binder *et al.* (1986), Clausing *et al.* (1987), Calabrese *et al.* (1989, 1991), van Wijnen *et al.* (1990) and Davis *et al.* (1990), utilizing the trace element methodology (U.S. EPA, 1994).

Hogan *et al*. (1998) applied an empirical comparisons exercise of the IEUBK method to evaluate three epidemiologic datasets consisting of blood lead levels of 478 children. These children were a subset of the entire population of children living in three historic lead smelting communities: Palmerton, Pennsylvania; Southern Kansas/southwestern Missouri; and Madison County, Illinois. The children's measured blood lead levels were compared with the IEUBK's blood lead predictions using measured lead levels in drinking water, soil and dust together with the model's default inputs such as soil/dust ingestion rates and lead bioavailability.

Results showed that there was reasonably close agreement between observed and IEUBK predicted blood lead distributions in the three studies. The geometric means for the observed and predicted blood lead levels were within 0.7 µg/dl. U.S. EPA (2008) used this study to do a back calculation on the soil and dust ingestion rates and concluded that the numbers (50 mg/d soil; 60 mg/d dust; and 110 mg/d combined) are "roughly accurate in representing the central tendency soil and dust ingestion rates" of children ages 1 to 6.

4.4~~3~~.6 U.S. EPA (2008)

The U.S. EPA (2008) *Child-Specific Exposure Factors Handbook* considered certain studies as "key" for developing recommendations for children's soil ingestion rates. Key tracer element methodology, biokinetic model comparison, and survey response studies were selected based on "judgment" about the study's design features, applicability, and utility of the data to U.S. children, clarity and completeness, and characterization of uncertainty and variability in ingestion estimates. Most of the key studies selected are similar to those described in this Section.

The soil ingestion recommendations represented ingestion of a combination of soil and outdoor settled dust. The dust ingestion recommendations included soil tracked into indoor environment, indoor settled dust and air-suspended particulate matter that is inhaled and swallowed. The recommended values for soil and dust are on a dry weight basis.

The recommended central tendency soil and dust ingestion for infants 6 months up to their first birthday is 60 mg/d (soil 30 mg/d, dust 30 mg/d), and for children ages 1 to <6 years is 100 mg/d (soil 50 mg/d, dust 60 mg/d, sum rounded to 100 mg/d). In the absence of data that can be used to develop specific central tendency soil and dust ingestion recommendations for children aged 6 to <11 years, 11 to <16 years and 16 to <21 years, U.S. EPA (2008) recommends using the central tendency soil and dust ingestion rate of 100 mg/d developed for children ages 1 to <6 years. An important factor is that the recommendations did not extend to issues regarding bioavailability of the contaminants present in the soil and dust.

Table 4.13~~2~~ Recommended Values for Daily Soil and Dust Ingestion From U.S. EPA (2008)

Age Group	Central Tendency Values, mg/day		
	Soil	Dust	Soil and Dust
6 to <12 m	30	30	60
1 to <6 y	50	60	100[a]
6 to <21 y	50	60	100[a]

[a] Sum of 110 mg/d rounded to one significant figure
Adapted from Child-Specific Exposure Factors Handbook, U.S. EPA (2008)

4.5Soil Ingestion Adult Studies

There are few studies that estimated adult soil ingestion. The three studies that provide data used in the estimation of soil ingestion in adults did not provide the ages of the individuals studied. They were not designed as adult soil ingestion studies but rather as a validation of the methodology used to study soil ingestion in children.

4.5~~4~~.1 Hawley (1985)

Hawley (1985) suggested a value of 480 mg/day for adults engaged in outdoor activities, a range of 0.6 to 110 mg/day of house dust during indoor activities, and an annual average of 60.5 mg/day. These estimates were derived from assumptions about soil/dust levels on hands, mouthing behavior, and frequencies of certain indoor and outdoor activities, without supporting measurements.

4.~~5~~4.2 Calabrese et al (1990)

This study was originally part of the study in children in Calabrese *et al.* (1989). The soil ingestion rates for the 6 volunteer adults were estimated by subtracting out the tracer quantities in food and soil capsules from the amounts excreted. The four most reliable tracers were aluminum, silicon, yttrium, and zirconium. Median soil ingestion rates were as follows: aluminum, 57 mg; silicon, 1 mg; yttrium, 65 mg; and zirconium, -4 mg. Mean values were: aluminum, 77 mg; silicon, 5 mg; yttrium, 53 mg, and zirconium, 22 mg. The average of the soil ingestion means based on the four tracers is 39 mg. The sample size is very small (n = 6) and the study was not designed to look at soil ingestion by the adults but rather as a validation of the overall soil ingestion tracer methodology.

4.~~5~~4.3 Stanek and Calabrese (1995b)

Stanek and Calabrese (1995b) reanalyzed the data from their 1989 study of children with data from Davis *et al.* (1990), and their adult study (Calabrese *et al.* 1990) using the Best Tracer Method (BTM). Distributions of soil ingestion estimates were based on the various ranked tracers for both children and adults. A description of this study is provided in Section 4.~~3~~4.3.~~5.~~ When the adult data from the Calabrese *et al.* (1990) study were reevaluated, soil ingestion rates were estimated to be 64 mg/day (mean), 87 mg/day (median), and 142 mg/day (95th percentile), using the BTM.

4.~~5~~4.4 Stanek et al. (1997)

Soil ingestion was evaluated in 10 adults as part of a larger study to evaluate soil ingestion in children. The average daily soil ingestion (taken over 4 weeks) was 6 mg/day. The estimation was based on four tracer elements aluminum, silicon, titanium, and zirconium, although 8 tracers were measured. The authors reported that “the broad range in estimates for different trace elements implies that a simple average estimate (over the eight trace elements) provides little insight into adult soil ingestion, since estimates based on different trace elements for the same adults and time periods are so highly variable”. To account for variability and bias, the authors decided to base the estimate of soil ingestion on trace elements whose concentrations in soil are relatively homogeneous across different particle sizes. Trace elements that satisfied this criterion include aluminum, silicon, titanium, yttrium and zirconium, and they were considered for estimating soil ingestion by the authors.

However, this study has some complications. One of the ten adults in the study had a high soil ingestion estimate (2 grams) on the first day. The subject also had 4 times higher freeze-dried fecal weight than on any day of the study suggesting that this may be due to days of fecal accumulation. The result is an inflated 95th percentile soil ingestion estimate.

Calabrese (2003) recommended that the upper 75th percentile estimate soil ingestion of 49 mg/day be used as an estimate of high-end soil ingestion by adults (letter to the General Electric Company concerning the U.S. EPA's Human Health Assessment for the Housatonic River) (Calabrese *et al.* 2003). Although the outlier subject in the study causes the 95% percentile soil ingestion estimate to be inflated, it should not be ignored as enhanced adult ingestion could occur among agricultural or utility workers. The study itself also shows that there are problems in the use of tracers and the results varied depending upon which set of tracers was used.

4.5~~4~~.5 Davis and Mirick (2006)

This study estimated soil ingestion in children aged 3 to 8 years and their parents (16 mothers and 17 fathers) for 11 consecutive days. Three trace elements (Al, Si, and Ti) were measured. The ages of the adults were not provided.

Since titanium exhibits much greater variability compared to other tracer elements due to its presence in various non-soil sources, only Al and Si were used to estimate the adult daily soil ingestion. The means of the mothers and fathers are calculated to be 58 and 47 mg/day, respectively. The weighed average for the combined adults is 53 mg/day.

Table 4.14~~3~~ Adult Soil Ingestion Estimates From Davis and Mirick (2006)

Tracer Element	Mean Adult Soil Ingestion (mg/day)	
	Mothers	Fathers
Al	92.1	68.4
Si	23.2	26.1
Mean	57.7	47.3
Mean of All Adults	52.5	

4.5~~4~~.6 Summary of Adult Soil Ingestion Estimates

The mean and 95th percentile adult soil ingestion rates are calculated from the studies as shown in Table 4-145. For soil ingestion in adults, the average of the mean and the 95th percentile are 41 and 213 mg/day, respectively.

Table 4.15~~4~~ Summary of Soil Ingestion Estimates (mg/day) in Adults

Study	Mean	P95
Calabrese et al (1990) and Stanek and Calabrese (1995b)	64	142

Stanek et al~~t~~ (1997)	6	331
Davis and Mirick (2006)	53	168[a]
Average	41	213

[a] The 95th percentile adult soil ingestion from Davis and Mirick (2006) was calculated from data in the paper assuming lognormal distribution.

4.6~~5~~ PICA

4.6~~5~~.1 General Pica

General pica is the repeated eating of non-nutritive substances including sand, clay, paint, plaster, hair, string, cloth, glass, matches, paper, feces, and various other items (Feldman, 1986). There are numerous reports on general pica among various populations and this behavior appears to occur in approximately half of all children between 1-3 years of age (Sayetta, 1986). Danford (1982) reported that the incidence of general pica was higher for black children (30%) than for white children (10-18%) between 1-6 years of age. There appears to be no sex differences in the incidence rates (Kaplan and Sadock, 1985).

However, general pica is reported to be higher among children in lower socioeconomic groups (50-60%) than in higher income families (about 30%) and is more common in rural areas (Lourie *et al.* 1963, Vermeer and Frate, 1979). A higher rate of general pica has also been reported in pregnant women, individuals with poor nutritional status, and mentally retarded children (Behrman and Vaughan 1983, Danford 1982, Illingworth 1983, Sayetta 1986).

General pica does not include the consumption of some condiments that contain clay or soil. Examples are the Hawaiian Red Alaea sea salt (containing the red volcanic clay called Alaea) and black sea salt found in many parts of the world (containing lava and other substances). These salts have characteristic taste and are used in cooking and food preservation.

4.6~~5~~.2 Soil Pica

ASTDR (2001) defines soil pica as the recurrent ingestion of unusually high amounts of soil of between 1,000 - 5,000 mg/day. Bruhn and Pangborn (1971) studied dirt ingestion in migrant agricultural workers among 91 non-black, low-income families in California. The incidence of pica was 19% in children, 14% in pregnant women, and 3% in non-pregnant women. However, in this study “dirt” was not clearly defined and may include non-soil substances.

Data from tracer studies (Binder *et al.*, 1986; Clausing *et al.,* 1987; Van Wïjnen *et al.*, 1990; Davis *et al.*, 1990; and Calabrese *et al.*, 1989) showed that only one child out of the more than 600 children studied ingested soil in significantly large amounts to indicate pica behavior. In addition, parental observations regarding

children who are likely to be high soil ingesters were reported to be often inaccurate (Calabrese *et al.*, 1997).

A study by Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., intentional earth eating) was about 16% among children from a rural black community in Mississippi. In this study, the intentional earth eating was described as a cultural practice in the community surveyed and may not be representative of the general population. However, there are cultures in many parts of the world where soil eating is practiced in religious or sacred rituals.

4.6~~5~~.3 Soil Pica Behavior in Children

Information on the amount of soil ingested by children with pica behavior is very limited. There is no study on pica children and infrequent pica behavior is often observed in normal children in soil ingestion studies.

4.6~~5~~.3.1 Calabrese et al. (1991); Calabrese and Stanek (1992)

Calabrese *et al.* (1991) reported a pica child among the 64 children who participated in the soil ingestion study. One 3.5-year-old female child had extremely high soil ingestion, from 74-2200 mg/day during the first week and from 10.1-13.6 g/day during the second week of observation. The upper soil ingestion values for this pica child range from approximately 5 to 7 g/day.

Using a methodology that compared differential element ratios, Calabrese and Stanek (1992b) quantitatively attempt to distinguish outdoor soil ingestion from indoor dust ingestion in this pica child. Using tracer ratios of soil, dust, and residual fecal samples, an analysis was performed which indicates that from 71 to 99% of the tracer originated from soil. The authors concluded that the predominant proportion of the fecal tracers originated from outdoor soil and not from indoor dust.

4.6~~5~~.3.2 Wong (1988) as reviewed by Calabrese and Stanek (1993)

Wong (1988) in his doctoral thesis studied soil ingestion by 52 children in two government institutions in Jamaica. This study was reviewed by Calabrese and Stanek (1993). The younger group contained 24 children with an average age of 3.1 years (range of 0.3 to 7.6 years). The older group contained 28 children with an average age of 7.2 years (range of 1.8 to 14 years).

Fecal samples were obtained from the children and the amount of silicon in dry feces was measured to estimate soil ingestion. An unspecified number of daily fecal samples were collected from a control group consisting of 30 hospital children with an average age of 4.8 years (range of 0.3 to 12 years). Dry feces were observed to contain 1.45% silicon, or 14.5 mg Si per gram of dry feces. This quantity was used as a baseline representing the background level of silicon

ingestion from dietary sources. Observed quantities of silicon greater than 1.45% were interpreted as originating from soil ingestion.

For the 28 children in the older group, soil ingestion was estimated to be 58 mg/day, based on the mean minus one outlier, and 1520 mg/day, based on the mean of all the children. The outlier was a child with an estimated average soil ingestion of 41 g/day over the 4-month period. This child was stated to be "developmentally disabled", but no information was provided on the nature or severity of the disability. Of the 28 children in the group, 7 had average soil ingestion greater than 100 mg/day, 4 had average soil ingestion greater than 200 mg/day, and one had average soil ingestion greater than 300 mg/day. Eight children showed no indication of soil ingestion. The mean soil ingestion of all the children was 470 ± 370 mg/day.

Of the 24 children in the younger group, 14 had average soil ingestion of less than 100 mg/day, 10 had average soil ingestion greater than 100 mg/day, 5 had average soil ingestion greater than 600 mg/day, and 4 had average soil ingestion greater than 1000 mg/day. Five children showed no indication of soil ingestion. Of the 52 children studied, 6 displayed soil pica behavior.

The use of a single soil tracer in this study may introduce error in the sampling because there may be other sources of the tracer in the children's environment. For example, certain types of toothpastes have extremely high silica concentrations, and children may ingest significant quantities during brushing. Silica may also be found in indoor dust that children could ingest. Despite these uncertainties, the results indicate that soil pica is not a rare occurrence in younger children in this study population. Results from this Jamaica study may not be indicative of similar behavior in children in the United States.

4.6~~5~~.3.3 ATSDR (2001)

ATSDR (2001) held a workshop to discuss and review the state of the science on soil pica behavior. The review acknowledges that soil pica clearly exists, but there were insufficient data to determine the prevalence of this behavior in children and in adults. The present ATSDR assumption that soil pica children ingest 5 g of soil/day is supported by only a few subjects (i.e., two children in Massachusetts and six children in Jamaica). The ATSDR (2001) committee advises ATSDR to err on the side of being health protective and to continue using the 5 g/day pica ingestion number until more data become available.

4.6~~5~~.3.4 Zartarian et al. (2005)

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates from several studies in the literature using the Stochastic Human Exposure and Dose Simulation (SHEDS) model of the U.S. EPA. Data from Calabrese's Amherst and Anaconda studies were used to fit distributions of soil/dust ingestion rates. A soil

pica distribution was obtained by sampling from the fitted lognormal distribution and retaining values above 500 mg/day. The mean and 95th percentile values for this population were estimated to be 963 mg/day and 2170 mg/day, respectively (See Section 4.4~~3~~.5.6).

4.7~~5~~.3.5 U.S. EPA (1984)

In a risk assessment for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) in an investigation on the exposure potential to 2,3,7,8-TCDD via soil ingestion used a value of 10 g/day to represent the amount of soil that a child with pica behavior might ingest (Kimbrough *et al.,* 1984). These values are based on only one pica child observed in the Calabrese *et al.* (1989) study where the intake ranged from 10-14 g/day during the second week of observation. The CDC suggests that an ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information.

4.6~~5~~.3.6 U.S. EPA (2008)

In the 2008 U.S. EPA's *Child-Specific Exposure Factors Handbook*, U.S. EPA redefined children's "soil-pica" as the quantity of soil ingested by children above 1000 mg/d. Using this definition, the upper 90th and 95th percentiles of soil ingestion from all the key primary studies were included in the assessment of children's pica soil ingestion. The soil-pica ingestion estimate for children up to age 14 ranged from 400 to 41,000 mg/d. The recommended value for soil pica in children was then set at 1000 mg/day. No data were available for children above 14-21 years. We believe this number is probably too low based on our calculations (see Table 4.16~~5~~).

4.6~~5~~.3.7 Summary of Pica Behavior Studies in Children

Soil ingestion in 8 children that exhibited pica behavior from two studies is given in Table 4-1~~5~~6. It is important to note that soil pica behavior in children in the studies used was observed over a very short period of time and may not reflect long-term pica behavior. In the absence of data, the ATSDR panelists recommended in the *Summary Report for the ATSDR Soil-Pica Workshop* (2001) that "ATSDR should err on the side of being protective and should use 5000 mg until more data are collected". We concur with this recommendation. Our calculation on pica children in two studies shows that the amount ingested is about 5000 mg/day (Table 4-16~~5~~).

Table 4.16~~5~~ Pica Behavior in Children

Sample Size	Observation (days)	Age	Soil Ingestion (mg/day)	Source
1	2	2.5	20,000; 22,000	Calabrese et al. (1989, 1991)

1	4	-	1000-2000	
1 1 1 1 1	1 1 "different days" "different days" 1	3.1[a]	1447 7924 1016; 2690; 898 10343; 4222; 1404; 5341 5341	Wong (1988) doctoral thesis. Study reviewed and presented by Calabrese and Stanek (1993)
1[c]	"different days"	7.2[b]	48,300; 60,692; 51,422; 3782	Wong (1988) doctoral thesis. Study reviewed and presented by Calabrese and Stanek (1993)

Number of Children	Average Pica Soil Ingestion (mg/day)
8	10,600
7[d]	5500

[a] Average age of 24 children
[b] Average age of 28 children
[c] This child was stated to be "developmentally disabled" by the author
[d] Excluding last child

4.6.4 Soil Pica Behavior In Adults

The ASTDR report (2001) views adult soil pica to be an extremely rare behavior that has not been characterized. Deliberate consumption of clays or soil (geophagy) has been reported in many parts of the world and is particularly prevalent among certain cultural groups especially during certain rituals or religious ceremonies. However, the clay or soil is typically from known uncontaminated sources. Thus, surface soils are generally not the source of geophagical materials consumed. Very little data are available to establish an unintentional soil ingestion rate for adults with pica behavior.

4.7~~6~~ Hand-To-Mouth Transfer

The studies discussed earlier examined soil intake using a mass balance methodology that measures trace elements in feces and soil. These studies have various shortcomings one of which is the paucity of data for estimating soil ingestion to a broader age range in children and adults. Data are lacking for children less than 1 and above 7 years of age, and for adults where ages are often not given in the studies.

U.S. EPA (2005) provides guidance on the appropriate age groups to consider when assessing children's exposure and potential dose of environmental contaminants. The recommended childhood age groups for exposure and risk assessments are: birth to <1 month, 1 to < 3 months, 3 to < 6 months, 6 to < 12 months, 1 to < 2 years, 2 to < 3 years, 3 to < 6 years, 6 to < 11 years, 11 to < 16 years, 16 to < 18 years, and 18 to < 21 years. These age groupings take into consideration human developmental and physiological changes that impact exposure and potential dose intake. Hand-to-mouth activities may provide

information that may be useful in assessing the ingestion of soil in age groups that do not have direct soil ingestion data.

4.7~~6~~.1 Hand-to-Mouth Transfer Behavior in Children

Children often put their hands, toys, and other objects in their mouths during normal exploration of their environment, as a sucking reflex and as a habit. This hand-to-mouth behavior may result in the ingestion of soil and dust, from outside and/or indoors. Transfer from the hand to the mouth can occur directly by handling of contaminated soil and indirectly by using products, materials and equipment that come in contact with contaminated soil. This can happen in both occupational and non-occupational settings. Soil ingestion can occur by touching the mouth with the hand, nail biting, finger sucking, eating food (especially with bare hands), smoking cigarettes, and other hand-to-mouth activities.

Generally, children's mouthing behavior is studied using both direct observation and videotaping methodologies (Zartarian *et al.* 1998; Reed *et al.* 1999; Freeman *et al.* 2001, 2005; AuYeung *et al.* 2006, 2008; Black *et al.* 2005; Ferguson *et al.* 2005). Observations may be conducted by an instructed parent, or by a trained person. Videotaping the child's behavior is usually done by a trained technician, and information from these recordings is obtained by a trained person who watches the videotapes.

4.7~~6~~.2 Probabilistic Models of Hand-to-Mouth Transfer

Estimation of non-dietary ingestion of a chemical via hand-to-mouth contact includes information of the hand residue/soil loading (µg/cm² or µg/g), hand-to-mouth frequency (number of contacts/hr), area of hand surface mouthed (cm²), and exposure duration (hr/day). Probabilistic models have been developed to estimate non-dietary ingestion of a chemical via hand-to-mouth contact (e.g., Calendex™ by Exponent Inc.; CARES™ by International Life Science Institute; Lifeline™ by Lifeline Group; and Residential-SHEDS by U.S. EPA's Office of Research and Development).

These models have certain limitations as the calculations are based on data from the few studies available on non-dietary ingestion via hand-to-mouth contact. The studies used in the models have their own limitations such as the different methods of data collection, analysis and reporting, different age groupings of research subjects, and even different definition of "mouthing". Models such as SHEDS that deal with various microenvironments assume a strong relationship between the total dust ingested and indoor dust loading. Although the ratio of ingested outdoor soil to ingested indoor dust is important, factors influencing exposure and risk such as the types of exposures, chemical pollutants indoors and outdoors, amount of track-in, resuspension and particle size, seasonal effects, and fate and transport are some of the issues still largely uncharacterized.

4.7~~6~~.3 Relevant Hand-to-Mouth Transfer Studies (Summary)

Studies that provide estimates for a hand load transfer factor or transfer efficiency include the analyses of Dubé *et al.* (2004), Beyer *et al.* (2003), and the report from the Consumer Product Safety Commission (CPSC, 2003).

4.7~~6~~.3.1 Dubé et al. (2004)

Using data from Stanek and Calabrese (1995a), Dubé *et al.* (2004) estimated the fraction of "dislodgeable" residue on the hands of children that was incidentally ingested daily. The estimate was 25% hand load per day (range: 7 – 100%) for 2 to 6 year olds, and 13% hand load per day (range: 3.5 – 50%) for 7 to 31 year olds. This assumed that individuals 7 years old and up would ingest half the amount of soil as 2 to 6 year olds. Information was not provided for a direct hand-to-mouth transfer factor for soil, the fraction of material on the hand in contact with the mouth that is transferred, the number of hand to mouth contacts, and losses through intermediate contacts.

4.7~~6~~.3.2 Beyer et al. (2003)

Beyer *et al* (2003), in their assessment of incidental ingestion of metals from laundered shop towels in the workplace, used a value of 13% as the fraction dislodged from the hands that was incidentally ingested on a daily basis by adults.

4.7~~6~~.3.3 CPSC (2003)

The Consumer Product Safety Commission (CPSC, 2003) developed an estimate of the percent of residue dislodged on the hands that is ingested on a daily basis by children. The estimate was based on data on soil ingestion, soil–skin adherence, and contact surface area of the hand with soil from multiple studies. There are large uncertainties in the available data analyzed. The daily intake estimates for children ranged from 3% to 700% of the mass loaded on the hand (i.e., "handload"), with an average of 43% for both direct and indirect hand-to-mouth activities combined.

4.7~~6~~.3.4 Zartarian et al. (2000)

Zartarian *et al.* (2000) used the U.S. EPA's Residential Stochastic Human Exposure and Dose Simulation (Residential-SHEDS, 2000) model for pesticides to estimate children's exposure to chlorpyrifos. The primary purpose of the study is to demonstrate the capabilities of the model by simulating the exposures and doses of children who contacted chlorpyrifos residues inside treated residences and on turf-treated residential yards. The hand-to-mouth transfer efficiency of chlorpyrifos was estimated to range from 10% to 50%, based on the data of

Zartarian *et al.* (1997); Leckie *el al.* (1999); Kissel *et al.* (1998) and Camann *et al.* (2000). The 50% hand-to-mouth transfer efficiency has been used by the CPSC (1997) in estimating hand-to-mouth exposure to lead from polyvinyl chloride products, and by the U.S. EPA's Office of Pesticide Programs as a default value for hand-to-mouth exposure to pesticides (U.S. EPA, 2001).

4.7~~6~~.3.5 Zartarian et al. (2005)

Zartarian *et al.* (2005) working under a contract from the U.S. EPA derived a statistical distribution for hand-to-mouth transfer efficiency for arsenic from chromated copper arsenate (CCA)-treated wood. Hand-to-mouth transfer efficiency is defined as the fraction of chemical mass that enters the mouth and remains in the mouth as a result of one hand-to-mouth contact. The value of 50% was used as the lower bound on the transfer efficiency, with 100% assigned as the upper bound and the mode of distribution set to 75%. The resulting fitted beta distribution of the hand-to-mouth transfer efficiency for arsenic had a mean value of 78% and a 75th percentile value of 84.9% per hand-to-mouth contact.

4.7~~6~~.3.6 OEHHA (2008)

OEHHA (2008) published a lead exposure guideline for calculating the hand-to-mouth transfer of lead from the use of fishing tackle in recreational fishing. The guideline examined both direct and indirect hand-to-mouth activities. No data were available from the scientific literature on the amount of lead transferred from the hand to the mouth as a result of handling fishing tackle products, but data from two studies (Camann *et al*, 2000; Kissel *et al*, 1998) were found to be useful. The study by Camann *et al*. (2000) provides data on the removal of three pesticides from the hands of three adults. The study by Kissel *et al.* (1998) provides estimates on the total soil loading on the hand, and its transfer to the mouth from particular parts of the hand (i.e., thumb; two fingers; palm) in four adults. After reviewing the data from these and other studies, OEHHA (2008) selected a value of 50% as the direct, and 25% as the indirect hand-to-mouth transfer factors for lead in fishing tackle products for adults.

U.S. EPA (2002) concluded from the data of Reed *et al.* (1999) and Zartarian *et al.* (1998) that hand-to-mouth contacts of 9 contacts/hour was a reasonable estimate for children 2 to 6 years old. Since then other published studies (Black *et al*., 2005 and Ko *et al*., 2007) reported that the hand-to-mouth value of 9 contacts/hour probably underestimates the frequency of children's hand-to-mouth activity and the frequency could be over 20 contacts/hour. OEHHA (2008) selected 9 contacts/hour as the average estimate, and 20 as the upper bound estimate of direct hand-to-mouth contact frequency for adults during fishing in contact with lead fishing tackle products.

4.7~~6~~.3.7 Xue et al. (2007)

A meta-analysis was conducted by Xue and colleagues (2007) to examine hand-to-mouth frequency based on study, age groups, gender, and location (indoor vs. outdoor). Data were gathered from 9 studies (Zartarian *et al.* 1998; Reed *et al.* 1999; Leckie *et al.* 2000; Freeman *et al.* 2001; Greene, 2002; Tulve *et al.* 2002; Hore, 2003; Black *et al.* 2005; Beamer *et al.* 2008). The combined studies represent 429 subjects and more than 2,000 hours of behavior observations. To pool and analyze the data from these studies collectively, Xue *et al* (2007) contacted the authors of the 9 studies to obtain and clarify needed and missing data for the analysis.

Results of the analysis indicate that age and location are important for hand-to-mouth frequency, but not gender. As age increases, both indoor and outdoor hand-to-mouth frequencies decrease, and this behavior is higher indoors than outdoors. Average indoor hand-to-mouth frequency ranged from 6.7 to 28.0 contacts/hour, with the lowest value corresponding to the 6 years to <11 years age group and the highest value corresponding to the 3 months to <6 months group. Average outdoor hand-to-mouth frequency ranged from 2.9 to 14.5 contacts/hour, with the lowest value corresponding to the 6 years to <11 years age group and the highest value corresponding to the 6 months to <12 months group. For the 3 months to < 6 months age group, outdoor hand-to-mouth contact frequency data were not available.

The study is an important effort to provide data on hand-to-mouth contact frequency by indoor/outdoor location and age groups based on the recommendations by the U.S. EPA (2005) for assessing childhood exposures. However, it did not analyze or collect data on other mouthing behaviors such as object-to-mouth. Also, data for older children, ages 11 and above, are not included; they are likely to have very different behaviors from the younger children.

Table 4.17~~6~~ Hand-to-Mouth Frequency (contacts/hour) in Children

Age Group	No. of Observations	Mean	Std Dev	P25	P50	P75	P95
		INDOORS					
3m to < 6m	23	28	21.7	8.0	23.0	48.0	65.0
6m to < 12m	119	18.9	17.4	6.6	14.0	26.4	52.0
1y to < 6y[a]	575	16.2	-	4.5	11.1	22.1	53.1
6y to < 11y	14	6.7	5.5	2.4	5.7	10.2	20.6
		OUTDOORS					

3m to < 6m	0	-	-	-	-	-	-
6m to < 12m	10	14.5	12.3	7.6	11.6	16.0	46.7
1y to < 6y[a]	133	8.7	-	1.1	5.1	11.6	32.0
6 to < 11y	15	2.9	4.3	0.1	0.5	4.7	11.9
		COMBINED					
3m to < 6m	23	28	21.7	8.0	23.0	48.0	65.0
6m to < 12m	129	18.6	-	6.7	13.8	25.6	51.6
1y to < 6y[a]	708	14.8	-	3.8	10.0	20.2	49.1
6y to < 11y	29	4.7	-	1.2	3.0	7.4	16.1

Adapted from Xue *et al.*, 2007; results are from 9 studies using Weibull distributions.

[a] Three age groups, 1y to < 2 y, 2y to <3y, and 3y to <6y, combined.

4.7.4 Extrapolation of Soil Ingestion from Hand-to-Mouth Contacts

U.S. EPA (2008) in their *Child-Specific Exposure Factors Handbook* recommends 100 mg/d as the central tendency value for daily soil and dust ingestion in children 1 year to <6 years. The actual sum (soil and dust) is 110 mg/d but rounded to 100 mg/d (to one significant figure) (U.S. EPA, 2008). In the absence of data that can be used to develop soil and dust recommendations for children aged 6 to <11 years, 11 to <16 years and 16 to <21 years, U.S. EPA (2008) recommended using 100 mg/d as the central tendency value for children aged 6 to <21 years.

Using the mean weighed average value of 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (from Table 4.13~~2~~ derived from the 2008 U.S. EPA document), and assuming this age group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Table 4.17~~6~~), soil ingestion in other age groups can be estimated (Table 4.18~~7~~).

OEHHA (2008) selects 9 and 20 as the average and upper bound estimates, respectively, of direct hand-to-mouth contact frequency for adults from the use of lead tackle in recreational fishing. Using the same extrapolation procedure above, the mean and the upper bound soil ingestion estimates were obtained. The combined soil and dust ingestion rate estimated from Xue *et. al.* (2007) data for children aged 6 months to < 12 months is higher than that provided by the U.S. EPA (2008) – 133 mg/d versus 60 mg/d, respectively. We believe that the value of 133 mg/d better reflects the soil and dust ingestion rate in children aged 6 months to < 12 months because children in this age group are known to have much higher hand-to-mouth contact behavior as they explore their environment (Xue *et al.* 2007).

Table 4.18~~7~~ Soil and Dust Ingestion Rates (mg/day) Extrapolated from Xue et al. (2007) Hand-to-Mouth Contact Data to Three Age Groups

Age Groups	Mean	P95
3m to < 6m	NC[a]	NC
6m to < 12m	133	370

1y to < 6y	106	352
6 to < 11y	34[b]	115[b]
Adult	64	143

[a] Not calculated as there is no hand-to-mouth contact in this group
[b] Low confidence level for this number due to low number of observations

OEHHA supports the U.S. EPA (2008) recommendations of 100 mg/day as the central tendency of the combined soil and dust ingestion rate for children aged 1 to <6 years. This number was rounded down from the actual number of 110 mg/d. Using 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (Table 4-13), and assuming this group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Figure 4-17), soil and dust ingestion in other age groups are extrapolated from hand-to-mouth data (Table 4-18). The value for the 6 to <11 year old group is not used because of the low number of hand-to-mouth observations in this group. The soil ingestion values for adults and children (mg/day) estimated for the various age groups are shown in Table 4.19.

Table 4.19 Soil Ingestion Estimates for Adults and Children (mg/day)*

Age Groups (years)	**Mean (mg/day)**	**95th percentile (mg/day)**
3rd Trimester[a]	**50**	**200**
0 < 2	150	400
2<9	100	400
2<16	100	400
9<16	100	400
16<30	50	200
30>70	50	200
PICA children	5000	-
PICA adult	NR[b]	-

[a] Assumed to be the mother's soil ingestion rate (adult age 16 <30)

[b] No recommendation

* Soil includes outdoor settled dust

4.8 References

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5. Breast Milk Intake Rates

5.1 Terminology and Nomenclature

In this section, we review breast milk intake estimates reported in the published literature. In the prior version of these guidelines, published rates as well as unpublished rates derived by OEHHA were presented. The OEHHA derived rates have been updated and revised to reflect breastfeeding practices most likely to occur in the United States (U.S.) (i.e., following the American Academy of Pediatrics recommendations). The revised OEHHA derived rates have been published in a peer-reviewed journal (Arcus-Arth et al, 2005) and are presented along with other published rates in these guidelines.

Specific terms and definitions have been adopted for use throughout this chapter (Table 5.1), because different and sometimes contradictory terms for various breastfeeding patterns are used in the literature.

Table 5.1 Breastfeeding terminology[a]

Term	Definition
Fully breastfed	
Exclusively breastfed	Breast milk is sole source of calories.
Almost exclusively breastfed	Breast milk is primary if not sole milk source with no significant calories from other liquid or solid food sources.
Predominantly breastfed	Breast milk is the primary if not sole milk source with significant calories from other liquid or solid food sources.
Partially breastfed	Combined breast milk and other milk intake where non-breast milk (e.g., formula) is a significant milk source whether or not the infant is consuming significant calories from other liquid or solid food sources.
Token breastfeeding	Minimal, irregular or occasional breastfeeding contributing minimal nutrition and few calories.
Extended breastfeeding	Breastfeeding beyond 12 months of age.
Weaning	Discontinuation of breastfeeding.

[a] Adapted from Labbok and Krasovec (1990)

These terms are important for our discussion in this section because breastfeeding patterns are important determinants of breast milk intake rates.

Fully breastfed infants are those that receive breast milk as the primary, if not sole, source of milk. This category encompasses three specific patterns of breastfeeding. Thus, the term “fully breastfed” is probably most often applied to the entire lactation

period (0-12 months). For example, an infant who was exclusively breastfed for the first 6 months, then predominantly breastfed from 6 through 12 months, would be considered fully breastfed for the lactation period. We use the term "almost exclusively breastfed" particularly for the common practice of exclusive breastfeeding during the day with a small bottle of formula fed at night. Older infants who are breastfed and do not receive significant amounts of formula (or other non-breast milk) but do receive supplementary solid foods would fit into the category of "predominantly breastfed." Partially breastfed infants, like fully breastfed infants, receive some breast milk but unlike fully breastfed infants they also receive significant amounts of milk, or formula from non-breast milk sources.

A few words about units and nomenclature are provided to avoid confusion. In toxicology and pharmacology "dose" is typically expressed as the amount received over time divided by body weight (e.g., mg/kg-day). Analogously, breast milk intake rates can be expressed as the amount received by the infant over time divided by the infant's body weight~~-~~ Daily breast milk intake rate (e.g., g/kg BW-day) is the most commonly used unit of measure. If multiple days of breast milk intake rate for a single infant are averaged together, the result is the "average daily breast milk intake rate." This averaging is over time rather than over individuals. This term is useful for characterizing an average intake over time (e.g., over the first 6 months of life).

A final note is that the means and standard deviations (SDs) reported in these guidelines are arithmetic means and arithmetic SDs, unless otherwise indicated.

5.2 Recommendations [This section was moved from the back of the chapter to the front]

OEHHA recommends the following to estimate dose to the infant through breast milk.

5.2.1 Default Point Estimate for Daily Breast Milk Intake During the First Year

For the default point estimate approach to assess dose and risk from breast milk intake by breastfed infants during the first year, OEHHA recommends using the mean and high-end estimates presented in Table~~s~~ 5.2. The average and high end point estimates are 101 and 139 g/kg BW *day.

Table 5.2 Point Estimates of Breast Milk Intake for Breastfed Infants

Infant Group	***Intake (g/kg-day)***
Fully breastfed over the first year (i.e., fed in accordance with AAP recommendations)[1]	
Mean	101
90th percentile	130
95th percentile	139

Exclusively breastfed During first year[2]	
Mean	113
90th percentile	141
95th percentile	149
Fully breastfed over first 6 months (i.e., fed in accordance with AAP recommendations)[1]	
Mean	130
90th percentile	138
95th percentile	165

[1] AAP = dataset based on American Academy of Pediatrics (1997) infant feeding recommendations; [2] EBF = dataset of exclusively breastfed infants

As discussed in Section 5.1, fully breastfed infants are those that receive breast milk as the primary, if not sole, source of milk. Thus, the term "fully breastfed" is probably most often applied to the entire lactation period (0-12 months). An infant who was exclusively breastfed for the first 6 months, then predominantly breastfed from 6 through 12 months, would be considered fully breastfed for the lactation period. Exclusively breastfed infants are those in which breast milk is sole source of calories.

5.2.2 Stochastic Approach to Breast Milk Intake Among Individuals During the First Year of Life

For a stochastic analysis of exposure and dose through the breast milk intake pathway, a normal distribution with a mean of 101 g/kg-day and standard deviation 23 g/kg-day, is recommended as a distribution for breast milk intake (Table 5.3).

Table 5.3 Recommended Breast Milk Intake Rates Among Breastfed Infants (Averaged Over an Individual's First Year of Life)

	Mean (SD)	***Percentile***							
		5	*10*	*25*	*50*	*75*	*90*	*95*	*99*
Intake (g/kg-day)	101 (23)	62	71	85	101	116	130	139	154

The recommended values for average and high end breast milk consumption rates are the mean and 95th percentiles (101 and 139 g/kg BW ~~-~~*day) for fully breastfed infants.
The recommended parametric model for stochastic risk assessment is a normal distribution with a mean and standard deviation of 101 ± 23

5.2.3 Consideration of Variable Age of Breastfeeding Mothers

Because some environmental toxicants continue to accumulate, older primiparous mothers could excrete higher concentrations of the toxicant in breast milk than younger mothers could when daily intake is constant over time. For example, Hedley et al (2007) reported that breast milk concentrations of POPs increased in a population of Asian women ~~increased~~by 1.45 pg/g-fat/y~~ea~~r. Incorporating a distribution or range of

age among breastfeeding mothers into the risk assessment is a refinement that could be considered in the future.

5.2.4 Analysis for Population-wide Impacts from Breast Milk Exposure

If the risk assessor is evaluating a population-wide risk (e.g., for the purpose of developing a range of cancer burden estimates from this pathway), it may be appropriate to incorporate information on the percent of the infant population that is breastfed at various ages. Information on the prevalence of breastfeeding by age of infant in California from the National Immunization Survey (NIS) specific to California in is available in ~~the~~ Appendix ~~to this chapter~~5A, Table 5A-11 ~~.~~for this purpose. Alternatively, values in Table 5A-17 could be used. This information should be re-evaluated periodically to take into account recent trends in breastfeeding and the outcome of the breastfeeding promotion policies of the last decade.

5.~~2~~3 Conceptual Framework for Variable Breast Milk Intake Rates

The Hot Spots program provides a tiered approach to risk assessment. ~~-~~Point estimate and stochastic approaches are available. ~~-~~The stochastic approach uses probability distributions for variates with sufficient data to estimate variability. The point estimate approach for the breast milk pathway uses average and high-end breast milk consumption values. ~~-~~Data on the distribution of breast milk intake rates allow selection of point estimates that represent average breast milk consumption and a specified percentile of high-end consumption. To incorporate the variability of breast milk intake into the infant dose of toxicant from breast milk, we use a stochastic approach to characterize parameters related to the breast milk pathway.

The data set that we use for breast milk intake rate distributions includes 130 infants for whom there are at least two measurement time points separated by at least 7 days during the lactation period. This is an unusually robust data set for evaluating variability in an important variate for risk assessment. The repeated measures help ensure that typical intake over time is captured thus reducing the effect of intraindividual variability on the distribution of values. Further, milk intake measurements and body weight for individual infants are included, and therefore breast milk intake can be normalized to body weight for each infant, ~~-~~Breast milk intake is correlated with infant body weight (e.g., large babies consume greater amounts of milk than small ones) and thus the variability simply due to body weight can be eliminated.

Interindividual variability is explicitly addressed through the distributional approach used in these guidelines. A distribution of intake rate quantifies the probability of the array of intake rate values in the population. This describes variability between individuals in the population.

Intraindividual variability is addressed by allowing intake to be a function of time (e.g., see Arcus-Arth et al., 2005; Burmaster and Maxwell, 1993), thus taking into account variability of an individual's intake over time. Intraindividual variability can also be

addressed by assessing the impact of different methods of averaging over time (e.g., Arcus-Arth et al., 2005).

The correlation of intake and body weight is taken into account by normalizing intake by body weight for each individual infant. That is, for each infant, their daily intake at that measurement is divided by his/her body weight at that measurement to give intake in units of g/kg-day. Because larger infants consume greater amounts of milk, normalizing to body weight reduces much of the variability due to differences in body weight among infants.

Exposure through mother's milk ingestion ($Dose_m$) is a function of the average substance concentration in mother's milk and the amount of mother's milk ingested. The minimum pathways that the nursing mother is exposed to include inhalation, soil ingestion and dermal, since the chemicals evaluated by the mother's milk pathway are multipathway chemicals. Other pathways may be appropriate depending on site conditions (e.g., presence of vegetable gardens or home grown chickens). The nursing mother in the mother's milk pathway is not herself subject to the mother's milk pathway. The summed average daily dose (mg/kg BW-day) from all pathways is calculated for the nursing mother using equations in the other chapters of this document.

The general algorithm for estimating dose to the infant via the mother's milk pathway is as follows:

$Dose_m = C_m * BMI_{bw} * EF * (1x10^{-3})$ ~~yr / 25,550~~ (~~EQ~~ Eq 5-1)

where:

$Dose_m$ = Dose to the infant through ingestion of mother's milk (mg/kg BW/day)

C_m = Concentration of contaminant in mother's milk is a function of the mother's exposure through all routes and the contaminant half-life in the body (mg/kg milk). Various equations for estimating Cm are presented in Appendix J

BMI_{bw} = Daily breast-milk ingestion rate (g-milk/kg BW/~~*~~day). See Table 5.2 for point estimates. See Table 5.3 for distribution for Tier 3 stochastic risk assessments.

EF = Frequency of exposure, unitless, (days/~~yr~~365 days)

~~yr = Breast-feeding period (yr)~~

~~25,550~~365 ~~= Exposure period (d)~~

$1x10^{-3}$ = Conversion factor~~s~~ (g to kg for milk, ~~µg to mg for contaminant~~)

The exposure frequency (EF) is the fraction of time the infant is exposed daily during the first year (i.e., 365 days) of breast-feeding. Thus, the EF is set at 1. For cancer risk in a screening level assessment, the risk via the mother's milk pathway ($RISKm_{(0<2\ yr)}$) occurs only during the first year in the 0<2 age group.

The risk is calculated for this age group using the appropriate, unitless, age sensitivity factor (ASF) of ~~-~~= 10, (see OEHHA, 2009) and the chemical-specific cancer potency factor (CPF), expressed in units of $(mg/kg\text{-}day)^{-1}$.

$$RISKm_{(0<2\ yr)} = Dose_m * CPF * ASF * ED * 0.5 \qquad \textbf{(Eq. 5-2)}$$

The cancer risk, $RISKm_{(0<2\ yr)}$ is the predicted number of expected cases of cancer over a lifetime as a result of the exposure (e.g., expressed as 1×10^{-6} or 1 case per million people exposed)

Exposure duration (ED) is the number of years within the age grouping, which is 2 years for the 0<2 year age group. Since risk for the mother's milk pathway is assessed only during the first year of the 0<2 year age group, a 0.5 adjustment factor is included in Eq. 5-2. The risk from other exposure pathways (e.g., the inhalation pathway) would not include this factor in the 0<2 age group.

To determine lifetime cancer risks (i.e., 70 years), the total risk for the 0<2 age group is then summed across the total risk of the other age groups:

$$RISK_{(lifetime)} = RISK_{(3rdtri)} + RISK_{(0<2\ yr)} + RISK_{(2<16\ yr)} + RISK_{(16\text{-}70yr)} \qquad \textbf{(Eq. 5-3)}$$

As explained in Chapter 1, different age groups for assessing risk are needed due to different ASFs for each group. We also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70-year lifetime cancer risk estimate. For example, assessing risk in a 9-year residential exposure~~cy~~ scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$RISK_{(9\text{-}yr\ residency)} = RISK_{(3rdtri)} + RISK_{(0<2\ yr)} + RISK_{(2<9\ yr)} \qquad \textbf{(Eq. 5-4)}$$

For the 30-year residential exposure scenario, the risk for 2<16 and 16<30 age groups would be added to the risks from third trimester and 0<2 exposures. For the 70-year residential exposure scenario risk, Eq 5-3 would apply.

~~**Recommended default values for EQ 5-1:**~~

~~BMI_{bw} = See Table 5.6 for point estimates. See Table 5.7 for distribution for Tier 3 stochastic risk assessments.~~
~~F = 365 (d)~~
~~yr = 1(yr)~~

~~For the residential MEI, the default assumptions are that the mother is exposed to facility emissions for 25 years, then her child receives milk for a year, and the child's exposure to facility emissions then continues for 9, 30, or 70 years. The dose of chemical (emitted from a given facility) from breast milk exposure for~~

~~each of the exposure durations is added into the dose of the chemical from other exposure pathways appropriate for the facility and the chemical. For all the exposure duration scenarios, the toxicant dose from the breast-feeding occurs in the first year and thus the ten-fold age sensitivity factor applies when determining cancer risk from the exposure to carcinogen during breast feeding.~~

The risk algorithm for the stochastic approach and for the point estimate approach is the same. In the stochastic approach, the distribution of mother's milk consumption is reflected as a distribution of dose to the infant.

The chemicals with human milk transfer coefficients (Tco_{hm}) to be analyzed in the breast milk exposure pathway are described in Appendix J.

5.~~2~~3.1 Transfer Coefficients for Chemicals From Mother into Milk

Tco_{hm} represent the transfer relationship between the chemical concentration found in milk and the mother's chronic daily dose (i.e. concentration (µg/kg-milk)/dose (µg/day) under steady state conditions. Transfer coefficients can be applied to the mother's chronic daily dose estimated by the Hot Spots exposure model to estimate a Cm for a specific chemical concentration in her milk by equation 5-~~3~~5. Appendix J has additional detail of the derivation of transfer coefficients for specific chemicals.

$$Cm = [DOSEair + DOSEwater + DOSEfood + DOSEsoil + DOSEdermal] \times Tco_{hm} \times BW \quad \text{(Eq. 5-~~2~~5)}$$

where: DOSEair = dose to the mother through inhalation (Eq 3-1) (mg/kg/day)
Dwi = dose though drinking water ingestion (mg/kg/day)
DOSEfood = dose through ingestion of food sources (Eq 7-1) (mg/kg/day)
DOSEsoil = dose through incidental ingestion of soil (Eq 4-1) (mg/kg/day)
DOSEdermal = dose from dermal absorption from contaminated soil (Eq 6-1) (mg/kg/day)
DOSEwater = dose through ingestion of surface water (Eq 8-2) (mg/kg/day)
Tco_{hm} = transfer coefficient (see Table 5-4) (day/kg-milk)
BW = body weight of the mother (default = 70.7 (kg)

However, if bio-transfer information is available for an individual exposure route, route-specific Tcos can be developed resulting in a modification of Eq. 5.~~2~~5:

$$Cm = [(DOSEair \times Tco_{mi}) + (DOSEwater \times Tco_{mw}) + DOSEfood \times Tco_{mf}) + (DOSEsoil \times Tco_{ms}) + (DOSEdermal \times Tco_{md}] \times BW \quad \text{(Eq. 5-~~3~~6)}$$

where: Tco_{mi} = biotransfer coefficient from inhalation to mother's milk (day/kg-milk)
Tco_{mw} = biotransfer coefficient from drinking water to mother's milk (day/kg-milk)
Tco_{mf} = biotransfer coefficient from food to mother's milk (day/kg-milk)

Tco_{ms} = biotransfer coefficient from incidental soil ingestion to mother's milk (day/kg-milk)
Tco_{md} = biotransfer coefficient from dermal absorption from contaminated soil (day/kg-milk)

Estimates of toxicant bio-transfer to breast milk are chemical-specific. Table 5.~~2~~ 4 shows the transfer coefficients for dioxin-like compounds, carcinogenic PAHs and lead that OEHHA has estimated from data found in the peer-reviewed literature. One key factor that plays a role in the difference between oral and inhalation transfer coefficient (e.g., for PAHs) is first pass metabolism which is lacking in dermal and inhalation exposures. Thus, for simplicity, OEHHA applies the transfer coefficients from inhalation to the dermal absorption pathway for lead and PAHs. For lead, we are using the inhalation Tco for all the other pathways of exposure to the mother. Likewise for PCDD/Fs and dioxin-like PCBs, we are using the oral Tco for the other pathways of exposure to the mother in Eq. 5-~~3~~7.

$$Cm = [(D_inh \times Tco_{m_inh}) + (D_ing \times Tco_{m_ing})] \times BW \qquad \text{Eq. 5-7}$$

where:

D_ing = the sum of DOSEfood + DOSEsoil + DOSEwater through ingestion (mg/kg-BW-day)
D_inh = the sum of DOSEair + DOSEdermal through inhalation and dermal absorption (mg/kg-BW-day)
Tco_{m_inh} = biotransfer coefficient from inhalation to mother's milk (d/kg-milk)
Tco_{m_ing} = biotransfer coefficient from ingestion to mother's milk (d/kg-milk)

Table 5.~~2~~ 4 Mother's Milk Transfer Coefficients (Tcos) (Taken from Appendix J)

Chemical/chem. group	**Tco (day/kg-milk)**
PCDDs - oral	3.7
PCDFs - oral	1.8
Dioxin-like PCBs - oral	1.7
PAHs – inhalation	1.55
PAHs – oral	0.401
Lead - inhalation	0.064

The chemicals evaluated in the mother's milk pathway are multipathway chemicals (Appendix E) for which sufficient data were available to estimate a Tco .

Each Tco estimate accounts for biological processes from intake to milk that affect the transfer of a toxicant in the mother's body. Appendix J further describes OEHHA's recommendations for estimating the concentration of chemicals in breast milk.

5.~~3~~4 Available Breast Milk Intake Rate Estimates

The literature contains several studies reporting measured breast milk intakes for infants at various ages and of different breastfeeding patterns. These studies typically have small sample sizes, are cross-sectional and do not represent the U.S. population of breastfeeding infants. However, the U.S. EPA (1997) Exposure Factors Handbook, the prior Hot Spots Exposure guidelines (OEHHA, 2000), and Arcus-Arth et al. (2005) compiled data from selected studies to derive summary intake rates for the population or certain subgroups of the infant population. Below we briefly summarize these reports.

5.~~3~~4.1 U.S. EPA Exposure Factors Handbook (1997) and Child Specific Exposure Factors Handbook (2008)

The U.S. EPA National Center for Environmental Assessment published an Exposure Factors Handbook in 1997 (U.S. EPA, 19997) that provides a review of the breast milk pathway intake rates, and recommends values for breast milk intake rate, lipid intake rate, and lipid content. The 1997 Exposure Factors Handbook recommended breast milk intake rate values based on data from five publications identified as “key studies” by the Agency: Butte *et al.* (1984a), Dewey and Lonnerdal (1983), Dewey *et al.* (1991a; 1991b), Neville *et al.* (1988), and Pao *et al.* (1980). The Handbook recommended mean time-weighted average milk intakes of 742 ml/day and 688 ml/day for infants 0-6 months and 0-12 months of age, respectively. The Handbook also recommends upper-percentiles for time-weighted average daily intakes of 980 ml/day and 1033 ml/day for 0-6 and 0-12 months of age, respectively. The upper percentiles were calculated as the “mean plus 2 standard deviations.” These estimates can be converted from ml to grams of breast milk by multiplying by 1.03. A disadvantage of these rates is that they are not normalized to infant body weight.

In September 2008, the U.S. EPA released the Child-specific Exposure Factors Handbook (CEFH). The CEFH reviewed relevant breast milk intake studies and provided recommended values (Table 5.3). In order to conform to the new standardized age groupings used in the CEFH, U.S. EPA used breast milk intake data from Pao et al. (1980), Dewey and Lönnerdal (1983), Butte et al. (1984), Neville et al. (1988), Dewey et al. (1991a), Dewey et al. (1991b), Butte et al. (2000) and Arcus-Arth et al. (2005). These data were compiled for each month of the first year of life.

Recommendations were converted to mL/day using a density of human milk of 1.03 g/mL rounded up to two significant figures. Only two studies (i.e., Butte et al., 1984 and Arcus-Arth et al., 2005) provided data on a body weight basis. For some months multiple studies were available; for others only one study was available. Weighted means were calculated for each age in months. When upper percentiles were not available from a study, these were estimated by adding two standard deviations to the mean value. Recommendations for upper percentiles,

when multiple studies were available, were calculated as the midpoint of the range of upper percentile values of the studies available for each age in months. These month-by-month intakes were composited to yield intake rates for the standardized age groups by calculating a weighted average.

U.S.EPA provides recommendations for the population of exclusively breastfed infants (Table 5.5) since this population may have higher exposures than partially breastfed infants. For U.S. EPA, exclusively breastfed refers to infants whose sole source of milk comes from human milk, with no other milk substitutes. Partially breastfed refers to infants whose source of milk comes from both human milk and milk substitutes (i.e., formula). Note that some studies define partially breastfed as infants whose dietary intake comes from not only human milk and formula, but also from other solid foods (e.g., strained fruits, vegetables, meats).

Table 5.~~3~~5. Recommended Values for Human Milk and Lipid Intake Rates for Exclusively Breastfed Infants by U.S. EPA Child-specific Exposure Factors Handbook (2008)

Age Group	Mean (mL/day)	Upper %tile (a) (mL/day)	Mean (mL/kg BW-day)	Upper %tile (a) (mL/kg BW-day)	Source
Human Milk Intake					
Birth to <1 month	510	950	150	220	b
1 to <3 months	690	980	140	190	b, c, d, e, f
3 to <6 months	770	1,000	110	150	b, c, d, e, f, g
6 to <12 months	620	1,000	83	130	b, c, e, g
Lipid Intake [h]					
Birth to <1 month	20	38	6.0	8.7	i
1 to <3 months	27	40	5.5	8.0	d, i
3 to <6 months	30	42	4.2	6.0	d, i
6 to <12 months	25	42	3.3	5.2	i

a Upper percentile is reported as mean plus 2 standard deviations
b. Neville et al., 1988.
c. Pao et al., 1980.
d. Butte et al., 1984.
e. Dewey and Lönnerdal, 1983.
f. Butte et al., 2000.
g. Dewey et al., 1991b.
h. The recommended value for the lipid content of human milk is 4.0 percent.
i. Arcus- Arth et al., 2005.

5.~~3~~4.2 OEHHA Hot Spots Exposure Assessment and Stochastic Analysis Guidelines (OEHHA, 2000)

In the prior version of this document (OEHHA, 2000), breast milk intake studies were identified using specified criteria (described in the prior guidelines). The studies are briefly described in the prior guidelines and are divided into two categories: those for which breast milk intake is reported as amount (e.g., ml or grams) per day and those for which intake is reported as amount per body weight per day. Mothers were described as healthy, well-nourished, and at or near normal body weight. Infants were described as healthy, near- or full-term, and single born.

In reviewing and evaluating studies, several factors potentially affecting the accuracy of breast milk intake estimates and their applicability to the general population of infants were considered. These are discussed in the prior guidelines and include (1) the methods for measuring the volume of breast milk consumed, (2) the correlation of breast milk intake with age and with body weight, (3) insensible water loss, and (4) the effect of maternal factors on breast milk intake.

In the prior version of this document (OEHHA, 2000), two datasets were selected with which to derive breast milk intake rates: Hofvander *et al.* (1982) and Dewey *et al.* (1991a; 1991b). These datasets were selected because the data were on a body weight and individual infant basis and the combined datasets provided data covering the 1-12 month age period (the majority of the typical breastfeeding period). For the Hofvander study, all infants were exclusively breast fed while infants in the Dewey et al. study were exclusively breastfed to about 4 months of age and many through 6 months of age. However, in Dewey et al., some infants (exactly who and how many were unspecified) were introduced to solid foods as early as 4 months of age (based on the age of food introduction of 5.3 $\pm$ 1.1 months reported in the published report). Therefore, the Dewey et al. infants did not fit the AAP recommendations at 6 months of age (i.e., exclusively breastfed). Nonetheless, the 3 (exclusive breastfeeding), 9 (fully breastfeeding), and 12 (fully breastfeeding) month ages were in accordance with AAP recommendations.

The normal distribution described the combined datasets fairly well and fit much better than the log normal distribution. The means at the 3-month age group were not statistically different between the Hofvander et al. and Dewey et al. studies. There was considerable variability in the intakes reported at any given age, with the range (60-120 g/kg-day) and standard deviation (18-25 g/kg-day) consistent among the different age groups.

There is an overall trend of decreasing consumption on a per kg basis with increasing age, with daily intake greatest at 30 days of age. A linear relationship fits the age versus consumption rate data fairly well. From this combined data set, an intake averaged across breastfeeding infants during the first year of life is estimated to be 102.4 g/kg-day. Assuming a normal distribution of intake among the infants in this population (with mean and standard deviation 102.4 and 21.82 g/kg-day, respectively),

the different levels of intake are derived and provided in Table 5.~~4~~6. Similarly, an estimate of average intake during the first 6 months of life is estimated to be 131.4 g/kg-day.

Table 5.~~4~~6 OEHHA (2000) - Distribution of daily breast milk intake (g/kg-day) for fully breastfed infants during their first 6 and 12 months of life*

Percentile	6 months	12 months
5	95.5	66.5
10	103	74.3
15	109	79.7
20	113	84.1
25	116	87.7
30	120	90.9
35	123	94.0
50	131	102
65	140	111
70	143	114
75	146	117
80	150	121
85	154	125
90	159	130
95	167	138
99	182	153

*Data from Hofvander et al. (1982) and Dewey et al. (1991a; 1991b), analysis conducted by OEHHA (2000).

5.~~3~~4.3 Arcus-Arth et al. (2005)

Arcus-Arth et al. (2005) extended the work presented in OEHHA (2000) and reported statistical distributions (i.e., percentiles and parameters) of breast milk intake rates for infants fed in accordance with the 1997 American Academy of Pediatrics recommendations (AAP, 1997). The AAP recommendations were for infants to be exclusively breast fed through 6 months of age, and then to receive breast milk as the sole source of milk through 12 months of age during which time solid foods and non-milk liquids are being introduced.

Arcus-Arth et al. also presented distributions of breast milk intake rates for infants exclusively breastfed for 0-12 months. The Arcus-Arth et al. rates are based on breast milk intakes normalized to body weight (g/kg-day) of individual infants seven days to one year of age, with many infants providing data at more than one age period but no infant providing intake measurements from early to late infancy (i.e., at periodic time points throughout the first year). The rates were found to be normally distributed at each measurement age (e.g., at 3 months) as well as over the one year age period (i.e., 7 days through 12 months).

Two methods were used to analyze the data. In the first method (Method 1), the daily intake per kg infant body weight was regressed on age. Intake was integrated over a 6 or 12 month period, and divided by 182.5 or 365 days, respectively. This resulted in a daily intake rate averaged over that period, i.e., an average daily intake. A pooled SD was calculated using the SD's at each measurement age. A distribution was then derived using an integrated average value calculated from the regression, the pooled SD, and an assumption of normality.

For the second method (Method 2), a dataset of breast milk intake over each of 6 or 12 months for 2500 hypothetical infants was created by randomly selecting values at each measurement age from the empirical distribution at that age and assuming normality. For each hypothetical infant, a line was fit using the generated "intake versus age" data, and an average daily intake for each infant was derived. The results are presented in Table 5.~~5~~ 7 below.

Table 5.~~5~~ 7 Daily Breast Milk Intake Rates Averaged Over 6 or 12 Months (g/kg-day)

Averaging Period	***Mean (SD)***	***Population Percentile***							
		5	***10***	***25***	***50***	***75***	***90***	***95***	***99***
AAP [1] ***0-6 Months*** **Method 1**	129.6 (21.3)	94.5	102.3	115.2	129.6	144.0	157.0	164.6	179.3
AAP [1] ***0-6 Months*** **Method 2**	126.3 (6.8)	115.2	117.7	121.8	126.3	130.9	135.0	137.5	142.1
AAP [1] ***0-12 Months*** **Method 1**	100.7 (22.7)	62.4	70.9	85.0	100.7	116.3	130.4	138.9	154.9
AAP [1] ***0-12 Months*** **Method 2**	101.6 (5.3)	92.8	94.8	98.0	101.6	105.2	108.4	110.3	113.4
EBF [2] ***0-12 Months***	113.0 (21.8)	77.1	85.0	98.3	113.0	127.7	140.9	148.8	163.8

[1] AAP = dataset based on American Academy of Pediatrics (1997) infant feeding recommendations
[2] EBF = dataset of exclusively breastfed infants

The variability, as measured by the SD and the range in values of the distribution, differ between Methods 1 and 2. Method 1 incorporated the correlation for an individual infant over time in their intake pattern (e.g., high-end consumers remained high-end consumers throughout the lactation period). Method 2 randomly selected intake values for a hypothetical infant at each age (measurement) point, and thus did not incorporate correlation between intakes. Because higher-end consumers tended to remain higher-end consumers while lower-end consumers remained lower-end, the range of values

from the 5th-percentile to the 99th-percentile is much greater for Method 1 than for Method 2.

In comparison to the breast milk intake rates derived for the prior Hot Spots Exposure guidelines (2000), the Arcus-Arth et al. (2005) rates are based on a larger sample size, include intake measurements as young as 7 days of age (the prior guidelines used data from infants only as young as 3 months), and are in accordance with AAP recommendations. Because pediatricians tend to refer to AAP guidance, it is likely that they would encourage mothers to follow AAP breastfeeding recommendations.

5.~~4~~5 Representativeness of Breast Milk Intake Estimates

The Exposure Factors Handbook (1997), prior Hot Spots Exposure and Stochastic Guidelines (2000), and Arcus-Arth et al. (2005) used data from mothers who were predominantly white, well-nourished and of relatively high socioeconomic (SES) and educational status, and therefore do not represent a cross-section of all California mothers. However, the literature indicates that SES does not affect the amount of breast milk produced by the mother or the amount of breast milk consumed by the infant, except when the mother is severely undernourished. This was the conclusion made by Ahn and MacLean (1980) who reported that studies generally agreed "that the milk output of mothers in [developing and industrialized countries are] comparable, except in populations of markedly undernourished women." Further, the World Health Organization (WHO, 1985) concluded that, for most mother-infant pairs, the volume of breast milk consumed by the infant is considerably less than the mother's potential supply. Thus, the breast milk intake rates reviewed in these guidelines are likely representative of the population of California infants.

5.6~~.0~~ Conclusion

Breastfeeding is an important indirect pathway of exposure for environmental toxicants, particularly persistent lipophilic chemicals, other substances that may accumulate in the body, and substances that are preferentially transferred into breast milk. Significantly larger quantities of some environmental toxicants stored in maternal tissue are delivered to breastfed infants compared to non-breastfed infants. Factors such as the duration of breastfeeding and maternal age at first breast feeding period can influence dose estimates. Breast milk intake should be considered when evaluating risks from environmental toxicants transferred to breast milk. This chapter provides a framework and the values needed for estimating the range of exposures to breast milk pollutants for breastfeeding infants.

The benefits of breastfeeding are widely recognized, and public health institutions promote and encourage breast feeding. In most situations, the benefits for the general infant population appear to outweigh the risks from exposure to toxicants in breast milk. It is a public health goal to minimize the risk and to understand the magnitude of the risk. Because the patterns of breastfeeding are changing, the duration of breastfeeding

and intake of breast milk at different ages should be re-evaluated periodically to ensure a sound basis for such calculations.

Appendix 5A

Appendix 5A includes some background information on the mother's milk exposure pathway that may be useful for some specialized risk assessment applications but is not currently used in the Hot Spots exposure assessment model.

5A-1 Breast Milk Lipid

5A-1.1 Breast Milk Lipid Content

Many chemicals of concern in breast milk are primarily found in the breast milk lipid. Thus information on the lipid content of breast milk may be useful for some risk assessment applications. The average lipid composition of breast milk is significantly different among women (Harmann, et al., 1998). Some researchers have reported monthly increases in breast milk lipid during the breastfeeding period (Ferris et al. 1988; Clark *et al.* 1982), while others have found that breast milk lipid does not change significantly over time (Butte *et al.* 1984b; Dewey and Lonnerdal, 1983). Mean reported values from various studies are provided in Table 5A-1.

Nommsen et al. (1991) measured lipid content in breast milk of 39 women at four measurement periods (3, 6, 9, and 12 months of infant age). The data were collected to be representative of a 24-hour nursing duration, thus accounting for within feeding and diurnal variation in lipid content. Examination of the subjects' lipid levels longitudinally reveals that a subject with high lipid levels in breast milk produced at three months will tend to have high levels at subsequent months. An analysis of variance (ANOVA) using the 39 subjects for which four lipid level measurements are available confirms that there is a highly significant subject effect. Some studies have reported that lipid levels increase over the lactation period (Allen et al., 1991). For the Nommsen et al. study, the average lipid levels among the 39 subjects increase from 3.63 g/100 ml at 3 months to 4.02 g/100 ml at 12 months. However, for 14 of the 39 individuals, the lipid level shows a downward trend (e.g., the 12-month lipid level is lower than the 3 month). There is increased variability in lipid content at later measurement periods relative to earlier periods.

Table 5A-1 Lipid Content of Breast Milk Reported by Various Researchers

Study	***Study Findings***
Butte *et al.* (1984c)	3.92 g lipid /dl - mean for preterm infants 4.31 g lipid /dl - mean for full term infants For infants aged 2 to 12 weeks. 13 full term and 8 preterm infants. Measurements taken at 2, 4, 6, 8, 10, 12 weeks postpartum. No significant changes in content noted over time. Standard deviations ranged from 0.78 to 1.57 g lipid /dl.
Clark *et al.* (1982)	Mean total lipid content in units g/100 ml increased between 2 and 16 weeks postpartum for 10 subjects: 3.9, 4.1, 4.6 and 5.2 at 2, 6, 12, and 16 weeks postpartum.
Ferris *et al.* (1988)	Mean lipid in g/100 ml were 3.98, 4.41, 4.87, and 5.50 at, respectively, 2, 6, 12, and 16 weeks postpartum in 12 subjects. Standard deviations ranged from 0.99 to 1.09 g/100 ml.
Dewey and Lonnerdal (1983)	Overall mean lipid content ranged from 4.3 to 4.9 g/100 ml 1-6 months postpartum, without significant differences at different months. Standard deviations ranged from 0.97 to 1.96 g/100 ml. Measurements taken at 1, 2, 3, 4, 5, and 6 months postpartum. Number of subjects at each month ranged from 13 to 18.
Dewey *et al.* (1991a; 1991b) – raw data provided by K. Dewey	Percent of Lipid in Breast Milk (mean +/- SD) (n=sample size) 3 Months age = 3.67 +/- 0.84 (n=72) 6 Months age = 3.92 +/- 1.04 (n=53) 9 Months age = 4.16 +/- 1.07 (n=46) 12 Months age = 4.02 +/- 1.55 (n=39) All ages = 3.9 +/- 1.1 (n=210)
Mitoulas et al. (2003)	3.55 g lipid/dl (mean for 1-12 months)

5A-1.2 *Breast Milk Lipid Intake Rates – Point Estimates*

The Exposure Factors Handbook (U.S. EPA, 1997) recommends values for breast milk lipid intake rates (Table 5A-2). Values for infants under one year were based on data of Butte *et al.* (1984a) and the Maxwell and Burmaster (1993) analysis of the Dewey *et al.* (1991a) study. A lipid intake rate of 26 ml/day (equivalent to 26.8 g/day) was recommended for risk assessment purposes, with an upper percentile value of 40.4 ml/day (equivalent to 41.6 g/day) ("based on the mean plus 2 standard deviations"). The high-end value is based on a statistical model but falls within the range of empirical values (maximum 51.2 g/day) from Dewey et al. (1991a). A disadvantage of these rates is that they are not normalized to infant body weight.

Table 5A-2. Recommended Values for Lipid Intake Rates for Exclusively Breastfed Infants by U.S. EPA Child-specific Exposure Factors Handbook[a] (2008)

Age Group	Mean (mL/day)	Upper %tile (a) (mL/day)	Mean (mL/kg BW-day)	Upper %tile (a) (mL/kg BW-day)	Source
Birth to <1 month	20	38	6.0	8.7	b
1 to <3 months	27	40	5.5	8.0	b,c
3 to <6 months	30	42	4.2	6.0	b,c,
6 to <12 months	25	42	3.3	5.2	b

a The recommended value for the lipid content of human milk is 4.0 percent.
b. Arcus- Arth et al., 2005
c. Butte et al., 1984.

Mitoulas et al. (2003) studied breast milk intake and lipid levels in 30 Australian mother-infant pairs. The infants were fully breastfed for at least 4 months, with complementary foods added between 4 and 6 months age. Measurements were made at 1, 2, 4, 6, 9, and 12 months of age. For the 0-6 and 0-12 month periods, the mean lipid intake was 13.50 and 12.96 g/day, respectively. For the period of exclusive breastfeeding (1-4 months age), mean lipid intake was 13.33 g/day.

5A-1.3 Breast Milk Lipid Intake Rates - Distributions

The Maxwell and Burmaster (1993) study presented a distribution of breast milk lipid intake by infants less than one year of age. They report that, at any given time, "approximately 22% of infants less than one year of age are being breastfed, the remaining 78% have no exposure to chemicals in their mother's breast milk." They found the mean lipid intake among nursing infants to be characterized by a normal distribution with mean 26.81 g/day and standard deviation 7.39 g/day. Their results are based on the fraction of infants at different ages being breastfed according to the reports of Ryan *et al.* (1991a, 1991b) and "on data for lipid intake from a sample of white, middle- to upper-income, highly educated women living near Davis, California" (Dewey *et al.*, 1991a).

Advantages of this study include the detailed analysis of the breast milk pathway, which addressed several of the key factors contributing to variable intakes among individual infants. However, some features of this study limit its usefulness for evaluation of acute and chronic exposure of breastfed infants to environmental toxicants. First, the study did not analyze data on breast milk intake during the first three months of life and instead extrapolated from the Davis study to predict intake during this period. Second, intake was expressed as amount per day, rather than amount per body weight per day;

the latter would facilitate more accurate dose calculations. Third, estimates of the breastfeeding population are made for the fraction of current feeders on any given day rather than the fraction of infants who breastfed at any time during their first year of life. For chronic exposure analyses it is important to consider prior intakes in addition to current intake of individual infants.

Arcus-Arth et al. (2005) presented lipid intake rates normalized to body weight by combining measured milk intake values with lipid content values. The first set of lipid intakes was derived using only Dewey et al. data (raw data provided by K. Dewey, and methodology described in Dewey et al. 1991a, b). The infants were exclusively breastfed through 3 months of age and fully breast fed thereafter. Milk intake and lipid content were measured at 3 (n=72), 6 (n=53), 9 (n=46), and 12 (n=39) months of age. The milk intake from each infant was multiplied by the corresponding measured lipid content value for that infant at that age to give lipid intake. These lipid intake rates were normally distributed at the 6-, 9-, and 12-month measurement ages.

The researchers also derived a second set of lipid intakes using the same milk intake values of Dewey et al. and a 4% lipid content value, which is the lipid content value commonly used as a default in risk assessment. The 4% lipid content derived rates differed by 2-10% from the measured lipid content derived rates, with probable overestimation at the mean and underestimation at the low- and high-end percentiles. Because the differences were not substantial, and because a dataset of lipid content values representing the population is not available, the 4% lipid content value was considered a reasonable default.

A third set of lipid intakes was derived to represent the subpopulation of infants fed in accordance with AAP recommendations (AAP, 1997). Because a few infants in the Dewey et al. study had consumed solid foods between 4 and 6 months of age, and because it is not known which infants these were, the 6-month data did not follow AAP recommendations and thus could not be used for this purpose. Therefore, Arcus-Arth et al. used the AAP dataset they had created and the default 4% lipid content value to derive a set of “AAP lipid intake rates.”

For each set of lipid intakes, the values were regressed by age to derive average daily lipid intake rates over the 0-6 and 0-12 month periods. While the 0-12 month derived lipid intake rates were available in the Arcus-Arth et al. journal article, the 0-6 month rates were not published but were obtained from the authors (Arcus-Arth, personal communication, 2008).

Arcus-Arth et al. derived lipid intakes and average daily lipid intake rates only for breastfed infants, not the entire infant population, resulting in intakes that are not directly comparable to those of Maxwell and Burmaster (1993). An advantage of the Arcus-Arth et al. derived rates is that they are normalized to infant body weight. A disadvantage is that lipid intake values for infants 0-3 months of age were derived using extrapolation because measured values for this age group were not available.

Inter- and intraindividual variation of lipid content over time should be considered when evaluating lipid intake for the infant population. We chose to use the average daily lipid intake rates of Arcus-Arth et al. because they have incorporated variability over time and have been normalized to body weight. The mean and selected percentiles of the average daily lipid intake rates are presented in Tables 5A-4, below.

Table 5A-3 suggests that assuming a 4% lipid content value tends to slightly overestimate the mean and slightly underestimate the high-end percentile of average daily lipid intake. Nonetheless, the values are similar, supporting the use of a 4% lipid content value as a reasonable default. Further, the Exposure Factors Handbook (U.S. EPA, 1997) recommends assigning a value of 4% (i.e., 4 g/dl) to breast milk lipid content based on data of the National Research Council (1991), Butte *et al.* (1984a), and Maxwell and Burmaster (1993).

Table 5A-3 Comparison of Lipid Content Assumptions: average daily lipid intake (g/kg day) of breastfed infants for the 0–12 month age period

		Population Percentiles							
	Mean	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**
Measured lipid content [A]	3.70	2.01	2.38	3.00	3.70	4.39	5.01	5.38	6.08
4% lipid content [B]	4.03	2.53	2.85	3.37	3.96	4.54	5.07	5.38	5.98

[A] Lipid intake derived by multiplying the lipid content measurement by the milk intake measurement for each infant in the dataset provided by K. Dewey. Includes a few infants who may have received some solid foods between 4-6 months age.
[B] Lipid intake derived by multiplying a 4% lipid content value by the milk intake measurements provided by K. Dewey. Includes a few infants who may have received some solid foods between 4-6 months age.
* Data source: Arcus-Arth et al. (2005)

Assuming a 4% lipid content value, the distribution of average daily lipid intake rates for the AAP dataset is presented in Table 5A-4, below.

Table 5A-4 Distributions of Average Daily Lipid Intake (g/kg day) over the 0-6 and 0–12 month age periods for AAP infants and assuming 4% milk lipid content*

		Population Percentiles							
Age	**Mean**	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**
0-6 months	5.18	3.78	4.09	4.61	5.18	5.76	6.28	6.58	7.17
0-12 [A] **months**	4.03	2.50	2.84	3.40	4.03	4.65	5.22	5.56	6.20

[A] includes infants exclusively breast fed through 6 months age and thereafter fully breast fed
* Data source: Arcus-Arth et al. (2005)

5A-2 Prevalence of Breastfeeding

Information on the prevalence of breastfeeding may be useful for assessing population impacts of pollutants. The majority of infants receive at least some breast milk during infancy. Of these infants, a significant number receive breast milk through at least 12 months of age. Using survey data, the prevalence of breastfeeding (i.e., percent of infants who are breastfed) can be estimated. The prevalence of in-hospital and early postpartum breastfeeding provides information regarding the initiation of breastfeeding and therefore the potential number of infants that may be exposed via the breast milk pathway. The prevalence of breastfeeding at later ages in the lactation period provides information on the duration of breastfeeding, which is a key determinant of the amount of breast milk, and therefore the total dose, to an infant over the lactation period.

Until recently, the only nationwide survey of breastfeeding prevalence was the Ross Mothers Survey (Ross Products Division, Abbott Laboratories). More recently, the National Immunization Survey and the National Survey of Children's Health have collected national data on breastfeeding prevalence, while the California Newborn Screening Program has collected data on infants in California (but only at an early postpartum (in-hospital) age). In addition, Hammer et al. (1999) provide prevalence data on a subpopulation of California infants (i.e., SF Bay area infants). These studies are briefly described below, and results are presented in Tables 5A-5 and 5A-6, below. The prevalence data can also be used in conjunction with breast milk intake rates to derive breast milk intake rates over the entire population of infants for the estimation of population cancer burden.

5A-2.1 The Ross Mothers Survey

The Ross Mothers Survey (RMS) is an annual nationwide mail survey conducted by Ross Products Division of Abbott Laboratories and is sent periodically sent to a probability sample of new mothers. Prior to January 1997, mothers received the survey at the time their babies turned six months of age. Since that time, surveys are sent to mothers at each month of age, from one through 12 months.

The survey asks mothers to recall the types of milk their babies received (1) in the hospital, (2) at one week of age, (3) in the last 30 days, and (4) most often in the last week. By using a multiple choice question, mothers select the kinds of milk fed to their infants from a listing that includes breast milk, commercially available infant formulas, and cow milk.

The weighting of the results reflects national demographics associated with the geography, race, age, and education of mothers throughout the United States. The 1998-2002 rates were weighted using U.S. Department of Health and Human Services 1997 natality data, while the 2002-2003 rates were weighted using year 2000 natality data. For 2002, the response rate was 21% (290,000 questionnaires returned out of 1,380,000 mailed) (Ryan, 2005).

The majority of infants in the U.S. receive breast milk at some time. The survey has consistently found that the percent of mothers breastfeeding in the U.S. varies considerably with geographic region. The highest rates of breastfeeding are in the Mountain and Pacific states (U.S. census regions). In the Pacific states in 2001, 82.9% of newborns were breastfed in-hospital, and 44.2% of infants were breastfed at 6 months (Ryan et al., 2002).

These rates are higher than the 1996 rates (75.1% and 30.9%, respectively for in-hospital and at 6 months age) reported in the prior guidelines.~~—~~ In addition to geographic differences, breastfeeding patterns vary considerably with maternal age and education, race/ethnicity, and economic status (National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996).

5A-2.2 The National Immunization Survey

The National Immunization Survey is conducted annually with approximately 35,600 questionnaires completed each year. Beginning July 2001 and continuing through December 2002, a sample of respondents was asked about breastfeeding using a set of breastfeeding questions. Starting January 2003, all respondents to the household telephone survey were asked these breastfeeding questions.

The NIS uses random-digit dialing to survey households about childhood immunization for children aged 19–35 months of age. The response rates for NIS years 2001–2006 ranged from 64.5% to 76.1%. Because children are 19–35 months of age at the time of the parent interview, each survey year represents children born sometime during a three calendar year period (Table A2 in NIS report). All analyses were conducted using statistical software that accounts for complex sample design. A more detailed description of the methods can be found at http://www.cdc.gov/nis.

Three modifications were made to the breastfeeding questions in 2004 and 2006. Only the change in January 2006 to Question 3, which consisted of asking the one question as two separate questions, resulted in significant effects on the prevalence rates (i.e., yielded significantly lower estimates of exclusive breastfeeding). Because of this large effect, the trends of exclusive breastfeeding by year of birth are shown separately for children whose caregivers were interviewed before and after January 2006.

Advantages of the NIS study include the relatively high response rates, California-specific data, and the inclusion in the survey of specific questions regarding the consumption by the infant of other foods or liquids in addition to breast milk. A disadvantage is the lengthy time interval between when the infant was breastfed and when the parent was asked questions pertinent to breastfeeding that infant, which may lead to inaccuracies in recall.

Table 5A-5 Prevalence of breastfeeding in the United States by birth year (percent ± ½ of confidence interval)

Age	Year					
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Early postpartum	68 ± 3	71 ± 2	71 ± 1	71 ± 1	73 ± 1	74 ± 1
At 6 months	33 ± 3	34 ± 2	37 ± 1	38 ± 1	39 ± 1	42 ± 1
At 12 months	15 ± 2	16 ± 2	18 ± 1	19 ± 1	20 ± 1	21 ± 1

* Exclusive breastfeeding information is from 2006 NIS survey data only and is defined as only breast milk — no solids, water, or other liquids.
* percent represents the proportion of infants
* Source: National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services

Table 5A-6 Prevalence of Breastfeeding California Infants by Birth Year and Type of Breastfeeding (percent ± ½ of confidence interval)[1]

	N	**Ever Breast-fed**	**Breast-fed at 6 Months**	**Breast-fed at 12 Months**	**N**	**Exclusive Breast-fed[2] at 3 Months**	**Exclusive Breast-fed[2] at 6 Months**
Born in 2004	1702	83.8 ± 3.3	52.9 ± 4.3	30.4 ± 4.0	1438	38.7 ± 4.5	17.4 ± 3.5
Born in 2003	1688	83.8 ± 3.2	49.3 ± 4.0	26.6 ± 3.5			

[1] percent represents the proportion of infants
[2] Exclusive breastfeeding information is from 2006 NIS survey data only and is defined as only breast milk — no solids, water, and other liquids.
* Source: National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services

5A-2.3 California Newborn Screening Program (MCAH, 2007)

In-hospital infant feeding practices in California are monitored using data collected by the Newborn Screening (NBS) Program. All non-military hospitals providing maternity services are required to complete the Newborn Screening Test Form prior to an infant's discharge. In addition to tracking genetic diseases and metabolic disorders, the NBS program gathers data on all infant feedings from birth to time of collecting the specimen for the genetic disease/metabolic disorder. The Maternal, Child and Adolescent Health (MCAH) Program staff, of the California Department of Public Health, analyze these data and publish the in-hospital breastfeeding rates (accessible at: http://www.cdph.ca.gov/data/statistics/Pages/BreastfeedingStatistics.aspx).

In September 2007, the MCAH published rates using 2006 Newborn Screening Program data. The prevalence rate for any breastfeeding in-hospital was 86.5% of mothers, while the rate of exclusive breastfeeding was 42.8%. The relatively low exclusive breastfeeding rate is only applicable to the in-hospital stay and not to the later period at home. This is because infants frequently receive some formula while in the hospital to prevent infant hypoglycemia which may result from an inability of the infant to properly nurse (e.g., latch on) initially or from the mother not producing sufficient milk for nursing yet.

5A-2.4 Hammer et al. (1999)

Hammer et al. (1999) prospectively studied the feeding patterns of 216 infants in the San Francisco Bay area from birth through weaning. Information on infant feeding practices was collected via an Infant Feeding Report form completed by the mother for a 3-day period at the end of every month. Parent-infant pairs were recruited from the well newborn nurseries at a university hospital, community hospital, and health maintenance organization (HMO). The parents' intention to feed the infant by a particular feeding pattern (e.g., bottle feeding) was not considered in selecting infants for the study.

Investigators or their staff in the laboratory did not give information or advice on feeding practices to parents, and all infants received routine health maintenance care from local physicians or clinics. Thus, the feeding patterns for these infants were not dictated by the study but instead are likely to have reflected prevalent feeding patterns in the general infant population of the SF Bay area. These patterns are likely to also be applicable to similar areas (e.g., urban) in California.

5A-2.5 Taylor (2006)

Taylor et al. (2006) analyzed data of singleton children of primiparous mothers from the 2002 National Survey of Family Growth. The data set included information on 3229 mother-child pairs when the child was 1-18 years of age. Women were asked if they had breastfed their child, and, if so, the number of completed weeks. A limitation of this study is the sometimes lengthy interval between infancy and when the mother was asked about infant feeding practices. An advantage of this study is the inclusion of only primiparous women, which is consistent with the assumption of the child being from a primiparous mother in these guidelines.

5A-2.6 Summary of Prevalence Data

Breastfeeding prevalence rates from the above studies are summarized in Table 5A-7, below. For the Ross Mothers Survey, rates for the Pacific region are presented because the Pacific region better represents California than the entire U.S.

Table 5A-7— Prevalence of Breastfeeding

Study	**NIS [1]**	**Ross Mothers Survey [2] (Pacific region)**	**New Born Screening Program [3]**	**Hammer et al. (1999) [4]**	**Taylor et al. (2006) [5]**
Study Background					
Sample Size	1702	39,600 (estimated 1999 sample size)	506,442	175	3229 primiparous, singleton
Geographic Region	U.S.	Pacific region	California	SF Bay Area, northern CA	U.S.
Year	2004	2001	2006	1997-1998 (presumed)	2002 (interview)1986-2001(birth year)
Percent of Infants Breastfeeding – Any Breastfeeding Pattern					
Ever breastfed	83.3%			90%	62%
In-hospital		82.9%	86.5%		
At 3 months					36%of all infants,58% of those who ever breastfed
At 6 months	52.9%	44.2%		48%	23% of all 38% of those who ever breastfed
At 12 months	30.4%			19%	6% of all,13% of those who ever breastfed

Table 5A-7— Prevalence of Breastfeeding (Cont.)

Study	**NIS [1]**	**Ross Mothers Survey [2] (Pacific region)**	**New Born Screening Program [3]**	**Hammer et al. (1999) [4]**	**Taylor et al. (2006) [5]**
Study Background					
Sample Size	1702	39,600 (estimated 1999 sample size)	506,442	175	3229 primiparous, singleton
Geographic Region	U.S.	Pacific region	California	SF Bay Area, northern CA	U.S.
Year	2004	2001	2006	1997-1998 (presumed)	2002 (interview)1986-2001(birth year)
Percent of Infants Breastfeeding - Exclusive Breastfeeding					
In-hospital		54.2%	42.8%		
At 2 months				31%	
At 3 months	38.7%				
At 6 months	17.4%	24.1%		14%	
At 12 months				7% (“sole breast-feeding”)	

[1] National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services
[2] Ryan et al. (2002)
[3] MCAH of the California Department of Public Health
[4] fed directly from the breast, does not include feedings from a bottle of breast milk
[5] data from the National Survey of Family Growth (2002)

5A-2.7 Trends in Breastfeeding at Early-postpartum, 6 month, and 12 Month Ages

The Ross Mothers Survey, National Immunization Survey, National Survey of Children's Health, and Hammer et al. (1999) collected data on the prevalence of breastfeeding at various times of the lactation period, and thus provide information on the initiation and duration of breastfeeding. The California Newborn Screening Program only provides information on in-hospital infants (i.e., initiation of breastfeeding).

The Ross Mothers Survey showed increases in breastfeeding both for in-hospital and at 6 months age between 1993 and 2003 for California (Mothers Survey, Ross Products Division of Abbott (2004) (Table 5A-8). It is of note that the in-hospital rate stabilized at about 80% from 1999-2002 but then decreased to 73.9% in 2003. Upon examination of rates for the other states (not shown here), a similar decrease of in-hospital rates occurred for 47 of the other 49 states (the exceptions being Delaware and North Dakota, which were noted as having 'variable' data associated with low sample sizes). A systematic calculation in the rates or a change in hospital policy might be responsible for this decrease. A decrease from 2002 to 2003 is also seen in 6-month rates for California and a little over half of the other states, but the decrease is much less than for the in-hospital rates and possibly not statistically significant. Thus, there appears to be a sudden unexplained decrease in the initiation of breastfeeding but the duration of breastfeeding has not significantly changed.

Table 5A-8 California-specific Breastfeeding Rates from the Ross Mothers Survey*

	In-hospital	*At 6 months*
1993	69.5	25.8
1994	70.6	27.1
1995	73.2	29.8
1996	72.0	29.4
1997	75.2	35.0
1998	76.9	38.4
1999	79.1	39.1
2000	80.2	40.1
2001	81.7	43.6
2002	79.7	41.7
2003	73.9	39.8

* Source: Mothers Survey, Ross Products Division of Abbott, 2004

The prevalence of infants who are exclusively breastfed at 6 months has also increased according to the RMS data (Table 5A-9, below). However, in-hospital exclusive breastfeeding does not appear to have changed. This might be because the mother's milk has not yet come in or that the infant has not yet learned how to latch on during the short stay in the hospital. Hospital staff may be anxious to feed the infant formula due to concern over hypoglycemia, which can occur very quickly in neonates.

Table 5A-9 Prevalence (percent of infants) of Breastfeeding for the United States from the Ross Mothers' Survey[1]

	Breastfeeding		Exclusive Breastfeeding	
	In-hospital	**At 6 months**	**In-hospital**	**At 6 months**
1994	57.4	19.7	46.8	11.2
1995	58.9	20.8	47.6	11.9
1996	59.2	21.7	47.3	12.2
1997	62.4	26.0	46.1	12.7
1998	64.3	28.6	46.2	13.8
1999	67.2	30.7	46.3	15.8
2000	68.4	31.4	46.0	16.0
2001	69.5	32.5	46.3	17.2
2001 – *Pacific Region*			54.2	24.1

[1] source: Ryan et al. (2002)

The National Immunization Survey Study (NIS) provides data from 1999 to 2004 for the entire U.S, which is sufficient for the assessment of trend over time. The NIS U.S. data show that from 2001 to 2006 slight to moderate progressive increases in breastfeeding prevalence occurred at the early postpartum period and at 6 and 12 months of age (Table 5A-10). California-specific data are available, but only for 2003 and 2004, which is insufficient for evaluating statistical trends over time (Table 5A.11). However, the data do reveal an increase from 2003 to 2004 in 6- and 12-month prevalence rates for California.

Table 5A-10 Prevalence of Breastfeeding in the United States by Birth Year (percent ± ½ of confidence interval)[1,2]

Birth Year

	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Early postpartum	68 ± 3	71 ± 2	71 ± 1	71 ± 1	73 ± 1	74 ± 1
At 6 months	33 ± 3	34 ± 2	37 ± 1	38 ± 1	39 ± 1	42 ± 1
At 12 months	15 ± 2	16 ± 2	18 ± 1	19 ± 1	20 ± 1	21 ± 1

1 Percent represents the proportion of infants

2 Source: National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services

Table 5A-11 Prevalence of Breastfeeding for California Infants by Birth Year and Type of Breastfeeding (percent ± ½ of confidence interval)[1]

	N	Ever Breast-fed	Breast-fed at 6 Months	Breast-fed at 12 Months		N	Exclusive Breastfed [2] at 3 Months (2006)	Exclusive Breastfed[2] at 6 Months (2006)
Birth Year 2003	1688	83.8 ± 3.2	49.3 ± 4.0	26.6 ± 3.5				
Birth Year 2004	1702	83.8 ± 3.3	52.9 ± 4.3	30.4 ± 4.0		1438	38.7 ± 4.5	17.4 ± 3.5

[1] Percent represents the proportion of infants

[2] Exclusive breastfeeding information is from interviews in 2006 and is defined as consumption of only breast milk (i.e., no solids, water, or other liquids).

* Source: National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services

Maternal education and age, and family socioeconomic status have been correlated with both initiation and duration of breastfeeding (NIS, National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996). The NIS data for infants born in 2004 shows that infants were more likely to have ever been breastfed, breastfed at 6 months, or exclusively breastfed if they were born to mothers 30 years of age or older, born to mothers who were college graduates, or born to families at the highest income level studied (i.e., the highest level over the poverty-to-income ratio).

Because the above data demonstrate continued trends towards increases in the initiation and duration of breastfeeding (including exclusive breastfeeding), these trends should be re-evaluated periodically. Factors affecting breastfeeding prevalence, such as maternal age and the promotion of breastfeeding (both discussed below), can help to assess breastfeeding trends.

5A-2.8 Age at Weaning

A few studies have examined the rate of breastfeeding cessation. Maxwell and Burmaster (1993) found that the fraction of infants breastfeeding (f) in the U.S. in 1989 was well described by a negative exponential distribution (e.g., $f = a\, e^{-c\, t}$) with a cessation rate of 0.5% per day for the 0-12 month period. Arcus-Arth et al. (2005) used Ross Mothers Survey data from the year 2000 and found a cessation rate of 0.2027% per day for the 0-6 month period and 0.07563% for the 6-12 month period.

We evaluated data from the National Survey of Children's Health (NSCH, CDC, 2003) to assess age of weaning data that are more recent and that are specific to California. The NSCH is a national survey funded by the Maternal and Child Health Bureau, U.S. Department of Health and Human Services, and administered by the National Center for

Health Statistics, Centers for Disease Control and Prevention. The survey collects data on national and state-level prevalence of a variety of physical, emotional, and behavioral child health indicators, including the age at which the child was completely weaned from breast milk.

The survey uses the State and Local Area Integrated Telephone Survey, which provides a consistent means to collect data across states. Phone numbers are selected randomly to identify households with one or more children less than 18 years of age. For these households, one child is randomly selected for inclusion in the study. Over 102,350 surveys were completed for children 0-17 years of age.

Survey results are weighted to represent the population of non-institutionalized children 0-17 years of age on both national and state levels. For the question on the age of weaning from breast milk, NSCH used only data from mothers whose children were 0-5 years of age at the time of interview. The reported age at weaning was reported as age intervals rather than age points.

These age intervals were <3, 3-6, 7-12, and over 12 months of age. Some women were still breastfeeding their child at the time of interview so it is unknown when these children were weaned. Data were available specific to California, with the most recent year being 2003. Results were based on those infants who were fed breast milk (versus based on all breastfed plus non-breastfed infants).

The NSCH Data Resource Center provides a website with an interactive data query feature for hands-on access to the survey data (http://www.nschdata.org/DataQuery/SurveyAreas.aspx). We used the website query system to assess age at weaning in California, by selecting "Survey Sections", then "California", "2003" and "Early Childhood", then "at what age did young children completely stop breastfeeding? (S6Q60 -- ages 0-5 who have been breastfed)." Results are presented in Table 5A-12, below.

Table 5A.12 Age interval when completely weaned from breast milk – California Infants[1]

	< 3 months	**3-6 months**	**7-12 months**	**> 12 months**	**Total**
Percent of breastfed infants[2]	19.9	30.2	31.3	18.6	100
Sample size	118	179	185	110	592

[1] data from the National Survey of Children's Health from 2003
[2] Excluding those still breastfeeding at time of interview

To evaluate the distribution of breast milk weaning age in California we used the data in Table 5A-13 and applied simulation and curve fitting functions in Crystal Ball version 7.2.1 (Decisioneering, 2007) to find the best-fit distribution and to identify distributional

parameters. We excluded infants (N=67) who were still breastfeeding at the time of interview, and adjusted the remaining data (i.e., percent weaned, N=592) to account for the exclusions. We found that the data best fit a gamma distribution with location = -0.17, scale = 3.60, and shape = 2.41464**.** The median age of weaning was 7.0 months and 75% of infants were weaned by 12 months, 90% by 16 months, and 95% by 18 months of age. It is noteworthy that a significant percentage of infants can be considered extended breast feeders (i.e., breastfed past 12 months of age). Our results are presented in Table 5.17.

Table 5A.13 -Mean and percentiles of the parametric model of age at weaning from breast milk for California infants in 2003 (in months) [1,2]

	mean	50%-ile	75%-ile	90%-ile	95%-ile
Weaning age (months)	8	8	12	16	18

[1] derived by OEHHA from the National Survey of Children's Health 2003 data
[2] excludes infants still breastfeeding at time of interview with mother

Other studies that provide information on the cessation of breastfeeding (weaning) include Hammer et al. (1999) (described above in Section 5A-2.~~8)~~4 and Rempel (2004). These two studies are summarized in Table 5A-14, below.

The Rempel (2004) study followed a cohort of Canadian mother-infant pairs from birth until 12 months of age. Of the 317 mothers who agreed to participate in the study, 289 initiated breastfeeding. The results are based on the 289 infants that breastfed. At 9 months of infant age, 27% of infants were still consuming some breast milk and 14% of the original 289 weaned between 9 and 12 months. Though the Rempel (2004) study involved Canadian mother-infant pairs, the results are likely similar to similar subpopulations in the U.S.

The mothers in the Rempel study were from Ontario (a fairly large cosmopolitan city), 16-42 years of age, had a mean +/- SD number years of education of 15 ± 2.8, 59% were employed full-time, 16% were employed part-time, 67% were married, 13% were born outside Canada. According to the authors "the participants represented a wide variety of cultural backgrounds." These demographics may be similar to some subpopulations of women in California cities.

Table 5A.14 -Age at Weaning

Study	N	Infants Studied	Infant Age at Weaning (month)	Year(s) of Study	Comments
Hammer et al. (1999)	175	General population	Median: 6.0 Range: 0.9-39.1	1996-1998 (approx)	SF Bay area
Rempel (2004)	312	General population	13% weaned between 9 &12	1999-2000	Canada

5A-3 Subpopulations of Special Concern

5A.3.1 Infants Breastfed for an Extended Period of Time

Documentation of extended breastfeeding is quite limited in this country both because there is little socio-cultural support for extended nursing (Stein et al., 2004) and because many health care practitioners do not consider asking about it (Sugarman and Kendall-Tackett, 1995). However, recent increases in the duration of breastfeeding (see Section 5~~.6~~A-2.7, above) as well as efforts by public agencies and the American Academy of Pediatrics to promote and support breastfeeding ~~(See Appendix E)~~ would suggest that the number (and proportion) of infants being breastfed beyond the first year of life may be increasing as well. Few studies have evaluated information on extended breastfeeding. These studies are described, and summarized in Table 5A-15, below.

Sugarman and Kendall-Tackett (1995) found that among a group of American women (n = 179) who breastfed past 6 months of infant age, the age of weaning averaged between 2.5 and 3.0 years, with a high end value of 7 years 4 months. Forty-three percent of children in this sample (i.e., breastfed past 6 months) were breastfed beyond their third birthday. The researchers also found in examining mothers who breastfed more than one child past 6 months of age, that in subsequent lactations the younger children were breastfed for longer periods of time than the older child(ren) had been.

Dettwyler (2004) reported results of an informal survey of children who were breastfed for periods greater than 3 years. The sample included 1280 children, most during the 1990s, but some in the 1980s and earlier. The average age at weaning was 4.24 years, with a median of 4.00, a mode of 3.50, and a standard deviation of 1.08 years. Close to half of the children weaned between 3.00 and 4.00 years of age.

Children whose weaning was characterized as “child led” weaned at an average age of 4.39 years, whereas those whose weaning was characterized as “mother led” were weaned at an average age of 3.83 years. The mothers were most often middle-class and upper-class, worked outside the home, and highly educated. More than 50% of the mothers were college graduates, and the sample included numerous women with advanced degrees. Of those who responded to the question on ethnicity of the mother, most said they were European-American. These characteristics mirror those found in previous studies of extended breastfeeding in the U.S. (Sugarman and Kendall-Tackett, 1995).

Although most infants in California are weaned during their first year (see Table 5A-14, above)), there is a subpopulation of infants who are breastfed for an extended period. The Hammer et al. (1999) study (see description in Section 5A-2.8, above), which did not seek to identify extended breastfeeding infants, demonstrates that extended breastfeeding may be more prevalent than is commonly thought. Of the 175 infants who were breastfed, the oldest age at complete weaning from the breast was 39.1 months (extended breastfeeding).

Table 5A.15 -Age at Weaning for Extended Breastfeeding Infants

Study	N	Infants Studied	Infant Age at Weaning	Year(s) of Study	Comments
Dettwyler (2004)	1280	Infants breastfed to at least 3 years	Mean: -4.24 yrs Median: -4.0 yrs SD: -1.08	1995-2000	U.S.
Hammer et al. (1999)	175	General population	Median: -6.0 mos Range: 0.9-39.1 mos	1996-1998 (presumed)	SF Bay area
Sugarman and Kendall-Tackett (1995)	134	Infants breastfed to at least 6 months	Mean: -2.5-3.0 yrs Range: 6 mo - 7 yrs 4 mos 43% breastfed past 3 yrs	1989-1991	U.S.

Immigrants to the U.S. may be more likely to practice extended breastfeeding, if they retain breast feeding practices from the home country. The 2003 joint WHO/UNICEF released a joint recommendation in 2003 that advocates exclusive breastfeeding for the first 6 months followed by breastfeeding with supplementation of complementary foods for at least the first two years of life (UNICEF/WHO, 1990). In the study by Buckley (2002), ten Hispanic mothers from Caribbean, South American or Central American countries, residing in the U.S. who breastfed their infant(s) beyond one year of age, stated that breastfeeding a child up to 4 years of age was common in their countries of origin.

In a “Challenging Case” of the Journal of Developmental Pediatrics, Dr. Boies reports personal communication with Anne Seshadri (2002) who states “mothers in India frequently breastfeed their infants until 3 or 4 years of age” (Stein et al., 2004). Immigration into the U.S. from locations, where extended breast feeding is practiced such as Hispanic countries and India, could cause an overall increase in the incidence of extended breastfeeding.

Currently there are little data on the composition of breast milk during extended breastfeeding. Studies have found that when milk volume decreases (e.g., near the time of weaning) that lipid content increases, while other studies have found the opposite result. It would be helpful to know the lipid content of breast milk during extended breastfeeding to better understand the importance of lipophillic chemical transfer to an extended breastfed infant.

Exposures to infants who are breastfed for an extended period should be further investigated and in some circumstances taken into account in non-default analyses. See Appendix ~~E~~ J for a more detailed discussion about the accumulation and transfer of chemicals in maternal body tissue and its potential impact on extended breastfed infants.

5A-3.2 Infants of Older Mothers

Older primiparous mothers have longer to accumulate toxicants with long body tissue half-lives (i.e., more than six years) and could therefore eliminate more toxicant to their breast milk than younger mothers would. Furthermore, older mothers tend to breastfeed for a longer duration than younger mothers do (Section 5A.3.1, above). Both conditions could lead to higher dosing of primiparous infants from the breast milk of older mothers than of infants from younger primiparous mothers' breast milk.

Many chemicals will reach a steady state in the mother's body before age 25. On the other hand, other substances do not reach steady state within 25 years. For example, lead continues to accumulate in cortical bone over the human lifetime (O'Flaherty 1998). Thus, women giving birth after 25 years of age will have accumulated greater amounts of lead that can be passed to the infant in breast milk relative to mothers 25 years of age and younger.

Older mothers tend to initiate breastfeeding of their infants and breastfeed for longer periods of time. Because substances such as lead can accumulate in maternal tissues past the default 25 years for exposure to facility emissions before birth of a child, it is important to consider maternal age in assessing infant exposure to such toxicants via breast milk.

5A-3.2.1 *Breastfeeding Practices of Older Mothers*

In Section 5A-2.1, we provide background on the Ross Mothers Survey and the NIS. These surveys have consistently found that both the initiation and duration of breastfeeding increased with maternal age. The Ross Mothers Survey data (Table 5A-16) show an increasing trend from 1996 to 2001 of older mothers to initiate breastfeeding and to continue to breastfeed for at least 6 months. The NIS data (Table 5A.17) show that older mothers are more likely to breastfeed and to exclusively breastfeed through 6 months in accordance with AAP recommendations (NSCH, 2007).

Table 5A-16 Prevalence (percent) of Breastfeeding by Maternal Age, Ross Mothers Survey

	Maternal Age				
	<20 years	**20-24 years**	**25-29 years**	**30-34 years**	**≥35 years**
In-hospital					
1996	43	53	62	68	69
2001	57	66	73	76	76
At 6 months					
1996	10	15	23	29	34
2001	20	26	35	42	44

* Source: Ryan et al. (2002)

Table 5A-17 Prevalence (percent) of Types of Breastfeeding by Maternal Age, Infants born in 2004

	Maternal Age		
	<20 years age	**20-29 years age**	**>=30 years age**
Ever Breastfeed	53	69	77
Breastfeed at 6 months	18	31	46
Breastfeed at 12 months	6	15	24
Exclusively breastfed at 3 months	17	26	35
Exclusively breastfed at 6 months	6	8	14

* Source: National Immunization Survey, Centers for Disease Control and Prevention, Department of Health and Human Services

5.3.2.2 *Prevalence of Older Women Giving Birth in California*

There is an increasing trend toward older women giving birth in California. Births to women 35 years of age and older showed a progressive increase from 1990 to 2006 (Table 5A-18, below) (CDPH, 2006).

Table 5A-18 California Births by Maternal Age and Year of Birth (percent of total births for that year)

	Maternal Age		
	35-39 years	**40-44 years**	**>=45 years**
1990	9	1.6	0.07
1995	11	2.3	0.12
2000	13	2.9	0.18
2006	14	3.3	0.25

Data source: California Department of Public Health, birth records

It should be noted that the above data are for maternal age at primiparous and multiparous births. Data on primiparous-only births are not readily available. For some lipophilic toxicants, primiparous birth is an important parity as this can be when the greatest amount of toxicant may be excreted in the mother's breast milk, and the mother's body burden is reduced, thus lowering the dose to subsequent children.

Increases in maternal age may continue due to the increasing use of in-vitro fertilization for older women, though such increases are likely to be very small relative to the population of women giving birth.

5.3.3 High-end Consumers

Under certain circumstances, information on individuals exposed at very high levels is of interest. For assessing high-end exposures, Table 5A-19 may be of use. It provides upper-end breast milk and lipid intake rate estimates for the breastfeeding population.

Table 5A-19 Intake estimates for the breastfeeding infant population

	Breast Milk Intake[1] (g/kg-day)		***Lipid Intake[2] (g/kg-day)***	
	6 month average	***1 year average***	***6 month average***	***1 year average***
99th percentile	179	155	7.1	6.2

[1]From Arcus-Arth et al. (2005)
[2] From correspondence with author (Arcus-Arth et al.) and based on lipid intakes at 3 and 6 months

Arcus-Arth et al. (2005) found that the rate of breast milk intake was highest during the second week of life. At this age, when susceptibility to certain toxicants is high, the mean intake is 160.6 g/kg-day and the 99th percentile is 257.8 g/kg-day.

5.11 References

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6. Dermal Exposure Assessment

6.1 Introduction

Semi-volatile and nonvolatile contaminants emitted into the air can be subsequently deposited onto soil or other surfaces. Exposure to chemicals can occur through skin contact with the contaminated soil. This exposure pathway is considered under the Air Toxics "Hot Spots" Act when evaluating chronic exposure. ~~Although dermal exposure to volatile chemicals can be significant with high air concentrations found in industrial settings, this pathway is not a significant exposure source for lower environmental air concentrations both relative to other exposure pathways and in terms of the magnitude of the dermal dose.~~

For semi-volatile organic compounds (SVOCs), OEHHA has not quantified exposure via the air-to-skin transdermal pathway for the Hot Spots Program. This pathway is inherently included in human and animal whole-body inhalation exposures to chemicals in toxicology and epidemiology studies for both VOCs and SVOCs. Whole-body inhalation studies almost always form the basis for determining Reference Exposure Levels (RELs) and Cancer Potency Factors (CPFs) where the metric of exposure is the airborne concentration. As such, exposure via the air-to-skin pathway is incorporated into the RELs and CPFs for individual chemicals.

The significance of the air-to-skin transdermal pathway for some Hot Spots SVOCs has been shown in a modeling study that utilized physical and chemical principles combined with empirical evidence to critically assess the significance of the dermal pathway as a contributor to total human exposure to SVOCs (Weschler and Nazaroff, 2012). In this study, it is proposed that intake by the air-to-skin transdermal pathway can exceed intake by inhalation for several SVOCs that humans can be exposed to. The air-to-skin pathway is of particular concern for the relatively more volatile SVOCs that both equilibrate rapidly with skin-surface lipids and also permeate the skin relatively quickly. Amphiphilic SVOCs (i.e., containing both hydrophilic and lipophilic properties) in particular are included this class. Hot Spots chemicals that fall into this class probably include the smaller molecular weight PCBs such as PCB77 and PCB81.

For a second group of SVOCs, direct air-to-skin transport can also contribute to total uptake, but perhaps not to the same fractional extent as the first group owing to slower equilibration with skin-surface lipids or slower migration through the stratum corneum (Weschler and Nazaroff, 2012). Hot Spots chemicals that fall into this group include many of the PAHs such as B(a)P and chrysene. In a third group of SVOCs, the equilibrium time is too long for air-to-skin transport to be important. Hot Spots chemicals in this third group include diethylhexylphthalate and probably the dioxins and furans (e.g., TCDD). However, skin contact with these SVOC-containing materials or surfaces (such as contaminated soil) may contribute to elevated levels in skin-surface lipids. Once sorbed at the skin surface, subsequent migration through the stratum corneum and viable epidermis can be relatively fast.

Although the air-to-skin transdermal pathway is generally taken into account in RELs and CPFs, the importance of this route should be discussed in the event RELs or CPFs are developed for some SVOCs based on studies that use other than whole-body inhalation (e.g., nose-only inhalation). Note that chronic inhalation exposures are always "whole body" for logistic reasons.

Likewise absorption of chemicals dissolved or deposited into water while swimming, bathing, or showering could be significant under certain exposure scenarios but usually not under the airborne release scenario considered in the "Hot Spots" program.

The significance of each of the above exposure pathways varies by type of chemical, but dermal uptake of chemicals from soil and other surfaces is considered the most relevant. This route applies to semivolatile organic chemicals such as PAHs, dioxins and PCBs, and some inorganic metals such as lead and lead compounds. Under the "Hot Spots" program, dermal exposure to soils contaminated with these chemicals is considered the principal dermal exposure pathway. The concentrations in soil around a specific facility due to long term deposition are estimated from facility emissions estimates, air modeling, estimates of soil half life and soil mixing depth.

As discussed in Section 6.5 below, OEHHA devised a new variate called the Annual Dermal Load, or ADL. This variate is a composite of the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates, which simplifies the calculation for risk assessors. In addition, ADLs have been determined for California climate zones, expressed as warm, mixed and cold. These climate zones recognize the different amount of time one spends outside during the year (depending on the climate zone), and the amount of clothing one wears in these different climate zones. All of which influences the ADL value.

6.2 Recommended Dermal Exposure Values

[Note: this Section was moved from the back to the front]
For assessing dermal exposure, we are recommending point estimates using the ADL variates presented in Table 6.1. These point estimates are the mean and 95th percentile values from the stochastic distributions shown in Tables 6.2a-d. Using Eq. 6-8 (see below), the variables that are needed to assess dermal exposure include the climate-dependent ADL, the soil concentration of contaminant and the ABS (dermal absorption value from soil).

Table 6.1. Recommended Annual Dermal Load Point Estimates (in mg/kg-yr) for Dermal Exposure

	3rd Trimester	Children 0<2 yrs	Children 2<9 yrs	Children 2<16 yrs	Adults[a]	Off-Site Worker
Warm climate						
Mean	1.2×10^3	3.6×10^3	7.5×10^3	6.4×10^3	1.2×10^3	2.6×10^3
95th percentile	2.6×10^3	4.3×10^3	9.1×10^3	8.5×10^3	2.6×10^3	5.0×10^3
Mixed climate						

Mean 95 th percentile	1.1 x 10^3 2.4 x 10^3	2.2 x 10^3 2.9 x 10^3	6.6 x 10^3 8.7 x 10^3	5.7 x 10^3 8.1 x 10^3	1.1 x 10^3 2.4 x 10^3	2.6 x 10^3 5.0 x 10^3
Cold climate Mean 95 th percentile	 0.7 x 10^3 2.1 x 10^3	 1.2 x 10^3 1.9 x 10^3	 3.1 x 10^3 5.2 x 10^3	 2.8 x 10^3 5.1 x 10^3	 0.7 x 10^3 2.1 x 10^3	 2.6 x 10^3 5.0 x 10^3

[a] Residential adults includes 16<30 and 16-70 year age groups

ADL distributions in Tables 6.2a-d are by age group and climate, with the adult age groups (16-30 and 16-70 years of age) sharing the same values. The ADL for the third trimester of the fetus is based on the ADL of the mother; when normalized to body weight, we assume that exposure to the mother and the fetus will be the same. The mother's exposure is based on the adults age 16-30 years of age in Table 6.2d.

Tables 6.2a-d. Annual Dermal Load Distributions by Age Group and Climate

Table 6.2a. Annual Dermal Load (mg/kg-yr) Distributions for the 0<2 Year Age Group

Climate Type	**Warm climate**	**Mixed climate**	**Cold climate**
Distribution	Student's t	Logistic	Triangular
Minimum			0.2 x 10^3
Likeliest			0.7 x 10^3
Maximum			2.6 x 10^3
Scale	0.41	0.28	
Deg. freedom	3		
Midpoint	3.6 x 10^3		
Mean	3.6 x 10^3	2.2 x 10^3	1.2 x 10^3
50th percentile	3.6 x 10^3	2.2 x 10^3	0.9 x 10^3
90 th percentile	4.1 x 10^3	2.8 x 10^3	1.9 x 10^3
95 th percentile	4.3 x 10^3	2.9 x 10^3	1.9 x 10^3
99 th percentile	4.7 x 10^3	3.1 x 10^3	2.1 x 10^3

Table 6.2b. Annual Dermal Load (mg/kg-yr) Distributions for the 2<9 Year Age Group

Climate Type	**Warm climate**	**Mixed climate**	**Cold climate**
Distribution	Min extreme	Min extreme	Triangular
Minimum			0.4 x 10^3
Likeliest	8.0 x 10^3	7.3 x 10^3	1.9 x 10^3
Maximum			6.9 x 10^3
Scale	0.1	1.3	
Mean	7.5 x 10^3	6.6 x 10^3	3.1 x 10^3
50 th percentile	7.7 x 10^3	6.5 x 10^3	2.3 x 10^3
90 th percentile	8.7 x 10^3	8.4 x 10^3	5.1 x 10^3
95 th percentile	9.1 x 10^3	8.7 x 10^3	5.2 x 10^3

99th percentile	9.7 x 10^3	9.4 x 10^3	5.7 x 10^3

Table 6.2c. Annual Dermal Load (mg/kg-yr) Distributions for the 2<16 Year Age Group

Climate Type	Warm Climate	Mixed climate	Cold climate
Distribution	Min extreme	Logistic	Triangular
Minimum			0.3×10^3
Likeliest	7.2×10^3		1.6×10^3
Maximum			6.9×10^3
Scale	1.29	0.91	
Mean	6.4×10^3	5.7×10^3	2.8×10^3
50th percentile	6.6×10^3	5.7×10^3	2.2×10^3
90th percentile	8.1×10^3	7.7×10^3	4.8×10^3
95th percentile	8.5×10^3	8.1×10^3	5.1×10^3
99th percentile	9.3×10^3	8.9×10^3	5.6×10^3

Table 6.2d. Annual Dermal Load (mg/kg-yr) Distributions for Residential Adults (Age 16-30 and 16-70 Years) and Offsite Workers

Receptor	Residential Adult			Offsite Worker
Climate Type	**Warm**	**Mixed**	**Cold**	**All Climates[a]**
Distribution	Beta	Beta	Gamma	Lognormal
Minimum	0.2×10^3	0.02×10^3		
Maximum	3.3×10^3	0.3×10^3		
~~Location~~			~~0.01~~	
Scale			0.07	
~~Shape~~			~~0.94~~	
~~Alpha~~	~~1.3~~	~~1.01~~		
~~Beta~~	~~0.02~~	~~2.05~~		
Mean	1.2×10^3	1.1×10^3	0.7×10^3	2.6×10^3
~~Std. Dev.~~				~~1.3~~
50th percentile	1.2×10^3	1.0×10^3	0.5×10^3	2.3×10^3
90th percentile	2.4×10^3	2.1×10^3	1.6×10^3	4.5×10^3
95th percentile	2.6×10^3	2.4×10^3	2.1×10^3	5.0×10^3
99th percentile	2.9×10^3	2.6×10^3	2.3×10^3	6.4×10^3

[a] Face, hands and forearms are exposed only, regardless of climate

There are several advantages for stochastically combining the four variates from the original dermal dose equation (see Equation 6-1 below) into an annual dermal load variate. First, using one variate (annual dermal load) rather than four separate variates simplifies calculations for risk assessors. Also, distributional information that previously was separate is now integrated into one distribution. In addition, selecting a high-end value from the annual dermal load distribution reduces the possibility of over-conservatism that can occur when high-end values of the variates are multiplied together as was done with Equation 6-1 in the prior edition of the Stochastic guidelines (OEHHA, 2000).

6.~~2~~3 Dermal Uptake from Contaminated Soil Contact

Although the dermal exposure route is generally considered a minor exposure pathway, a screening study by Johnson and Kissel (1996) of over 200 risk assessments for Superfund sites resulted in identification of 37 sites at which projected lifetime excess cancer risks attributed to dermal contact with contaminated soil were greater than 1 in 10,000. Dermal exposure was the dominant exposure route at 9 sites. Thus it is possible for dermal exposure to reach a level of significance, although the soil concentrations resulting from airborne deposition tend to be lower than when more concentrated pollutants are present in hazardous waste sites. The primary soil contaminants in these dermal risk assessments included dioxins, PAHs, PCBs and arsenic. Johnson and Kissel (1996) highlighted early concern for the dermal pathway and the need for better information for dermal exposure variates, such as the chemical fractional skin absorption, surface area exposure and soil adherence, in order to better assess dermal absorption potential.

The potential for skin contact with soil near the home can be significant. In a national survey known as the Soil Contact Survey, almost half of households reported the presence of bare spots (44.7%) other than gardens in their yards (Wong et al., 2000a). A majority (63.7%) of respondents with homes also reported a vacant lot or field within walking distance of the home.

As discussed above, dermal absorption varies by exposure pathway and with the properties of the chemical. Other major factors which influence dermal absorption include the anatomical region exposed (Maibach et al., 1971; Wester and Maibach, 1985), the amount of skin exposed, soil or particle type and size, amount of soil adhering to skin (Duff and Kissel, 1996; Choate et al., 2006), type of surface contacted, chemical concentration (Nomeir et al., 1992; Sartorelli et al., 2003), duration of exposure, ambient temperature and humidity (Chang and Riviere, 1991), and activities which limit exposure (e.g., washing the skin).

The inherent variability in some of the exposure factors can be estimated, such as in total skin surface area of children and adults. In other cases, the actual variation is not as well known, such as soil loading on specific body parts in young children. Also, the factor involved may be well known but the net effect on dermal absorption of chemicals may not be readily described or quantified. For example, dermal absorption varies with skin temperature and blood flow, which tends to vary with ambient temperature and physical activity. However, the magnitude of this effect is insufficiently documented to support distribution modeling. Overall, there is generally not enough information to generate probability distributions for all of the key variates for estimating dermal absorption, although ranges are available for some variates.

This discussion of dermal exposure estimates includes the primary variates involved and can be reasonably quantified or estimated, based on the more common human

activities that result in soil skin contact (e.g., gardening). Dermal exposure is expressed as a variate called the dermal dose (Eq. 6-1). The dermal dose is defined as the amount of contaminant absorbed through the skin per unit of body weight per day (mg/kg-day). For the Air Toxics "Hot Spots" program, the dermal dose resulting from contact with contaminated soil can be estimated using the following equation:

$$DOSEdermal = (Cs \times SA \times SL \times EF \times ABS \cancel{\times ED}) \ / \ (BW \cancel{\times AT} \times 1x10^{6}) \qquad \text{(Eq. 6-1)}$$

where:

DOSEdermal	= exposure dose through dermal absorption (mg/kg-d)
Cs	= average concentration of chemical in soil (µg/kg)
SA	= surface area of exposed skin (m^2)
SL	= soil loading on skin (g/m^2-d)
EF	= exposure frequency (d/~~yr~~365 d)
ABS	= fraction of chemical absorbed across skin
BW	= body weight (kg)
$1x10^6$	= conversion factors for chemical and soil (µg to mg, g to kg)

The dermal absorption factor (ABS) is a chemical-specific, unitless factor that is discussed in Section 6.4.1 below. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) to allow for a two-week vacation away from home each year (US EPA (1991).

[The following paragraph and associated equation were moved from Section 6.5 to here:]

Equation 6-1 requires multiplying values together, which could lead to overly conservative exposure estimates when high-end values for variates were used. By combining information from several variates into one composite distribution, over-conservatism may be avoided (see Section 6.5). To this end, OEHHA created a new variate, "annual dermal load", or ADL, which is a composite of the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates:

$$ADL = (BSA / BW)^* [(SL_b)(SA_b\%_b)] * EF \qquad \textbf{(Eq. 6-2)}$$

Where :

ADL	= Annual dermal load (mg/kg BW-yr)
EF	= Exposure frequency (d /yr)

Thus, the dermal-dose equation (Eq. 6-1) can be reduced to the following:

$$\text{Dermal dose (mg/kg-d)} = ADL * Cs * ABS * (yr/365\ d) * 1x10^{-9} \qquad \textbf{(Eq. 6-3)}$$

Where

yr/365 d	= Conversion factor (years to days)
$1x10^{-9}$	= Conversion factor for chemical and soil (µg to mg, mg to kg)

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (CPF) expressed in units of $(mg/kg\text{-}day)^{-1}$:

$$RISKdermal = DOSEdermal * CPF * ASF * ED/AT \quad \textbf{(Eq. 6-4)}$$

RISK is the predicted risk of cancer (unitless) over a lifetime as a result of the exposure, and is usually expressed as chances per million persons exposed (e.g., 5×10^{-6} would be 5 chances per million persons exposed).

The dose-response phase of a cancer risk assessment aims to characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. This is usually expressed as a cancer potency factor, or CPF, in the above equation. The CPF is the slope of the extrapolated dose-response curve and is expressed as units of inverse dose $(mg/kg\text{-}d)^{-1}$, or inverse concentration $(\mu g/m^3)^{-1}$.

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (OEHHA, 2009), the exposure for each age grouping must be separately calculated. Because cancer risk has been shown to be greater in sensitive age groups, different ASFs are applied to different life stages used for cancer risk assessment (see below). DOSEdermal can vary depending on the type of outdoor activities that involve soil exposure. The type of outdoor activities may be specific for the age of the individual, such as general outdoor play on bare soil by young children, or gardening by adults. Thus, the DOSEdermal and ED are different for each age grouping.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)
7 yrs for 2<9 age group	(ASF = 3)
14 yrs for 2<16 age group	(ASF = 3)
14 yrs for 16<30 age group	(ASF = 1)
54 yrs for 16-70 age group	(ASF = 1)

DOSEdermal includes indirect exposure to the fetus via direct exposure to the mother during the third trimester of pregnancy. Fetal exposure during the third trimester will be the same as that of the mother on a body weight-normalized basis, and is taken into account in the final determination of the annual dermal load presented in Section 6.2.

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKdermal_{(lifetime)} = RISKdermal_{(3rdtri)} + RISKdermal_{(0<2\ yr)} + RISKdermal_{(2<16\ yr)} + RISKdermal_{(16\text{-}70yr)} \quad \textbf{(Eq. 6-5)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well

as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as follows:

$$RISKdermal_{(9\text{-yr residency})} = RISKdermal_{(3rdtri)} + RISKdermal_{(0<2\ yr)} + RISKdermal_{(2<9\ yr)} \quad \textbf{(Eq. 6-6)}$$

For 30-year residential exposure scenario, the 2<16 and 16<30 age group RISKdermal would be added to the risk from the third trimester to 0<2 age group. For 70 year residency risk, Eq 6-5 would apply.

~~ED = exposure duration (yrs):~~

~~2.25 yrs for 0<2 age group~~
~~7 yrs for 2<9 age group~~
~~14 yrs for 2<16 age group~~
~~14 yrs for 16<30 age group~~
~~54 yrs for 16-70 age group~~

~~AT = averaging time days, to assess carcinogenic risk:~~
~~90 days for third trimester fetal stage~~
~~730 days for 0<2 yr age group~~
~~2554 days for 2<9 age group~~
~~5110 days for 2<16 yr age group~~
~~5110 days for 16<30 age group~~
~~19,711 days for 16-70 yr age group~~

~~The dermal dose can vary depending on the type of outdoor activities that involve soil exposure. The type of outdoor activities may be specific for the age of the individual, such as general outdoor play on bare soil by young children, or gardening by adults. Because cancer risk has been shown to be greater in sensitive age groups, dermal absorption variates in dermal dose Eq. 6-1 have been estimated from soil exposure studies based on life stages used for cancer risk assessment (i.e., third trimester, 0<2 yrs, 2<9 yrs, 2<16 yrs, 16<30 yrs and 16-70 yrs). Dermal exposure includes indirect exposure to the fetus via direct exposure to the mother during the third trimester of pregnancy. For the dermal exposure derivations presented below, only postpartum exposure (i.e., birth to 2 years of age, etc.) is determined. Fetal exposure during the third trimester will be the same as that of the mother on a body weight-normalized basis, and is taken into account in the final determination of the annual dermal load presented in Section 6.4.~~

~~The averaging times (AT) in Eq. 6-1 are based on the life stage of exposure. If the averaging time for dermal dose is estimated based on residence time, the default residence times are 9 years (3285 days), 30 years (10,950 days) and 70 years (25,550 days). Note that residence times may overlap the 0<2, 2<16, and 16-70 year age groupings used for estimating cancer risk.~~

Because distributional data are available for the total surface area, body weight and exposure frequency variates, a stochastic approach can be used to derive one distribution by combining these variates for the specified age groups. This stochastic approach provides an alternative means for estimating dermal exposure and is presented below in Section 6.~~5~~2.

The term Cs, concentration of the contaminant in soil, can be derived in the Hot Spots Analysis and Reporting Program (HARP) using air dispersion and deposition modeling (CARB, 2003). The concentration is a function of the deposition, accumulation period, chemical-specific soil half-life, mixing depth, and soil bulk density. The formula used is:

$$Cs = [Dep \times X)] \ / \ [K_s \times SD \times BD \times T_t] \qquad \textbf{(Eq. 6-~~2~~7)}$$

where:

Cs	= average soil concentration over the evaluation period (μg/kg)
Dep	= deposition on the affected soil area per day (μg/m^2-d)
X	= integral function accounting for soil half-life (d)
K_s	= soil elimination time constant = 0.693/$T_{1/2}$
SD	= soil mixing depth = 0.01 m for playground setting and 0.15 m for agricultural setting
BD	= bulk density of soil = 1333 kg/m^3
T_t	= 25,550 days (70 yrs), total averaging time for the chemical accumulation period (i.e., 70 yrs, the presumed life of the facility emitting chemicals)

The deposition on the affected soil area per day is expressed as:

$$Dep = GLC \times Dep\text{-}rate \times 86{,}400 \qquad \textbf{(Eq. 6-~~3~~8)}$$

where:

GLC	= ground level concentration from air dispersion modeling (μg/m^3)
Dep-rate	= vertical rate of deposition (m/sec) (see Chapter 2 for values)
86,400	= seconds per day conversion factor (sec/d)

The integral function, X, is as follows:

$$X = [\{Exp\ (-K_s \times T_f) - Exp\ (-K_s \times T_0)\} / K_s] + T_t \qquad \textbf{(Eq. 6-~~4~~9)}$$

where:

Exp	= exponent base e = 2.718
K_s	= soil elimination constant = 0.693/ $T_{1/2}$
$T_{1/2}$	= chemical-specific soil half-life (d)
T_f	= end of exposure period (d)
T_0	= beginning of exposure period (d) = 0 days
T_t	= total days of exposure period = Tf - T_0 (d)

Chemical-specific soil half-lives ($T_{1/2}$) are presented in Appendix G.
T_f = 25,500 d = 70 yrs. Identifies the total number of days of soil deposition.
T_f = 9,490 d = 25 yr for nursing mother in mother's milk pathway.

The assumptions in the soil concentration algorithm include:

1) Uniform mixing of pollutants in the soil and a constant concentration over the duration of the exposure.
2) The bulk density (BD) of soils is similar over a wide variety of soil types.
3) Substances are not leached or washed away, except where evidence exists to the contrary
4) For the mother's milk pathway, the mother is exposed for 25 years, the child receives milk for one year (from mother's 25th birthday to 26th birthday), and then is exposed to all other pathways.

6.~~3~~4 Derivation of Key Dermal Exposure Variates

Other than the soil concentration of a chemical, which is estimated from the emission, meteorological, terrain, and other data using HARP (or other software), the key variates in equation 6-1 are the chemical-specific fractional absorption factor (ABS), the surface area of exposed skin (SA), body weight, the soil loading or soil adherence of contaminated soil on skin (SL) in mg soil per cm^2 skin, and the exposure frequency (EF) in number of days exposed per year. The description of how point estimates or distributions were derived for each of these variates using existing literature sources are summarized below, and in Appendix F for the chemical ABS.

6.~~3~~4.1 Chemical-specific Absorption Factors

Skin permeability is related to the solubility or strength of binding of the chemical in the delivery matrix (soil or other particles) versus the receptor matrix, the skin's stratum corneum. This skin layer, which is the major skin permeability barrier, is essentially multiple lipophilic and hydrophilic layers comprised of flattened, dead, epidermal cells. The greatest rate of skin permeation occurs with small moderately lipophilic organic chemicals. However, such chemicals may not have the greatest total uptake, because they may evaporate off the skin. The highest penetration thus is expected from larger, moderately lipophilic chemicals with negligible vapor pressures. Organic chemicals which dissociate in solution, or metal salts that are more soluble in the aqueous phase of stratum corneum and insoluble in the lipid phase, will not penetrate the skin readily.

These principles of skin absorption are presented in US EPA (1992), and summarized in Appendix F of this document as it pertains to dermal absorption from contact with contaminated soil. Fractional dermal absorption point estimate values were derived by OEHHA from available literature sources for the semi-volatile and nonvolatile chemicals under the "Hot Spots" program (Table 6.~~1~~3). The rationale for the chemical-specific dermal absorption fraction values, and the use of default values in cases where sufficient data are lacking, can be found in Appendix F.

Table 6.~~1~~3. Dermal Absorption Fraction Factors (ABS) as Percent from Soil for Semi-Volatile and Solid Chemicals under the OEHHA "Hot Spots" Program

Chemical	ABS
Inorganic chemicals	
Arsenic	6
Beryllium	1
Cadmium	0.2
Chromium (VI)	2
Fluorides (soluble compounds)	1
Lead	3
Mercury	4
Nickel	2
Selenium	1
Organic chemicals	
Creosotes	13
Diethylhexylphthalate	9
Hexachlorobenzene	4
Hexachlorocyclohexanes	3
4,4'methylene dianiline	10
Polychlorinated biphenyls	14
Polychlorinated dibenzo-p-dioxins and dibenzofurans	3
Polycyclic aromatic hydrocarbons	13

Most exposure estimates have utilized a single value for presumed dermal uptake rate or percent without distinguishing between the specific skin regions that might be involved under different scenarios. However, it is known that the permeability of skin to chemicals may vary depending on the skin site of absorption. In general, hands are least permeable, and face and neck are most permeable (Maibach et al., 1971; Wester and Maibach, 1985). Other site-specific and scenario-specific factors are involved in dermal absorption, as discussed in Appendix F, which can result in significant differences in dermal uptake under different conditions. Data are inadequate to describe potential changes in fractional dermal absorption with changing scenarios. Thus, point estimate values are used for the ABS.

6.~~3~~4.2 Body Surface Area / Body Weight Distributional Variate

Total body surface area (BSA) and body weight are known to be highly correlated with a reported correlation coefficient (r) ranging from 0.88-0.96 (Durnin, 1959). Although there are distributional human body weight data, there are no directly measured data for BSA representative of the population. However, Gehan and George (1970) derived a BSA formula based on direct measurements of BSA from 401 individuals. Their formula accounted for over 99% of the variation in BSA and was derived using more BSA

measurements that were directly measured than other BSA formulae. The Gehan and George formula is shown as:

$$BSA\ (m^2) = (Wt^{0.51456}) \times (Ht^{0.42246}) \times 0.02350 \qquad \text{(Eq. 6-~~5~~10)}$$

where:

Wt = body weight (kg)
Ht = body height (cm)

For body weight and height data, OEHHA used the National Health and Nutrition Examination Survey (NHANES) 1999-2004 dataset (CDC, 2007). NHANES provides weights for each individual in the dataset and for the study design so that estimates using NHANES data can be weighted to be nationally representative. Total body surface estimates for each individual in the NHANES 1999-2004 dataset were derived using these individuals' body weight and height and equation 6-5. Means and specific percentiles are shown in Table 6.~~2~~ 4 and 6.~~3~~5. The sample size for NHANES, and for many subpopulations within NHANES (e.g., each year of age), is sufficiently large to provide information on interindividual variability and distributions. There are other sources of body weight and height data, but NHANES is the most recent national dataset, thus reflecting the current population, and has data on each individual for the assessment of interindividual variability.

Table 6.~~2~~4. Summary Distribution Estimates of Total Body Surface Area (in m^2) by Age Group[a]

	Children 0<2 years	**Children 2<9 years**	**Children 2<16 years**	**Adults >16 years**
Sample size	2106	3250	9007	16,718
Mean	0.459	0.884	1.177	1.942
SEM	0.003	0.005	0.006	0.003
50th percentile	0.470	0.824	1.124	1.923
90th percentile	0.564	1.107	1.730	2.302
95th percentile	0.583	1.212	1.880	2.414

[a] Derived using the equation 6.3 and the body height and weight data of the NHANES 1999-2004 study

Table 6.~~3~~5. Summary Estimates of Total Body Surface Area over Body Weight (m^2/kg) by Age Group[a]

	All ages	Children 0<2 years	Children 2<9 years	Children 2<16 years	Adults >16 years
Sample size	27831	2106	3250	9007	16718
Min	0.016	0.034	0.022	0.016	0.016
Max	0.077	0.077	0.054	0.054	0.040
Mean	0.028	0.049	0.039	0.035	0.025
SEM	0.000068	0.0001	0.000019	0.000097	0.000038
50th percentile	0.026	0.048	0.040	0.035	0.025
75th percentile	0.029	0.051	0.043	0.040	0.027
90th percentile	0.038	0.056	0.045	0.043	0.029
95th percentile	0.043	0.059	0.046	0.045	0.029
99th percentile	0.049	0.063	0.048	0.047	0.031

[a] Derived from NHANES 1999-2004 data

6.~~3~~4.3 Skin Surface Area Exposed

The amount of skin or body region that is exposed to soil contact is dependent on the type of clothing worn. Clothing is expected to significantly reduce exposure to the covered skin area from contaminated soil. Dermal risk assessment procedures used by U.S. EPA (2004) assumes no exposure of skin that is covered with clothing. The few studies that investigated this issue found that clothing had a protective effect for soil exposure, although some exposure may occur under clothing (Kissel et al., 1998; Dor et al., 2000). Considering Kissel et al. (1998) showed incomplete coverage of exposed body parts occurred in a soil exposure study, it appears unlikely that the limited soil exposure that occurs under clothing will underestimate total exposure. Consequently, the model OEHHA uses assumes no exposure to covered skin. Exposed skin is essentially limited to face, hands, forearms, lower legs, feet, or some combination thereof (U.S. EPA, 2004). However, the amount of skin exposed as a result of clothing choices is dependent on exposure activity, age group, and the climatic conditions. Because California has geographically diverse climatic regions, studies investigating clothing choices by children and adults during warm and cold weather outdoor activities were used to estimate skin exposure for different climate regions within the state.

6.~~3~~4.3.1Fractional Body Part Surface Area

U.S. EPA (2004) provides data on the percent of surface area for different body parts that may be exposed to soil. When the fractional surface area of a specific body part, such as hands, is multiplied by total surface area, the surface area of the specified body part in m^2 or cm^2 is determined. As mentioned above, normalized surface area can be derived for each individual in the NHANES dataset. Multiplying normalized surface area for each individual by the percent surface area of each body part gives an estimated normalized surface area of each body part for that individual. Individuals are then grouped by age to derive the surface area for each body part for each age group. Because the percent surface area is a constant, multiplying normalized total surface

area by the percent surface area maintains the same probability distribution of the NHANES normalized total body surface area. That is, the probability distribution of body surface area from the nationally representative NHANES data is preserved.

In the children's Soil Contact Survey by Wong et al. (2000b), the activity patterns of children (≤18 years) that would result in dermal soil contact were investigated. Of 680 households, 500 (73.5%) had children that were reported to play outdoors on bare dirt or mixed grass and dirt surfaces. An age breakdown of the children showed that those reporting little outdoor play were either very young (≤1 year) or relatively old (≥14 years for females; ≥16 years for males).

The Soil Contact Survey also asked about clothing choices during outdoor play in warm weather and determined estimated percentage skin surface area exposed (Table 6.~~4~~6). For children under 5 years of age, outdoor play was treated as a single activity. Information on outdoor activity of children aged 5 to 17 was categorized as gardening/yardwork and as organized team sports. The combination of short sleeves and short pants was a common clothing choice for outdoor activities. Skin exposure was lowest for participants in organized team sports because that group had the highest fraction wearing shoes and high socks.

The mean skin area exposed for children age 5-17 during gardening and yardwork (33.8%) is essentially the same as the default mean surface area value of 33.9% used by U.S. EPA (2004), based on soil adherence data, for children age 6 years and up. Together, the findings indicate that soil contact exposure in warm weather is primarily limited to face, hands, forearms, and lower legs, with feet exposure most common in young children up to about 6 years of age.

Table 6.~~4~~6. Estimated Skin Surface Area Exposed During Selected Warm Weather Outdoor Activities by Children[a]

	Skin area exposed (% of total) based on expressed clothing choices		
	Outdoor play (age <5 yrs)	Gardening/yardwork (age 5-17 yrs)	Organized team sports (age 5-17 yrs)
Mean	38.0	33.8	29.0
Median	36.5	33.0	30.0
SD	6.0	8.3	10.5

[a] Table adapted from data in Wong et al. (2000)

In the Soil Contact Survey of adults, Garlock et al. (1999) conducted a regional (Washington and Oregon state) and national telephone survey for four outdoor activities among 450 adults for each sample. The activities included gardening, other yard work, outdoor team sports and home construction or repair with digging. The reported participation rate for any activity was 89% for the regional survey and 79% for the national survey, with more than half of the respondents reporting participation in 2 or 3 of the activities. Table 6.~~5~~ 7 presents both the national and regional (in parentheses) percentage skin area exposed during warm and cold months among the outdoor

participants for these activities. Warm- and cold-weather months were defined by the respondent

Table 6.~~5~~7. Estimated Skin Surface Exposed During Outdoor Activities by Adults in the National and Regional (in parentheses) Surveys[a]

	Skin area exposed (% of total) based on expressed clothing choices			
	Gardening	Other yard work	Team sports	Repair/Digging
Warm months				
Median	33 (33)	33 (31)	33 (33)	28 (28)
95th %tile	69 (68)	68 (68)	43 (68)	67 (67)
Cold months				
Median	8 (3)	3 (3)	8 (8)	3 (3)
95th %tile	33 (14)	31 (12)	33 (30)	14 (14)

[a] Table adapted from data by Garlock et al. (1999).

In most activities, the median and 95th percentiles were remarkably similar between the two surveys. Current U.S. EPA guidelines (U.S. EPA, 2004; 2011) for skin area exposed to soil contact assumes roughly 25% exposure for adults, corresponding to head, forearms, lower legs and hands. These findings show that the median exposure during warm months exceeds 25%, suggesting some exposures occur with no shoes or no shirt (males) or with a halter (women).

Based on the results of the Soil Contact Surveys and the activity-dependent soil adherence data in U.S. EPA (2004), the anticipated exposed body parts for children and adults during cold and warm weather are shown in Table 6.6. In cold weather, the findings by Garlock et al. (1999) for adults suggest that the hands and face are most often exposed for some activities (e.g., gardening and team sports), but that only the face is most often exposed or partially exposed for other activities (e.g., other yard work and repair/digging), corresponding to wearing gloves. Given that the most common activities in this study, gardening and team sports, suggest both hands and face were exposed, our assessment will include both body parts for soil exposure of adults and children in a cold climate. Very limited data suggested body part exposure in young children during cold weather months was similar to findings in adults (Holmes et al., 1999). Accordingly, we will also use hands and faces as the exposed body parts for the cold climate assessments in children.

In warm weather, the adult fractional skin exposure during outdoor activities in the Soil Contact Study had a median ranging from 28-33% (Garlock et al., 1999). This finding is only slightly higher than the median fractional skin exposure of about 27% for face, hands, forearms and lower legs combined shown in Table 6.~~6~~8. Review of the U.S. EPA (2004) soil adherence data for adults shows that shoes are predominantly worn during outdoor activities, and that a halter (for women) or no shirt were choices of some participants as indicated by the Garlock et al. study. For the stochastic assessment, only face, forearms, hands and lower legs were considered “exposed” in warm weather.

For the offsite worker, fractional skin exposure is similar, but since full length pants are worn, assessments only included faces, hands and forearms.

For children in warm weather climates, the survey by Wong et al. (2000b) observed that in addition to the face, hands, forearms and lower legs, the feet were often exposed. For example, young daycare children ages 1 to 6.5 years with free access to both the indoors and outdoors were all found to go without shoes, exposing bare feet or socks, at least once during the day. No data were presented for children less than one year of age. Nevertheless, for the warm weather exposure assessment of the 0<2 age group, the body parts considered exposed include feet, face, hands, forearms and lower legs.

For older children, Wong et al. (2000b) noted that organized team sports are common activities in children ages 5<17 years which may result in soil contact with skin. However, shoes are likely worn during many of these activities. In another study that monitored children's microactivity patterns, it was observed among children ages 3-13 years that younger children were more likely to be barefoot both indoors and outdoors compared to older children (Freeman et al., 2001). The average age of the barefoot children was 5.8 years, and the average age of children that wore shoes was 8.2 years. To account for the greater tendency of younger children in the 2< 9 and 2<16 year age group to go barefoot during outdoor play, OEHHA designated that feet exposure will be given 2/3 and 1/3 weighting for the 2<9 and 2<16 year age groups, respectively, during warm weather activities. This feet exposure adjustment was assessed in the soil adherence section below, in which the soil adherence value for 2< 9 and 2<16 year-olds was reduced to 2/3 and 1/3, respectively, of the initial soil load.

Table 6.~~6~~8. Exposed Body Parts by Age Group and Weather Conditions, with the Corresponding Mean Values for the Percentage of Total Body Surface for each Body Part in Parenthesis.

	Children 0<2 yrs[a]	**Children 2<9 yrs[a]**	**Children 2<16 yrs[a]**	**Residential Adult[b]**	**Offsite Worker[b]**
Body Part Exposed	**Cold Weather**				
	Hands (5.5) Face (5.8)	Hands (5.3) Face (4.4)	Hands (5.4) Face (3.7)	Hands (5.2) Face (2.5)	Hands (5.2) Face (2.5)
	Warm Weather				
	Hands (5.5) Face (5.8) Forearms (6.0) Lower legs (8.7) Feet (6.4)	Hands (5.3) Face (4.4) Forearms (5.9) Lower legs (10.8) Feet (7.2)	Hands (5.4) Face (3.7) Forearms (6.0) Lower legs (11.8) Feet (7.2)	Hands (5.2) Face (2.5) Forearms (6.1) Lower legs (12.8)	Hands (5.2) Face (2.5) Forearms (6.1)

[a] The percentage of total body surface area for the specified body parts was estimated for each age group from data in Exhibit C-1 of U.S. EPA (2004). All values are averages for males and females combined.
[b] Body part percentage estimated from data in Table B-3 of U.S. EPA (1985).

OEHHA believes the surface area exposure estimates in Table 6.~~6~~ 8 are health protective, but not overly conservative. For example, soil exposure under clothing is not included in the algorithm, even though some studies have shown that a limited degree of exposure may occur under clothing (Kissel et al., 1998; Dor et al., 2000). Also, the neck is not included as an exposed skin region in this document, even though a field study by Dor et al. (2000) showed that soil contact on the exposed neck can occur. Future studies of soil contact to skin may need to include the neck as a potential skin region for soil contact.

6.~~3~~4.3.2 California Climate Regions and Skin Exposure

Climate will strongly influence people's choice of clothing. Due to California's varied climatic regions and existing data on clothing choices at different temperatures, three levels of climatic conditions, warm, mixed, and cold, are used to describe California's climate regions. The type of climate will, in turn, be used to assess the fraction of exposed skin for soil contact.

The "warm" climate is characteristic of Southern California areas such as Los Angeles, which can have warm to hot temperatures throughout the year. The "cold" climate is representative of San Francisco, Eureka, and other northern coastal communities, which have cool temperatures (daily highs of less than 65 degrees) for the majority of the year and can receive a considerable amount of fog and rainfall. The "mixed" climate is one that has warm-to-hot temperatures during much of the year (daily highs over 80 degrees are common), roughly from April to October, and cold temperatures (lows near or below freezing) during the remainder of the year. The mountains and central valley are examples of a mixed climate. Specifically, the mixed climate is described as seven months/year of warm temperatures, resulting in warm-temperature clothing choices, and the remaining five months a year as a cold climate with cold-temperature clothing choices. Thus, the average surface area exposed over a year is proportional to seven months of warm weather skin exposure and five months of cold weather skin exposure.

6.~~3~~4.4 Soil Adherence Factors

Assessing risk from dermal exposure with contaminated soil requires an estimate of the amount of soil that will stick to skin long enough for the chemical to transfer from the soil and into the skin. This estimate has been given the term soil loading, or soil adherence, and is expressed in mass of soil per area of skin (usually in mg/cm^2). Because some body parts may have substantially greater soil adherence rates relative to other body parts, we assigned body part-specific soil adherence values to the corresponding body part surface area. Soil adherence estimates utilized published studies that were body part-specific, measuring soil adherence to hands, forearms, face, lower legs, and feet resulting from specific outdoor activities. Knowledge of body-part specific soil adherence and surface area exposure can be applied in equation 6-6 below to determine a weighted soil adherence factor (U.S. EPA, 2004; 2011). The example equation presented here is based on potential skin exposure resulting from a choice of

clothing that allows soil contact with face, hands, forearms, lower legs and feet (e.g., children in a warm weather climate):

Weighted AF = Eq. 6-~~6~~9

$$\frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands}) + (AF_{feet})(SA_{feet}) + (AF_{lower\ legs})(SA_{lower\ legs})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lower\ legs} + SA_{feet}}$$

where:

Weighted AF = overall weighted adherence factor of soil to skin (mg/cm^2-event)
AF_i = adherence factor for specific body part (mg/cm^2-event)
SA_i = specific skin surface area exposed for soil contact (cm^2)

U.S. EPA (2004) provided individual data on body-part-specific soil adherence for numerous activities (e.g., playing in dry soil, gardening, etc.), which were derived from published work (Kissel et al., 1996b; Kissel et al., 1998; Holmes et al., 1999). Although soil load was measured for quite a few activities, the number of individuals measured was small for each activity and soil adherence data for some body parts were not available for certain activities and age groups. Thus, OEHHA chose to use the arithmetic average of the soil loading rate for each body part rather than attempt to define a distribution for soil adherence. Table 6.~~7~~ 9 presents the body part-specific soil adherence factors, in g/m^2, resulting from common outdoor activities in children and adults.

Lack of soil adherence data is particularly evident among children in the 0<2 year age group. Soil adherence data are essentially absent under one year of age. For children 1<2 yrs of age, soil adherence on specific body parts can be calculated from a small group of daycare children that had roamed freely indoors and outdoors and had access to outdoor soil (Holmes et al., 1999; U.S. EPA, 2004).

For infants less than 1 yr of age, Wong et al. (2000b) observed that these children remained mostly indoors and were likely given little opportunity for direct contact with soil when outdoors. In another children activity survey, parents reported that only 17% of infants age 7-12 months had contact with outdoor dirt the previous day, while 70% of children age 1 to 4 yrs had contact with outdoor soil the previous day (Black et al., 2005).

Notably, the outdoor soil contact findings by Black et al. (2005) contrast with their findings of time spent by children playing indoors on the floor, with considerably greater time spent on the floor among infants compared to older children. Although this chapter is focused on exposure to contaminated outdoor soil, there is much evidence that shows a significant amount of outdoor soil can be found in indoor house dust (Culbard and Johnson, 1984; Davies et al., 1985; Thornton et al., 1985; Culbard et al., 1988; Fergusson and Kim, 1991; Stanek and Calabrese, 1992). From these studies, an

average of about one-third of indoor house dust is composed of soil (range: 20-78%). Because infants <1 year old spend more time indoors and play on the floor more frequently than older children, soil exposure from indoor sources may be important source of dermal contact for this age group. However, lack of soil adherence data for infants and lack of soil adherence data due to indoor soil exposure prevent an estimation of the extent of the risk.

To avoid underestimating indoor soil exposure in infants of the 0<2 age group, the infants (i.e., 0≤1 yr olds) are assumed to have the same soil adherence levels on specified body parts as the 1<2 yr old children in a daycare facility (Holmes et al., 1999; U.S. EPA, 2004). Thus, the average soil adherence for the entire 0<2 age group is based on the 1<2 yr old daycare children and is presented in Table 6.~~7~~9.

A limitation of this data is the lack of soil adherence data for the faces of the young children. To avoid non-participation in the studies, the faces of the children were not examined for soil adherence. As a surrogate, soil adherence data on the faces of 8-12 yr old children playing in dry and wet soil were averaged and used to represent soil adherence on faces of the 0<2 yr age group (Kissel et al., 1998b; U.S. EPA, 2004).

For the 2<9 and 2<16 year-old child groups, equal weighting for soil adherence was given to three groups of children: those that played in dry soil, those that played in wet soil, and those that played team sports (Kissel et al., 1996b; Kissel et al., 1998; U.S. EPA, 2004). Team sports were included to account for the greater tendency of older children to play team sports as opposed to general play in dry or wet soil (Wong et al., 2000b).

The methodology for outdoor play by the children stipulated that shoes be worn. However, studies show that during unrestricted play by children <8 years of age many go barefoot during outdoor play (Freeman et al., 2001). To account for the tendency of younger children in the 2<9 and 2<16 age groups to be barefoot during outdoor play, the soil adherence data on feet of children with access indoors and outdoors at a daycare facility were used (Holmes et al., 1999; U.S. EPA, 2004). Although the ages of the daycare children ranged from 1 to 6.5 years, these data represent the best information currently available for soil adherence on feet of children. OEHHA decided feet exposure during warm weather activities will be given 2/3 weighting for the 2<9 year-olds and 1/3 weighting for the 2<16 year-olds, corresponding to frequent exposure of bare feet to soil primarily in younger children.

For residential adults, a number of outdoor activities that resulted in soil contact were investigated (U.S. EPA, 2004; 2011). Among these activities, gardeners were chosen to estimate body part-specific soil adherence for adults (Table 6.~~7~~9). Outdoor gardening represents not only one of the more common activities resulting in soil contact, but is also a high-end soil contact activity relative to some of the other outdoor activities examined.

In addition, a number of soil contact activities by adult workers have been examined for soil adherence (U.S. EPA, 2004). The calculated geometric mean weighted soil adherence factors from these data range from 0.02 (grounds keepers) to 0.6 mg/cm^2 (pipe layers in wet soil). Soil adherence values for adult workers in Table 6.~~7~~ 9 were based on utility workers, as soil adherence in this line of work appears to be near the median for soil-contact related jobs presented by the U.S. EPA report.

Table 6.~~7~~9. Body Part-Specific Soil Adherence Factors (in g/m^2) Resulting from Common Outdoor Activities in Children and Adults

	Children 0<2 years	**Children 2<9 years**	**Children 2<16 years**	**Residential Adults**	**Adult Workers**
Activity	General outdoor play	Sports, play in wet & dry soil	Sports, play in wet & dry soil	Gardening	Utility workers
Hands	1.334	5.919	5.919	3.179	3.487
Face	0.063[a]	0.082	0.082	0.574	1.102
Forearms	0.306	0.228	0.228	0.819	3.279
Lower legs	0.183	1.332	1.332	0.42	na[b]
Feet	0.744	1.23[c]	0.41[c]	na	na

[a] No soil adherence data for the face are available for young children. Soil adherence data for the face in 8-12 year old children playing in wet and dry soil were used as a surrogate.
[b] Not applicable
[c] Soil adherence to feet was reduced, corresponding to exposure of bare feet to soil primarily in the lower 2/3 of the 2<9 year age group and lower 1/3 of the 2<16 year age group.

There are a number of limitations in these types of soil adherence studies that may result in greater or lesser dermal absorption of contaminants in contact with skin. Equation 6-1 assumes uniform soil coverage over the specific body-parts exposed. Gardening studies in a greenhouse using soil amended with fluorescent marker shows that soil contact is uneven and occurs most predictably on those specific body parts, such as hands and knees, that routinely come in direct contact with surfaces (Kissel et al., 1998). This is potentially significant because contaminant absorption is likely reduced in absolute terms as contact area is reduced and as a percent of total contaminant available as soil loading increases beyond monolayer coverage (Duff and Kissel, 1996). As discussed in greater detail in Appendix F, increasing soil loading beyond monolayer coverage will likely reduce fractional absorption of a chemical in soil, as a portion of the soil-bound chemical will not be in direct contact with skin.

Alternatively, there are factors related to soil loading that may underestimate adherence or chemical absorption estimates. A potential underestimation of risk is that hands were washed before hand press studies to estimate pre-loading soil levels (Kissel et al., 1996; Kissel et al., 1998b). Choate et al. (2006) observed that nonwashed hands had considerably greater soil loading after exposure to soil when compared to soil loading on recently washed hands. The lower adhered mass on prewashed hands was probably due to the removal of oils from the skin that aid in the adherence of soil particles. In addition, Sheppard and Evenden (1992) observed a 30% increase in the concentration of a contaminant in soil adhering to the hands compared to the bulk soil

that the hands were pressed in. Sparingly soluble contaminants were observed to accumulate in the clay fraction of the bulk soil, characterized as the smallest particles in soil, which was the fraction adhering to hands in greatest abundance.

6.~~3~~4.5 Duration and Frequency of Exposure to Contaminated Soil

Frequencies (in days/year) and durations (in hours/day) of soil exposures have not been well characterized in past studies. Recent surveys of adult and child activity patterns in relation to soil contact behavior are now available to help reduce the uncertainty associated with these variates. Regarding soil contact duration, the ABS of a particular chemical is dependent on duration of exposure. Thus, dermal absorption studies that most closely reflect the expected duration of soil contact are the most useful for estimating a chemical-specific ABS.

6.3.5.1 Exposure Duration

US EPA (2004) recommends a soil exposure time of 24 hrs and one soil exposure event per day. The exposure duration of 24 hrs assumes soil adhered to skin for 24-hrs starting from the time of first soil contact with skin to soil removal by hand washing and bathing.

One event per day can be defined as one period of exposure to soil per day. Algorithms have also been developed to assess multiple exposure events per day, which can be thought of as replenishment or replacement with a fresh layer of soil on skin (Bunge and Parks, 1997). If soil replacement is frequent enough, the soil concentration is not depleted before the next exposure, and the concentration remains essentially constant for the entire exposure period. Notably, activities involving multiple soil contacts may be better represented by a single contact scenario, if soil from the initial contact interferes with direct exposure to subsequent soil encounters. For the purposes of simplicity, one exposure event per day will be synonymous to a daily exposure, with the assumption that soil depletion of the chemical does not occur before removal from the skin with washing.

For children, exposure durations of 24 hrs are supported by national survey data reported in Wong et al. (2000b) which showed a median child bathing of one time per day. Similarly, regional data from Washington and Oregon reported median child bathing of 7 times per week. The 5th percentile for bathing was 2 and 3 times/week for cold and warm weather, respectively. However, Shoaf et al. (2005) reported a median value of two times per week for child bathing. The deviance from the national survey results was considered to be due to parents being more relaxed in interviews and less inclined to report conservative estimates.

Hand washings were more frequent than bathing among children. Wong et al. (2000b) reported median hand washing of 3 to 5 times per day in the national survey and a median hand washing of 4 times per day in the regional survey. The 5th percentile for hand washing was 2 times/day. Again, Shoaf et al. (2005) reported a less frequent

median value of one time per day for hand washings. Videotaping of children's microactivity patterns by Freeman et al. (2001) also tends to support fewer hand washings per day than the national and regional surveys reported by Wong et al. (2000b).

Considering that hands tend to have higher soil loadings than other parts of the body, except perhaps the feet, but are washed more frequently than other body parts, 24 hr exposure to contaminated soil is supported by OEHHA as a reasonable estimate for an overall default assumption for exposure duration. This health protective approach is not considered overly conservative given that some studies show bathing behaviors in children may be as few as 2 times per week.

National and regional bathing and hand washing patterns in adults were reported by Garlock et al. (1999). Nearly all respondents in both surveys (72 to 99%) reported washing hands right away after soil contact activities including gardening, yard work, team sports and home repair and digging. Bathing was reported to occur mainly within 1 hr or later that day after an activity. Only 1 to 8% did not bathe until the next day. Similar to the child bathing/hand washing survey data, the authors cautioned that the washing/bathing findings may be biased towards more socially desirable responses and should be interpreted with caution. Accordingly, the health protective assumption is to also use a soil contact duration of 24 hrs for adults, as recommended by U.S. EPA (2004).

The duration of the activity does not appear to be a good predictor of soil loading. Kissel et al. (1998) noted that initial soil contact involves a substantial portion of key body parts and is followed by continual gain and loss of soil during activity due to abrasion of skin surfaces. Soil amended with fluorescent marker does suggest increasing involvement of skin surfaces with time, but this outcome was not clearly reflected in the gravimetric results.

6.~~3~~4.5.2 Exposure Frequency

Soil exposure frequency is the final parameter of significance in these exposure estimates. Prior research by Hawley (1985) based estimates for frequency of contact with soils largely on professional judgment. The U.S. EPA (1992) used Hawley's estimate in arriving at a default value for frequency of contact with soil of 40 events (days) per year as typical for adults, with a high-end estimate of 350 events per year. Hawley also estimated soil contact in young (<2-5 years of age) and older children at 130 events per year. In the revised U.S. EPA dermal risk assessment guidelines (U.S. EPA, 2004), a reasonable maximum exposure (RME) frequency for a residential scenario is 350 days/year for both adults and children.

The Soil Contact Surveys in adults (Garlock et al., 1999) and children (Wong et al., 2000b) provided more specific estimates of time or days spent involved in outdoor activities that may result in soil contact. For the child Soil Contact Survey, adult participants with children recorded outdoor play activities of their children in both warm

and cold weather. The play participation rate was 73.5% of all children surveyed. The term "play" or "player" referred specifically to participation in outdoor play on bare soil or mixed grass and soil. Of the 500 children reported to play outdoors, 407 were reported to play outdoors during warm weather months and 390 were reported to play outdoors in cold months. Child players in both seasons were 57.4%.

The child frequency in days/week and hours/day for participants of outdoor play activities is shown in Table 6.~~8~~10. Among child players, the median play frequency was 7 days/week in warm weather (April-October) and 3 days/week in cold weather (November-March). Arithmetic or geometric means were not reported in the study.

Table 6.~~8~~10. Frequency of Outdoor Activities with Soil Contact Among Child* Participants in Warm and Cold Climates

Percentile	Cold Months (November-March)		Warm Months (April-October)	
	days/week	hours/day	days/week	hours/day
5	1	1	2	1
50	3	1	7	3
95	7	4	7	8

* Data from Wong et al. (2000b) for children <18 years of age

The exposure frequencies of outdoor play activities in days/week were multiplied by 50 weeks/year (assumes a two-week vacation per year away from the contaminated environment) to arrive at exposure frequencies in days/year (Table 6.~~9~~11). For a mixed climate, outdoor play activity in days/year was calculated as 7 months of warm climate (e.g., April-October) and 5 months of cold climate (e.g., November-March), with the assumption of one week vacation away from the contaminated environment during each of the cold and warm climate periods.

Table 6.~~9~~11. Estimated Frequency of Outdoor Activities with Soil Contact in Days/Year for Children <18 Years of Age*

Percentile	Cold	Mixed	Warm
5	50	60	100
50	150	267	350
95	350	350	350

* Extrapolated from data of Wong et al. (2000b)

For adults, outdoor activities in the Soil Contact Survey by Garlock et al. (1999) were categorized as (1) gardening, (2) other yardwork, (3) team sports, and (4) home repair involving digging. The reported participation rate for the first three activities ranged from 79 to 89% while that for the last activity was 30 and 18% for regional and national surveys, respectively. The report presented activity frequency for warm and cold climates, with climate defined by the survey respondents. Results were presented for "doers", or participants, of the activity as well as all survey respondents. The survey was conducted on a national basis and for a regional area around Hanford, Washington. Because the Hanford area does not get the extreme weather conditions that some

areas of the nation outside of California do, the Hanford area data were considered more likely representative of California than the national data. For three of the activities, gardening, other yardwork, and team sports, the results were presented in hours/month. These soil contact frequency data are not directly applicable to the Hot Spots dermal exposure algorithm because the algorithm requires a different unit of measure (days/year). The frequency of each of these three activities was combined and the results are presented in Table 6.~~10~~12.

Table 6.~~10~~12. Total Reported Activity Duration (hrs/mo) Among Adult Participants of Three Activities: Gardening, Other Yard Work, and Team Sports[a]

Hanford (regional) Survey[b]		
Percentile	Cold	Warm
5	1	4
50	6	27
95	31	126
National Survey		
Percentile	Cold	Warm
5	2	4
50	9	22
95	130	108

[a] Data from Garlock et al. (1999)
[b] Participants of regional survey were from counties in Oregon and Washington surrounding the Hanford Nuclear Reservation.

The fourth activity surveyed by Garlock et al. (1999), home repair involving digging, was reported in event days per season. No statistical difference was found between the two survey regions in terms of event days/season among participants for this activity. OEHHA chose not to use the "home repair involving digging" activity data because these data add uncertainty (significant bias may exist in the "digging" data due to the low participation rate) with only small gain in sample size. Table 6.~~11~~ 13 presents the results for the home repair involving digging activity.

Table 6.~~11~~13. Frequency of Home Repair Involving Digging in Events/Season (Days/Season)

	Cold	Warm
	Hanford	
50th percentile	3	4
95th percentile	24	28
	National	
50th percentile	4	6
95th percentile	35	31

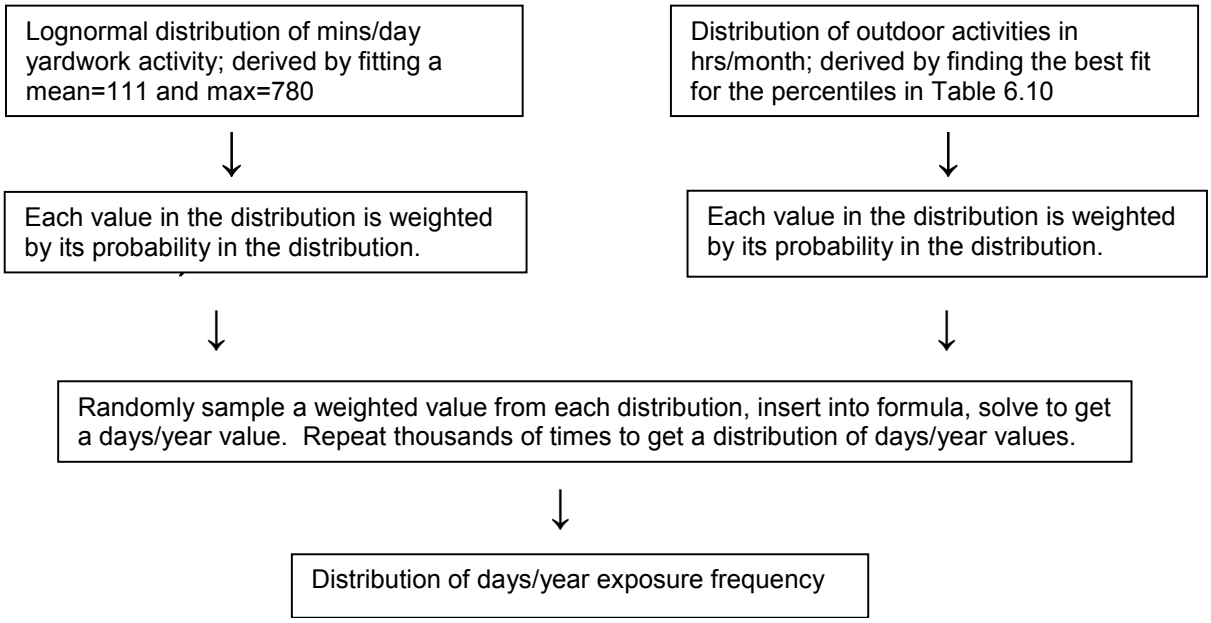
OEHHA chose to use the first three of the Garlock et al. activities (gardening, other yardwork, and team sports) for estimating soil contact frequency of adults. Using Monte Carlo simulation in Crystal Ball (Decisioneering, 2008), OEHHA calculated the best fit distribution for exposure frequency in hours/month for each climate (Table 6.~~10~~12). In

order to use these distributions for the exposure variate in these guidelines, the units need to be converted from hours/month to days/year. To do so, a similar activity survey by Jenkins et al. (1992) was employed. The Jenkins et al. study was a statewide survey of Californians' activity patterns, including "yard work/outdoor chores." Results were reported in minutes/day and were given for both participants of the activity as well as extrapolated to the population. OEHHA used only the participant results to convert the Garlock et al. study's hours/month data to estimates of days/year. The following formula was used for the conversion:

Days/year = (hrs/mo * 60 mins/hr *12 mos/yr) / (mins/day)

For the time spent by California participants in the "yardwork" activities, Jenkins et al. reported a mean and maximum of 111 and 780 minutes/day, respectively. We fit a lognormal distribution to the mean and maximum values using Monte Carlo simulation (Decisioneering, 2008). For this fit, we considered the maximum to be the 99th percentile. We applied Monte Carlo methods to solve the above formula using the minutes/day and hours/month distributions. We repeated the Monte Carlo analysis of the formula for each climate. As was done for the child exposure frequencies, a mixed climate was considered to have seven months of warm climate (e.g., April-October) and five months of cold climate (e.g., November-March). Diagram 1 outlines the derivation of the distribution of days per year.

Diagram 1. Derivation of distribution of days/year using Monte Carlo methods



In order to perform a Monte Carlo analysis, we assumed a correlation exists between the number of minutes per day and the number of hours per month spent in outdoor activities. We also assumed a maximum exposure frequency of 350 days/year in the

analyses. The analyses resulted in distributions of days/year for each climate (Table 6.~~12~~14).

Table 6.~~12~~14. Days/Year of Soil Contact Activities by Adults*

Climate		Cold	Mixed	Warm
Mean		97	150	168
Percentiles	5th	11	25	31
	50th	70	135	161
	75th	140	220	241
	90th	227	290	302
	95th	276	318	326
	99th	331	343	345

* Derived from data of Garlock et al. (1999) and Jenkins et al. (1992)

Several potential limitations exist for using an unrelated activity survey to estimate exposure frequency in days/year from the Soil Contact Survey. The category yard work/outdoor chores in the California survey may include activities not involving soil contact, and the two survey populations (i.e., Jenkins' California survey and Garlock's regional/national survey) were mainly from different states. The Jenkins study included participants age >11 years, whereas the adult Soil Contact Survey was conducted with adults 18 years and older. However, these survey data together provide the best available estimate for daily exposure to soil in California resulting from common outdoor activities.

Although specific soil exposure frequency of adult workers was not part of the Soil Contact Survey, a reasonable estimate would assume exposure five d/wk with roughly two weeks off per year, regardless of the California climate region, resulting in an exposure frequency of 250 d/yr. U.S. EPA (2004) uses 350 d/yr as a Reasonably Maximally Exposed individual for industrial workers, and an exposure frequency of 219 d/yr as a central tendency for this variate.

Soil exposure frequency estimates in d/yr for use in Hot Spots programs are summarized below in Table 6.~~13~~15. The exposure frequency percentiles from the child Soil Contact Survey are most representative for children in the 2<9 and 2<16 year age group. Only about 10% of the children in the Survey were under 2 yrs of age. For the 0<2 year age group, as noted above, Wong et al. (2000b) observed that most newborns (20% or less) up to the first year after birth generally stay indoors and are not exposed to outdoor surfaces with bare dirt. However, most children age 1<2 years participate in outdoor play activities, similar to older children.

As discussed above in Section 6.3.3, about 30% of indoor dust is composed of soil that is brought in from outside. The tendency of infants to play on the floor and be exposed to soil in the dust is much greater when compared to older children. Although infants spend significantly less time outdoors than older children, they may be exposed to contaminated soil via indoor dust as often as older children are exposed to soil

outdoors. To address this issue, which involves a sensitive age group, OEHHA used a health-protective approach by assuming that the same exposure frequency occurred for the 0<2 age group as the older child age groups (Table 6.~~13~~15).

Table 6.~~13~~15. Cumulative Probability Distributions of Soil Exposure Frequency for Children and Adults in Days/Year

Age Group	Cumulative Probability	Warm Climate	Mixed Climate	Cold Climate
0<2 years	5% 50% 95%	100 350 350	79 267 350	50 150 350
2< 9 and 2<16 years	5% 50% 95%	100 350 350	79 267 350	50 150 350
Adult – residential	5th 50th 95th	31 165 326	25 137 318	11 70 276
Adult – offsite worker	central tendency	250	250	250

6.~~4~~5 Point Estimates and Stochastic Approach for Dermal Dose Assessment

The dermal exposure pathway generally contributes only a small portion of the risk of airborne substances under the typical facility operation and exposure scenarios in the Air Toxics "Hot Spots" program. In the previous edition of this exposure guidelines document (OEHHA, 2000), OEHHA recommended using specified average and high-end point estimate values for four of the variates in equation 6-1:

body weight (Table 6.5)
exposed surface area of skin (SA) (Table 6.5)
soil load on skin (SL) (Table 6.9)
frequency of exposure (EF) (Table 6.15)

~~Equation 6-1 requires multiplying values together, which could lead to overly conservative exposure estimates when high-end values were used in the equation 6-1. By combining information from the four variates into one composite distribution, over-conservatism may be avoided. To this end,~~ As explained in Section 6.3, OEHHA created a new variate, "annual dermal load", or ADL, which is a composite of the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates. Point estimates from the composite "annual dermal load" can be used for point estimate assessments while parameters and information on the type of distribution (e.g., lognormal) can be used for stochastic assessments.

Distributional data are available for the body surface area per kg of body weight (BSA/BW) and exposure frequency variates. Thus, a stochastic approach could be used to derive a distribution by combining these variates. On the other hand, only point estimates for soil loading and percent of surface area for specific body parts for

activities that result in soil contact are available. These constant values (means) can be used in the stochastic derivation of a composite distribution because they will not affect the distributional type or shape of the combined BSA/KG and exposure frequency distribution. Using a Monte Carlo simulation in Crystal Ball (Decisioneering, 2008) a distribution for the ADL was derived combining these variates. The ADL is in units of mg of soil loaded onto skin per kg body weight per year (mg / kg-yr~~) and expressed as:~~

~~ADL = (BSA / BW)* [(SL_b)(SA_b%$_b$)] * EF (Eq. 6-7)~~

~~Where :~~

~~BSA/BW = total body surface area / body weight (cm^2/kg)~~
~~SL_b = daily soil loading on a specific body part (mg/cm^2-d)~~
~~SA%$_b$ = percent surface area of the exposed specific body part~~
~~EF = exposure frequency (d /yr)~~

~~Thus, the dermal dose equation (Eq. 6-1) can be reduced to the following:~~

~~Dermal dose (mg/kg-d) = ADL*Cs *ABS * ED / AT * $1x10^9$ (Eq. 6-8)~~

To derive a distribution of ADL values that can be used to stochastically derive dermal dose, nationally representative values of “BSA per kg body weight” and “exposure frequency” distribution data are used together with mean values of “soil adherence” and “%BSA-exposed”. For each age group and climate, a value is sampled from each of the “BSA/BW” and “Exposure Frequency” distributions based on its probability in the distribution. These values are multiplied by the mean “soil adherence” and “%BSA-exposed” values for a given body part (and age group and climate). This product gives an ADL for that body part ($ADL_{bodypart}$). This process is repeated for up to four more times using the same “BSA/kg” and “Exposure Frequency” values but with “soil adherence” and “%BSA-exposed” values for a different body part each time. This results in five $ADL_{bodypart}$ values, one for each of face, hands, feet, forearms, and lower legs. The five $ADL_{bodypart}$’s are summed to give an ADL for a hypothetical person for a specific age group and climate.

This process of deriving an ADL for a hypothetical person is repeated thousands of times to give a distribution of ADL values (for that age group and climate). This distribution of ADL values has incorporated the population distribution information from the “body surface area normalized to body weight” and “exposure frequency” variates. Diagram 2 outlines the procedure of stochastically estimating a probability distribution of ADL values and Table 6.~~14~~ 2 in Section 6.2 above ~~presents~~present the stochastically-derived ADL distributions for each of the five age groupings.

Diagram 2. Derivation of Annual Dermal Load (ADL) using Monte Carlo methodology

Distribution of BSA/bodywt for each individual in NHANES.

Distribution of exposure frequency in days/year (see Diagram 1).

↓

Each value in the distribution is weighted by its probability in the distribution.

Each value in the distribution is weighted by its probability in the distribution.

↓

List of mean values of soil adherence for each body part.

Mean values of %BSA-exposed for each body part.

↓

1. Calculate $ADL_{bodypart}$
   1) Randomly sample a weighted value from the "BSA/kg" and "Exposure Frequency" distributions above
   2) Choose one body part (face, forearms, lower legs, feet, hands). Use mean value of soil adherence and %BSA-exposed for that specific body part
   3) Insert values from 1) and 2) into the formula below

   $ADL_{bodypart}$ = (BSA/kg * Exposure Frequency * soil-adherence$_{bodypart}$ * %BSA$_{bodypart}$)

2. Repeat above using the same values from 1) but for each body part in 2) until the $ADL_{bodypart}$ for each body part has been solved.

3. Sum the five $ADL_{bodypart}$'s to get a value for ADL for a hypothetical person.

4. Repeat the above procedure thousands of times to obtain a population distribution of ADL values.

↓

Distribution of Annual Dermal Load for each climate and age group.

↓

Repeat the above to derive a distribution of ADL for each climate and age group.

6.~~5~~6 Dermal Uptake Equations by Other Agencies

6.~~5~~6.1 U.S. EPA Exposure Estimates

The U.S. EPA (2004) suggested using the following equation for estimating dermal exposure to chemicals from soil:

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \qquad \text{(Eq. 6-~~9~~12)}$$

where:

DAD = dermal absorbed dose (mg/kg-d)
DA_{event} = absorbed dose per event (mg/cm^2-event)
EV = event frequency (events/d)
EF = exposure frequency (d/yr)
ED = exposure duration (yrs)
SA = skin surface area available for contact (cm^2)
BW = body weight (kg)
AT = averaging time (d); for noncarcinogenic effects, AT = ED x 365 d/yr, for carcinogenic effects, AT = 70 yrs or 25,550 d

The absorbed dose per event, DA_{event}, uses a percent absorption calculation which considers chemical-specific absorption estimates and the soil type and skin adherence factor:

$$DA_{event} = C_{soil} \times CF \times AF \times ABS_d \qquad \text{Eq. 6-~~10~~13}$$

where:

DA_{event} = absorbed dose per event (mg/cm^2-event)
C_{soil} = chemical concentration in soil (mg/kg)
CF = conversion factor (10^{-6}/mg)
AF = adherence factor of soil to skin (mg/cm^2-event)
ABS_d = dermal absorption fraction

US EPA (2004) recommends an age-adjusted dermal exposure factor (SFS_{adj}) when dermal exposure is expected throughout childhood and into the adult years. This accounts for changes in surface area, body weight and adherence factors over time. The SFS_{adj} is calculated using the US EPA age groupings of 1-6 years (children) and 7-31 years (adult):

$$SFS_{adj} = \frac{(SA_{1\text{-}6})(AF_{1\text{-}6})(ED_{1\text{-}6})}{(BW_{1\text{-}6})} + \frac{(SA_{7\text{-}31})(AF_{7\text{-}31})(ED_{7\text{-}31})}{(BW_{7\text{-}31})} \qquad \text{Eq. 6-~~11~~14}$$

where:

SFS_{adj} = age-adjusted dermal exposure factor (mg-yrs/kg-events)
AF_{1-6} = adherence factor of soil to skin for a child 1-6 yrs (mg/cm^2-event)
AF_{7-31} = adherence factor of soil to skin for an adult 7-31 yrs (mg/cm^2-event)
SA_{1-6} = skin surface area available for contact during ages 1-6 yrs (cm^2)
SA_{7-31} = skin surface area available for contact during ages 7-31 yrs (cm^2)
ED_{1-6} = exposure duration during ages 1-6 (yrs)
ED_{7-31} = exposure duration during ages 7-31 (yrs)
BW_{1-6} = average body weight during ages 1-6 yrs (kg)
BW_{7-31} = average body weight during ages 7-31 yrs (kg)

6.~~5~~6.2 Cal/EPA Department of Pesticide Regulation Guidance for the Preparation of Human Pesticide Exposure Assessment Documents

The Department of Pesticide Regulation (DPR) has developed guidelines for exposure assessment that include a dermal absorption component for occupational exposure to pesticides. The guidelines are currently under revision and have not been posted as of this writing (DPR, 2007). Previously, the DPR dermal absorption estimate procedure used a default uptake value of 100% unless a pesticide registrant chooses to collect specific data. However, DPR has revised the dermal absorption default for pesticides to 50% absorption on the basis of a survey of previous pesticide absorption studies, and the finding that 100% absorption in humans has not been observed for any pesticide (DPR, 1996). Experimental absorption values prior to the current revision process were calculated from in vivo data as follows:

$$\text{Percent dermal absorption} = \frac{\text{Applied dose} - \text{Unabsorbed dose}}{\text{Applied dose}} \times 100 \qquad \text{Eq. 6-}\cancel{12}15$$

The absorbed portion may also be calculated from the sum of all residues found in excreta, expired air, blood, carcass, and skin at the site of application (after washing), or estimated from the asymptotic plot of all (radioactively-labelled) residues excreted in feces, urine, and air. Absorption rate in an animal experiment in vivo is assumed to be applicable to humans, unless it can be corrected with the ratio of in vitro uptake in animal vs. human skin.

6.~~5~~6.3 CalTOX

The Department of Toxic Substances Control (DTSC) developed the CalTOX computer program to estimate potential exposure to chemicals at hazardous waste sites (DTSC, 1993; 1994). The program incorporates variable parameters in each exposure pathway to estimate multimedia uptake of a chemical by all exposure routes, with the uncertainty assumptions explicitly presented. The program provides a mechanism for screening health risks at hazardous waste sites. CalTOX incorporates explicit assumptions for distributions of all exposure parameters, but with regard to dermal exposure, is focused

on dermal uptake of contaminants poured directly onto soil, and at concentrations higher than one would anticipate from airborne deposition. The basic uptake model is:

$$ADD = AR_s \times SA_b \times 0.3 \times 15 \times EF_{sl}/365 \times C_g \qquad \text{(Eq.6-~~13~~16)}$$

where:

ADD = average daily dose in mg/kg-day, for one exposure event/d
AR_s = ratio of the absorbed dose to the soil concentration, e.g., uptake per unit area of skin per unit concentration in soil in mg/cm^2 per mg/cm^3
SA_b = body surface area per kg, in m^2/kg
0.3 = fraction of total body exposed to soil, default value; coefficient of variation (CV) assumed = 0.04
15 = conversion factor for soil density, in kg/cm-m^2, based on a soil bulk density of 1500 kg/m^3
$EF_{sl}/365$ = exposure frequency in days/year, divided by the days in a year; mean assumed = 137, CV = 0.6
C_g = chemical concentration in soil (mg chemical/kg soil).

The absorbed dose for each event is calculated with the following equation:

$$AR_s = T_s \times \left\{ 1 - \exp\left[\frac{-K^s_p \times ET_{sl}}{T_s} \right] \right\} \qquad \text{(Eq. 6-~~14~~17)}$$

where:

AR_s = skin uptake as defined above
T_s = thickness of soil layer on skin, in cm
$-K^s_p$ = permeability factor for chemical movement from soil into skin, in cm/hr
ET_{sl} = soil exposure time, in hrs/d

The thickness of the soil layer on skin, T_s, depends on the soil loading factor, which was assumed to be 0.5 mg/cm^2, with CV = 0.4. The permeability factor, K^s_p, is derived from permeability values, K_p, from water, with a correction for decreased skin hydration. ET_{sl} is set equal to half the total exposure time at home.

6.~~6~~ 7 References

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7. Home Produced Food Exposure Assessment

7.1 Introduction

Semivolatile organic toxicants and toxic heavy metals emitted into the air by California facilities (e.g., dioxin and lead) are subject to deposition onto vegetation, soil, and surface water bodies. Homegrown produce can become contaminated through the deposition of the toxicant onto the surface of edible leaves, exposed edible portions of vegetables, and fruit, or, in the case of metals, may be taken up from the soil into the roots of the plant. Food animals may become contaminated from consuming contaminated vegetation (e.g., pasture, grains), water, or soil, or from inhaling the airborne toxicants. Humans may then be exposed by consuming the contaminated produce (leafy greens, fruits, vegetables), or animal products (meat, milk, and eggs).

Commercially grown produce or commercially raised beef, chicken, pork, cow's milk, and eggs come from diverse sources, so that the potential public health impacts from a single Hot Spots facility impacting a commercial operation are minimal. Therefore, only the risks from Hot Spots facility contamination of homegrown produce and home-raised beef, chicken, pork, eggs, and milk are assessed.

In order to quantify risks (cancer and chronic noncancer) from homegrown, or home raised food exposures the dose must be determined. Dose is proportional to the consumption rate of the homegrown food items and the concentration of the toxicant in the homegrown products (i.e., produce, meat, eggs, and milk). In this chapter, we discuss and present consumption rates (both probability distributions and point estimate values) and methods to determine toxicant concentration levels for homegrown foods. The equation for determining the dose from home grown foods is shown in Equation 7.1.

7.2 Home Produced Food Exposure Recommendations[Sections 7.2.X were moved from the back of the chapter to the front]

OEHHA has used the National Health and Nutrition Examination Survey (NHANES) 1999-2004 survey data to generate per capita consumption distributions for produce (exposed, leafy, protected, and root categories), meat (beef, chicken, and pork), dairy products, and eggs. The NHANES data are the most recent data available with which to estimate consumption rates for the food categories discussed and that are relatively representative of the California population. The variability in food consumption that may be associated with interindividual variability in body weight was accounted for by presenting the rates on a body weight basis.

There is uncertainty in the estimations of produce, meat, dairy products, and eggs. The consumption rates are based on a single day of surveyed food intake. One day of survey data per individual is not adequate for capturing typical intake which means that the lower and upper percentiles are likely to be overestimated. Unfortunately these data are the best representative data for the United States population.

7.2.1 Point Estimates

OEHHA is recommending that the default values presented in Table 7.1 be used, as needed, for the point estimate approach (Tier 1). These default values represent the mean and 95th percentiles of the empirical distributions presented in Tables 7.8 through 7.13 . When the food pathway is a dominant pathway, and multiple homegrown produce, home raised meat, milk, and eggs categories all are assessed, the 95th percentiles default consumption rate for the highest risk category (e.g. leafy produce) should be used. OEHHA recommends the mean consumption values for the remaining categories. This procedure will help avoid overly conservative estimation of risk that would arise from assuming that a single receptor would be a high consumer of all homegrown categories.

Table 7.1 Recommended Average and High End Point Estimate Values for Home Produced Food Consumption (g/kg-day)

Food Category	**Third Trimester**		**Ages 0<2**		**Ages 2<9**	
Produce	Avg.	High End	Avg.	High End	Avg.	High End
Exposed	1.9	5.9	11.7	30.2	7.4	21.7
Leafy	0.9	3.2	3.8	10.8	2.5	7.9
Protected	1.7	5.8	5.9	17.5	4.7	13.3
Root	1.7	4.6	5.7	15.3	3.9	10.8
Meat						
Beef	2.0	4.8	3.9	11.3	3.5	8.6
Poultry	0.9	2.9	2.9	10.5	2.2	7.8
Pork	1.8	4.7	4.5	11.4	3.7	9.0
Milk	5.4	15.9	50.9	116	23.3	61.4
Eggs	1.6	4.2	6.1	15.0	3.9	9.4
	Ages 2>16		**Ages 16<30**		**Ages 16-70**	
Produce	Avg.	High End	Avg.	High End	Avg.	High End
Exposed	1.9	5.9	1.9	5.9	1.8	5.6
Leafy	0.9	3.2	0.9	3.2	1.1	3.4
Protected	1.7	5.8	1.7	5.8	1.6	5.2
Root	1.7	4.6	1.7	4.6	1.5	4.2
Meat						
Beef	2.0	4.8	2.0	4.8	1.7	4.4
Poultry	0.9	2.9	0.9	2.9	0.9	2.8
Pork	1.8	4.7	1.8	4.7	1.5	3.8

Food Category	Third Trimester		Ages 0<2		Ages 2<9	
Milk	5.4	15.9	5.4	15.9	4.3	13.2
Eggs	1.6	4.2	1.6	4.2	1.3	3.4

[a] Food consumption values for 3rd trimester calculated by assuming that the fetus receives the same amount of contaminated food on a per kg BW basis as the mother (adult age 16 to less than 30).

7.2.2 Stochastic Approach

OEHHA is recommending that the parametric models for food consumption distributions presented in Tables 7.2 through 7.7 be used as needed in Tier III stochastic risk assessments. The methods leading to these distributions are described in Section 7.4.1.

Table 7.2 Parametric Models of Per Capita Food Consumption (g/kg-day) for All Ages

Food Category	Distribution Type	Anderson -Darling Statistic	Mean	Std. Dev	Location	Scale	Shape
Produce							
Exposed	LogN	62	11.8	11.9			
Leafy	Gamma	88			0.0	1.26	0.9664
Protected	Gamma	95			0.0	2.49	0.8076
Root	Gamma	70			0.0	1.77	1.0592
Meat							
Beef	LogN	16	1.97	1.73			
Poultry	LogN	19	1.84	1.64			
Pork	LogN	144	1.08	1.76			
Dairy	LogN	358	8.74	21			
Eggs	LogN	114	1.62	1.55			

Table 7.3 Parametric Models of Per Capita Food Consumption (g/kg-day) for 0 <2 Years.

Food Category	Distrib. Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape	Like-liest
Produce								
Exposed	Gamma	60			0.01	6.56	0.830	

Food Category	Distrib. Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape	Like-liest
Leafy	Gamma	167			0.01	3.30	1.161	
Protected	LogN	67	6.03	7.31				
Root	Gamma	83			0.06	4.44	1.28	
Meat								
Beef	LogN	16	1.97	1.73				
Poultry	LogN	58	4.5	4.08				
Pork	LogN	230	3.00	4.46				
Dairy	Max Ext.	169				27.82		33.79
Eggs	LogN	172	6.11	4.21				

Table 7.4 Parametric Models of Food Consumption (g/kg-day) for Ages 2<9

Food Category	Distribution Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape	Rate
Produce								
Exposed	Exponential	206						0.14
Leafy	LogN	127	2.64	3.89				
Protected	Weibull	68			0.02	4.76	1.063	
Root	LogN	60	3.95	3.85				
Meat								
Beef	LogN	35	3.55	2.79				
Poultry	LogN	17	3.71	2.67				
Pork	LogN	66	2.25	2.84				
Milk	LogN	12	23.4	20.78				
Eggs	LogN	38	3.93	3.00				

Table 7.5 Parametric Models of Food Consumption (g/kg-day) for Ages 2<16

Food Category	Distribution Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape
Produce							
Exposed	Gamma	60			0.01	6.54	0.8325
Leafy	LogN	68	1.83	2.91			
Protected	Gamma	47			0.00	3.69	0.9729
Root	LogN	51	3.10	3.44			
Meat							
Beef	LogN	10	2.96	2.49			
Poultry	LogN	27	2.98	2.52			
Pork	LogN	48	1.84	2.79			
Milk	LogN	35	16.8	19.2			
Eggs	LogN	71	3.16	2.95			

***Table 7.6 Parametric Models of Food Consumption (g/kg-day) for Ages* 16< 30[a]**

Food Category	Distribution Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape
Produce							
Exposed	Gamma	70			0.01	2.05	0.9220
Leafy	Weibull	191			0.00	0.88	0.8732
Protected	LogN	93	1.81	3.31			
Root	LogN	43	1.69	1.69			
Meat							
Beef	LogN	26	1.98	1.54			
Poultry	LogN	26	1.80	1.42			
Pork	LogN	242	1.01	1.74			
Milk	Gamma	22			0.02	5.66	0.9421
Eggs	LogN	29	1.55	1.36			

[a] These distributions are also recommended for the third trimester.

***Table 7.7 Parametric Models of Food Consumption (g/kg-day) for Ages* 16-70**

Food Category	Distribution Type	Anderson-Darling Statistic	Mean	Std. Dev	Location	Scale	Shape
Produce							
Exposed	Gamma	148			0.01	2.07	0.8628
Leafy	Gamma	83			0.00	1.15	0.9713
Protected	Gamma	78			0.01	1.90	0.8325
Root	Gamma	14			0.00	1.28	1.166
Meat							
Beef	LogN	20	1.75	1.40			
Poultry	LogN	18	1.53	1.18			
Pork	LogN	190	0.97	1.59			
Milk	Gamma	20			0.00	4.50	0.9627
Eggs	LogN	30	1.3	1.01			

7.~~2~~3 Home Grown Food Intake Dose

7.~~2~~3.1 Point Estimate (Deterministic) Algorithm

The general algorithm for estimating dose via the food pathway is as follows:

DOSEfood = (Cf * IF * GRAF * L)* EF* (1 × 10^{-6})- (Eq. 7-1)
AT

where: DOSEfood = (mg/kg-day)
Cf = concentration of toxicant in food type F (μg/kg)
IF = consumption for food type F (g/kg body weight per day)
GRAF = gastrointestinal relative absorption factor (unitless)
L = fraction of food type consumed from contaminated source (unitless)
1 × 10^{-6} = conversion factor (μg/kg to mg/g) for Cf term
EF = exposure frequency (days/365 days)

~~ED = exposure duration (years)~~
~~AT = averaging time, period over which exposure is averaged (days).~~

The gastrointestinal relative absorption factor (GRAF) is currently only available for dioxins and furans. In most cases, a GRAF factor of one is used because it assumed that absorption would be similar in the animal oral studies as it would for humans consuming the contaminated food. In addition, data for estimating a GRAF are almost never available. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) following US EPA (1991).

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (POTENCY):

RISKfood = DOSEfood *POTENCY*ASF*ED/AT **(Eq. 7-2)**

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (see OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the DOSEfood and ED are different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)
7 yrs for 2<9 age group	(ASF = 3)
14 yrs for 2<16 age group	(ASF = 3)
14 yrs for 16<30 age group	(ASF = 1)
54 yrs for 16-70 age group	(ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKfood_{(lifetime)} = RISKfood_{(3rdtri)} + RISKfood_{(0<2\ yr)} + RISKfood_{(2<16\ yr)} + RISKfood_{(16\text{-}70yr)} \quad \textbf{(Eq. 7-3)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential exposure scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$RISKfood_{(9\text{-}yr\ residency)} = RISKfood_{(3rdtri)} + RISKfood_{(0<2\ yr)} + RISKfood_{(2<9\ yr)} \quad \textbf{(Eq. 7-4)}$$

For the 30-year residential exposure scenario, the risk for the 2<16 and 16<30 age group would be added in to the risk from exposures in the third trimester and from age 0<2 yr. For 70 year residency risk, Eq 7-3 would apply.

7.~~2~~3.2 Stochastic Algorithm

The algorithm for the stochastic method is the same as the point estimate algorithm. Recommended distributions, as parametric model of empirical data on variability, are available to substitute for single values, where data permit.

7.~~3~~4 Food Consumption Variates for the Hot Spots Exposure Model

The homegrown produce and home-raised meat, eggs, and milk pathways in the Hot Spots program are used to assess chronic noncancer risks and cancer risks. Separate consumption estimates are needed for the third trimester, 0 to <2 years, 2<16 years, 16<30 years and 30 to 70 years in g/kg body weight per day, in order to account for the greater exposure of children and the differential impact of early in life exposure.

The ideal data for such long-term exposure determinations would be recent, representative of the California population, and have repeated measures on the same individuals to characterize typical intake over time. The amount of homegrown produce, and home-raised meat, eggs and milk would be addressed. Such data are not available. The available data while not perfect are nonetheless useful for the purposes of chronic exposure assessment. In the next Section, we review the currently available data and discuss the reasons for our recommendations.

7.4.1 Derivation of Consumption Rates

7.~~3~~4.1.1 Data

Several survey methods have been used to estimate consumption of various foods or food items by a population. These include market basket, food frequency, diary, and consumption recall methods. The USDA has conducted market basket surveys in which the amount of food that enters into the wholesale and retail markets was

measured (Putnam and Allshouse, 1992). These amounts are then divided by the U.S. population to give per capita consumption. This methodology does not allow determination of food consumption rates for individuals in the age ranges that are needed. It provides data on the amount bought at the market, not the amount consumed, which differ due to trimming, water and fat loss during processing and cooking (Putnam and Allshouse, 1992). The USDA market basket studies are thus not useful for assessing chronic exposure in our model because of these limitations.

The food frequency method asks subjects to recall the frequency with which they consumed certain food items over a previous period of time. Typically, information is collected on specific food items (e.g., green tea) or food groups (e.g., grilled red meat) that are being evaluated for their relationship to a certain disease (e.g., cancer). These surveys are conducted on relatively small groups of individuals or on large groups of a certain subpopulation (e.g., nurses in the Nurses Health Study). The food frequency method could provide very helpful information for estimating 'usual' consumption of foods that are typically consumed on a less than daily basis (e.g., berries), and for assessing intraindividual variability (Block, 1992). However, food frequency data from current studies are not representative of the general population and thus not ideal for assessing chronic exposure in the Hot Spots model.

The U.S. Department of Agriculture (USDA) conducted seven Nationwide Food Consumption Surveys (NFCS) beginning in 1935 and ending in 1987-88 that collected data on household food consumption (http://www.ars.usda.gov/Services/docs.htm). The two most recent NFCS studies (1977-78 and 1987-88) included data on individuals. Because one of our objectives for food consumption rates was that the rates reflect current dietary patterns, the NFCS were considered too old to meet our needs. The USDA also conducted a series of food consumption surveys called the Continuing Survey of Food Intake of Individuals (CSFII) (1985, 1986, 1987, 1989, 1990, 1991, 1994-96, and 1998). OEHHA used the 1989-91 CSFII data to determine distributions of food consumption rates for the previous version of the Hot Spots Exposure Assessment and Stochastic Analysis Guidelines (OEHHA, 2000).

The three days of consumption data per individual in the CSFII 1989-1991 capture typical intake better than the fewer days in more recent surveys but are still not considered a sufficient number of repeated measures for a good determination of intraindividual variability (Andersen, 2006). The CSFII 1994-96, 1998 and the National Health and Nutrition Examination Survey (NHANES) 1999-2004, with more recent data, have become available. We therefore chose to consider the more recent datasets because the advantages of the more recent data outweighed the greater number of individual measures on the same individual in the older surveys.

The CSFII 1994-1996, 1998 survey (hereafter referred to as CSFII) collected data on two non-consecutive days of consumption, 3-10 days apart, by over 20,000 individuals, while the NHANES 1999-2004 (hereafter referred to as NHANES) dataset provided only one day of consumption (with the exception of the 2004 year) on over 30,000 individuals. OEHHA considered that the two days of intake of the CSFII did not provide

sufficient additional information on typical intake to outweigh the advantage of the more recent NHANES data.

Further, the number of days between data collection for each individual in the CSFII was not available in the dataset and CSFII reported that there was no standard procedure used to determine the second day of food consumption. This likely resulted in the interval between the first and second days of data collection to be widely variable among individuals.

California specific food consumption data are not available. The CSFII data are available for the Pacific region, but not for California alone. Neither California-specific nor Pacific region-specific data are available for NHANES. Therefore, OEHHA chose to use the NHANES dataset since the need for the most recent data was considered more important than having data specific to California.

7.~~3~~4.1.2 The NHANES Data

The NHANES uses a multistage sampling design to select individuals for the survey. Some of these stages do not use simple random sampling to select units to be surveyed (i.e., “sampled”) resulting in uneven probability and non-independent selection. Therefore, statisticians also created weights to account for these issues. These weights allow for proper estimation of variance, the standard error of the mean (SEM), and confidence intervals (CIs). These parameters (variance, SEM, CIs) estimate confidence that the value of a statistic (e.g., the mean) is the true population value. Therefore, accounting for a multistage survey design is important for estimating confidence in the numerical value of the results. This differs from the sampling weights that provided results that best represent the targeted population.

It is common that some individuals selected to participate in a survey end up either voluntarily or for other reasons, such as incomplete responses, not participating or contributing to the survey. This may result in a surveyed sample of individuals that do not reflect the targeted demographics of the survey. In NHANES, the statisticians created “sample weights” that account for non-participation. Using these weights in statistical analyses provides results that are more representative of the population.

NHANES is designed to collect the most accurate information possible. Participants are interviewed in a private setting, the mobile examination center (MEC), which consists of several mobile units specially designed and equipped for the survey. The MEC is used by NHANES to collect dietary information as well as body measurements (e.g., height, X-rays) and body specimens (e.g., urine) that are also part of the total survey for some participants. The privacy and professional setting of the MEC is thought to encourage greater accuracy in food consumption reporting. The dietary interview room of the MEC contains measuring devices (e.g., cups, spoons, photos) to help participants better estimate the amounts of various foods consumed. In 2002, NHANES implemented the automated multiple pass method, a method intended to solicit greater and more accurate recall of food consumption.

The NHANES survey is quite comprehensive in the range of prepared and non-prepared foods for which data are collected. These foods include beverages, sweets, and condiments, as well as items more commonly considered foods. Further, some food entries contain very detailed information about the food (e.g., peaches, sliced, canned, in light syrup).

We chose to use NHANES data for the derivation of consumption rates because the data are the most recent available, have a larger sample size than CSFII, use detailed procedures to best estimate consumption (e.g., automated pass), and provide weights (sampling and multistage) with which to generate results that are the most representative of the population. Further, because NHANES is now considered a continuous survey (a complete nationwide survey is completed every two years), past results can be compared with future ones due to consistent operating procedures and study design, and future data can be added to past data to provide a more statistically sound sample size.

The disadvantage of the NHANES data is that the single day of data will tend to exaggerate the higher percentiles of the distribution. For example, if chicken consumption were investigated for 2 separate days, and the individual indicates consumption on one day but not on the second survey day, then chicken consumption would be the average of the two survey days. The average of the two days is probably closer to typical intake for the individual than the one day of chicken consumption that is captured by the NHANES survey.

7.~~3~~4.1.3 Methodology for the Derivation of Food Consumption Rates

Since 1999, NHANES has been conducted in two-year increments on a continuous basis. The two-year increment is needed to collect data on the full national sample of selected participants. Thus, the NHANES data are composed of datasets from the 1999-2000, 2001-2002, and 2003-2004 periods and the survey is sometimes called the "Continuous NHANES."

The NHANES collected two days of intake for some individuals in the 1999-2004 period. In 2002, a pilot test of collecting two days of intake was conducted on 10 percent of the participants. The pilot study results were not publicly released because of confidentiality issues. In 2003-2004, two days of intake were collected. However, the 2003-2004 dataset has a much smaller sample size relative to the 1999-2004 dataset. We decided that the increased interindividual information available from the larger sample size of one-day intake from the 1999-2000 dataset was advantageous to the two-day intake from a smaller sample size of the 2003-2004 dataset.

7.~~3~~4.1.4 Categorization of Produce

For the risk assessment of home produced foods, food items can be grouped into food categories to simplify calculations. For produce (i.e., fruits and vegetables), we

reviewed the study of Baes et al. (1984) who considered exposure to radionuclides from produce consumption. The physical processes by which plants can be contaminated by airborne radionuclides are analogous to the processes by which airborne low volatility chemical contamination may occur. In the Baes et al. study, produce is divided into three categories based on the manner in which contamination from air deposition could occur.

The first category, leafy produce, consists of broad-leafed vegetables in which the leaf is the edible part with a large surface area and can be contaminated by deposition of the toxicant onto its surface (e.g., spinach). The next category, exposed produce, includes produce with a small surface area subject to air deposition (e.g., strawberries, green peppers). The third category, protected produce, includes produce in which the edible part is not exposed to air deposition (e.g., oranges, peas).

OEHHA has chosen to use an additional category, root produce, which includes produce for which root translocation could be a source of contamination (e.g., potatoes). In Baes et al., root produce had been placed into one of the other three categories. For the semi-volatile organic and heavy metal toxicants addressed in the AB-2588 program, the produce items from NHANES are classified into the four categories of leafy, exposed, protected, and root produce.

7.~~3~~4.1.5 Categorization of Meat, Eggs, and Dairy

In addition to homegrown produce, animals are sometimes raised at home, depending on space and zoning regulations, for meat, egg, and milk consumption. Animal derived food items such as lamb, goat meat, or goat milk where consumption rates are small are not included in our risk assessment model.

Cattle, pigs, and poultry differ in the types (e.g., pasture vs. grain) and quantities (g/kg-body weight) of feed consumed and thus food products from these animals are likely to differ in contaminant concentrations. The transfer of contaminant into meat differs from that into eggs and milk. Therefore, we categorized animal derived foods into beef, pork, poultry, eggs, and milk product groups. These groups include the main food item (e.g., milk) as well as products from that item (e.g., cheese).

7.~~3~~4.1.6 Estimating and Analyzing Consumption Rate Distributions

We used the NHANES 1999-2004 data to estimate consumption rates for the third trimester, 0 to<2 years, 2<9 years, 9<16 years, 16 <30 years, 30 to 70 years, and 0-70 years age groups. The NHANES dataset contained data on food items as eaten (e.g., grams of raw apple or grams of cheeseburger), which resulted in two issues for data analysis. In order to estimate the dose of toxicant from the beef component of the hamburger, we need to estimate the grams of beef in hamburger. Toxicant concentration is calculated based on grams of raw or harvested food. Therefore, for foods composed of multiple food items (e.g., ground beef, cheese, tomato, lettuce), the weight of each food item in the food was estimated based on the food item's typical

proportion in that type of food. For example, ground beef is considered to be 50 percent of the weight of the cheeseburger while tomatoes in a lettuce and tomato salad are estimated at 50 percent of the reported weight of salad.

The second issue was that ideally we would use the weight of the raw food (rather than the food as eaten) because the concentration of toxicant in a food group (e.g., exposed produce) is based on the raw food at the time of produce harvesting, meat butchering, milking, or egg laying. In particular, the gram weight of food consumed was adjusted for food items such as jams, jellies, juices, and cheese (a complete list of adjustments, including adjustments to the grams consumed for other reasons, is presented in Appendix D). This is because it takes one part fruit to make 2/3 part juice while one needs 1.5 parts milk to make 1 part cheese. OEHHA did not adjust meats for the amount of moisture lost during cooking. This is because the percent moisture can be highly variable but the majority of the time it is less than 10 percent of initial raw weight, and a default adjustment would have introduced significant uncertainty due to highly variable methods of cooking.

For each participant in the survey, the grams of each food item eaten at each eating occasion was divided by that participant's body weight in kg to give g/kg for each food item-occasion. For food items (e.g., cheeseburger) with multiple components (e.g., ground beef, cheese, lettuce, tomato) the proportional g/kg of each food component was determined (e.g., g/kg ground beef, g/kg cheese). For some food item components the consumption amounts were adjusted, as described above, to account for differences in "as eaten" weights and raw/harvested weights.

We then summed the g/kg of the food item components across eating occasions during the day (e.g., ground beef in cheeseburger at lunch and in meatballs at dinner) to give g/kg-day for each food item component. The sum of the g/kg-day of each food item component was then assigned to its appropriate food group category (an example of this is described in the paragraph following this one). The g/kg-day of all food item components in a food group category were summed to give g/kg-day of the food group category for that participant (e.g., g/kg-day exposed produce).

As an example of assigning food item components to food group categories, we can use a study participant who consumed the following foods: strawberries on cereal at breakfast;~~:~~ a tomato, lettuce and cheese salad and strawberry shake for lunch;~~:~~ chicken, a baked potato, and broccoli, and a slice of apple pie for dinner.

In this example, the g/kg of strawberries at breakfast and at lunch would be added together and then added to the g/kg of the summed g/kg tomatoes, and apples to give the g/kg daily intake for the exposed produce group. Likewise, the g/kg of lettuce at lunch, and broccoli at dinner would be added together for the leafy produce group, the g/kg of onion (in the salad) and potato would be added together for the root produce group. For the poultry food group, the g/kg of chicken at lunch would have been the daily intake for the poultry food group. Beverages were also included as food items so that the g/kg of milk on cereal and in the shake would be added together. These intake

rates of milk would then be added to the g/kg of cheese on the salad for the milk products food group for that survey participant. In this manner we obtain the g/kg-day values for each participant for each food group.

Foods that could not be grown in California (e.g., bananas, pineapple) or are only available commercially (e.g., canned milk) were excluded from our analyses. Some food items were not easily identified as to whether they were commercial or home produced (e.g., frozen berries). In these cases, the assumption was made that they were home produced. Canned produce was also included because the product of home canning is sometimes referred to as canned (e.g., "canned peaches"). The list of foods eligible to be used in deriving the food consumption rates for these guidelines is in Appendix D.

Resultant g/kg-day values for each food group category were analyzed across all ages and the third trimester to <2 years, 2<9 years, 9<16 years, 16<30 years, 16<70 years age groups. It was assumed that during the third trimester that food consumption (and exposure to food borne contaminants) was the same as during ages 0<2 years. This is clearly a simplification but the third trimester is a short time period and the error introduced by this assumption is likely to be small. The "Proc Surveymeans" procedure in SAS 9.1 (SAS Institute, 2007) was used to derive mean, SEM, and 50th-, 90th-, 95th-, and 99th-percentile values. The "Proc Surveymeans" procedure incorporates information from each stage of the sampling, which is needed to provide non-biased variance estimates (e.g., the SEM), as well as incorporating information from the sampling weights to provide results that are the most representative of the population.

7.~~3~~4.1.7 Produce, Meat, Dairy and Egg Consumption Distributions

Produce, meat, dairy and egg consumption empirical distributions are presented for 0-70, 0<2 years, 2<9 years, 2<16 years, 16<30 years, and 16-70 years (Tables 7.8, 7.9, 7.10, 7.11, 7.12, and 7.13 respectively). The empirical distribution for 16<30 is also recommended for the third trimester because the fetus is assumed to receive the same dose (mg/kg BW) as the mother, and this age category is most representative of the child-bearing years. Consumption is expressed in terms of grams of food per kilogram body weight per day in these tables. The average and high end point estimate recommendations are presented above in Table 7.4.1. These point estimates are the mean and 95th percentiles from the distributions.

The parametric model that best fit each distribution was estimated using the fitting function in Crystal Ball® version 7.2.1 (Oracle, 2007) and presented in Tables 7.2, through 7.7. Of the three goodness-of-fit tests available in Crystal Ball, the Anderson-Darling test was chosen to identify the best-fit distribution since this test is more sensitive to the tails of the distributions than the other two goodness-of-fit tests (the Chi-Square and the Kolmogorov-Smirnov). For an individual dataset and distribution, the better the distribution fits the data set, the smaller the Anderson-Darling statistic will be.

There are 20 distributions that Crystal Ball can test for distributional fit to the dataset of interest, including the Lognormal, Beta, Gamma, Logistic, Beta, and Pareto. For a few consumption rate stratifications (i.e., for a specific age group and food category), the best fit was determined to be Pareto. However, the mean and percentiles estimated for the Pareto distribution were significantly different from the empirically derived mean and percentiles. For these consumption rate strata, we chose to use the second best fit rather than the Pareto, which more clearly fit the empirically derived mean. Tables 7.2 – 7.7 present the best fit distribution for the consumption rates (noted in the column labeled "distribution type").

Table 7.~~34.18~~ Empirical Distributions of Food Consumption (g/kg-day) for All Ages (0-70 years)

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	9683	3.1	0.05	0.0	84.3	1.7	3.5	4.3	7.2	10.8	23.5
Leafy	7049	1.2	0.03	0.0	19.9	0.8	1.6	1.8	2.7	3.8	7.0
Protected	7033	2.0	0.04	0.0	49.8	1.2	2.5	3.0	4.8	6.8	13.3
Root	11,467	1.9	0.01	0.0	39.5	1.3	2.4	2.8	4.0	5.6	10.8
Meat											
Beef	9043	2.0	0.03	0.0	26.8	1.5	2.5	2.9	4.0	5.2	8.5
Pork	3585	1.1	0.03	0.0	21.4	0.6	1.4	1.6	2.4	3.5	6.8
Poultry	8813	1.9	0.02	0.0	22.5	1.4	2.3	2.6	3.8	5.1	8.7
Milk	17,635	8.4	0.14	0.0	285.3	4.2	9.1	11.3	19.5	31.3	70.6
Eggs	5056	1.7	0.03	0.0	27.1	1.2	2.0	2.3	3.6	5.1	9.3

7.~~34.29~~ Empirical Distributions of Food Consumption (g/kg-day) for Ages 0<2 Yrs

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	941	11.7	0.05	0.1	84.3	8.9	15.4	17.6	23.9	30.2	55.3
Leafy	169	3.8	0.04	0.0	19.9	2.8	5.3	6.6	9.2	10.8	14.5
Protected	464	5.9	0.04	0.1	49.8	3.9	7.5	9.1	12.8	17.5	28.8
Root	783	5.7	0.02	0.1	51.4	4.2	8.2	9.2	12.3	15.3	24.0
Meat											

Beef	301	3.9	0.03	0.1	17.7	3.1	5.6	6.4	8.4	11.3	15.6
Pork	91	2.9	0.37	0.0	14.0	1.7	3.8	4.9	6.8	10.5	14.0
Poultry	472	4.5	0.02	0.0	21.8	3.5	5.9	6.7	9.3	11.4	19.6
Milk	924	50.9	1.9	0.0	285.3	44.1	72.3	80.4	100.1	116.1	167.6
Eggs	330	6.1	0.03	0.1	27.1	4.9	7.7	8.5	13.4	15.0	18.8

Table 7.~~34.3~~10 Empirical Distributions of Food Consumption (g/kg-day) for Ages 2<9 Years

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	1944	7.4	0.26	0.0	74.2	5.6	9.9	11.0	15.6	21.7	35.2
Leafy	689	2.5	0.15	0.0	14.0	1.6	3.3	3.9	6.0	7.9	12.3
Protected	970	4.7	0.17	0.0	33.9	3.5	6.3	7.3	10.2	13.3	19.3
Root	643	3.9	0.12	0.0	34.9	3.1	5.0	5.7	8.0	10.8	17.7
Meat											
Beef	1288	3.5	0.10	0.0	26.8	2.9	4.6	5.0	6.8	8.6	13.6
Pork	434	2.2	0.17	0.0	21.4	1.4	2.7	3.4	4.6	7.8	10.6
Poultry	1430	3.7	0.10	0.0	22.5	3.1	4.7	5.2	7.0	9.0	14.1
Milk	3294	23.3	0.59	0.0	181.8	18.0	30.6	35.2	47.4	61.4	91.2
Eggs	782	3.9	0.15	0.1	19.7	3.4	5.0	5.7	7.4	9.4	15.2

***Table 7.~~34.4~~11 Empirical Distributions of Food Consumption (g/kg-day) for Ages* 2<16 Years**

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	3764	5.5	0.15	0.0	74.2	3.5	7.3	8.4	12.4	16.6	32.1
Leafy	1833	1.7	0.09	0.0	14.5	1.0	2.3	2.6	4.0	5.8	11.3
Protected	2128	3.6	0.11	0.0	34.7	2.5	4.9	5.6	8.5	10.6	17.5
Root	3599	3.0	0.06	0.0	34.9	2.2	3.9	4.5	6.4	8.7	15.5
Meat											
Beef	3119	3.0	0.07	0.0	26.8	2.3	3.9	4.3	5.7	7.6	11.8
Pork	1018	1.8	0.10	0.0	21.4	1.1	2.2	2.7	4.0	5.7	10.4
Poultry	3093	3.0	0.06	0.0	22.5	2.4	3.9	4.4	5.9	7.5	11.4
Milk	7082	16.5	0.34	0.0	181.8	11.6	21.8	25.2	36.7	48.4	78.6
Eggs	1500	3.1	0.09	0.0	19.7	2.4	4.2	4.6	6.4	8.1	13.5

Table 7.~~34.5~~12 ***Empirical Distributions of Food Consumption (g/kg-day) for Ages 16<30 Years***

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	1757	1.9	0.06	0.0	20.6	1.4	2.6	3.2	4.3	5.9	9.1
Leafy	1774	0.9	0.04	0.0	11.4	0.6	1.3	1.6	2.2	3.2	5.2
Protected	1523	1.7	0.09	0.0	22.7	1.0	2.1	2.5	3.9	5.8	10.7
Root	2703	1.7	0.05	0.0	13.0	1.2	2.2	2.5	3.6	4.6	7.5
Meat											
Beef	2462	2.0	0.05	0.0	19.4	1.6	2.6	2.9	3.9	4.8	7.4
Pork	843	0.9	0.04	0.0	9.0	0.5	1.4	1.6	2.3	2.9	4.9
Poultry	2208	1.8	0.04	0.0	12.1	1.4	2.3	2.5	3.5	4.7	7.5
Milk	3806	5.4	0.16	0.0	116.3	3.6	7.1	8.4	12.4	15.9	27.6
Eggs	1053	1.6	0.06	0.0	11.6	1.2	1.9	2.3	3.2	4.2	5.8

Table 7.~~34.6~~13 *Empirical Distributions of Food Consumption (g/kg-day) for Ages 16-70 Years*

Food Category	N	Mean	SEM	Min	Max	50th-%ile	75th-%ile	80th-%ile	90th-%ile	95th-%ile	99th-%ile
Produce											
Exposed	4978	1.8	0.06	0.0	23.2	1.3	2.4	2.8	4.1	5.6	8.8
Leafy	5047	1.1	0.03	0.0	15.6	0.8	1.5	1.7	2.5	3.4	5.8
Protected	4441	1.6	0.05	0.0	30.6	1.0	2.1	2.4	3.7	5.2	9.7
Root	6852	1.5	0.02	0.0	13.0	1.1	2.1	2.3	3.2	4.2	6.6
Meat											
Beef	5623	1.7	0.03	0.0	19.4	1.4	2.3	2.5	3.4	4.4	6.8
Pork	2476	0.9	0.03	0.0	14.6	0.5	1.3	1.5	2.2	2.8	4.8
Poultry	5248	1.5	0.02	0.0	12.1	1.3	2.0	2.2	2.9	3.8	6.1
Milk	9629	4.3	0.08	0.0	116.3	3.0	5.8	6.6	9.9	13.2	22.6
Eggs	3226	1.3	0.03	0.0	11.6	1.0	1.6	1.8	2.5	3.4	5.4

*Min = 0 (zero) is due to amounts consumed <0.05 that were rounded to 0.0 (zero)

7.~~4~~5 Calculating Contaminant Concentrations in Food

The previous sections focused on consumption rates for a variety of foods, and included development of means and distributions for those consumption rates. Consumption rates represent one exposure variate in the algorithm for calculating human exposure to contaminants through the food chain. As in Eq. 7-1, concentrations of contaminants in food products, Cf, must also be estimated. The following sections describe the algorithms and default values for exposure variates used in estimating concentrations in foods.

7.~~4~~5.1 Algorithms used to Estimate Concentration in Vegetation (Food and Feed)

Vegetation that is consumed directly by humans will be referred to as 'food', while that consumed by animals is termed 'feed'. Humans can be exposed to contaminants from vegetation either directly through food consumption or indirectly through the consumption of animal products derived from animals that have consumed contaminated feed.

The concentration of contaminants in plants is a function of both direct deposition and root uptake. These two processes are estimated through the following equations:

$$Cf = (Cdep)*(GRAF) + Ctrans \qquad \text{(Eq. 7-2)}$$

where:
- Cf = concentration in the food (μg/kg)
- Cdep = concentration due to direct deposition (μg/kg)
- GRAF = gastrointestinal relative absorption fraction
- Ctrans = concentration due to translocation from the roots (μg/kg)

7.~~4~~5.1.1 GRAF

A gastrointestinal relative absorption fraction (GRAF) is included in the calculation of concentration via deposition to account for decreased absorption in the GI tract of materials bound to fly ash or fly ash-like particulate matter relative to absorption of a contaminant added to the diet in animal feeding studies (i.e., laboratory animal studies used to determine oral chronic Reference Exposure Levels). At the present time, GRAF data are only available for polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), based on the 2,3,7,8-TCDD congener. The GRAF for those compounds is 0.43. All other compounds have a GRAF of 1.0. There are no data available to describe differential absorption onto feed from fly ash particles as compared to other compounds. Consequently, the factor comes into play only in calculating dose of PCDD/F through this pathway. Note that the factor is not applied to the material translocated through the roots, as toxicants taken up by the roots are assumed to be absorbed to the same extent as that in the feed of the experimental animals in the study, which is the basis for both the cancer potency factor and reference exposure level.

7.~~4~~5.1.2 Deposition onto Crops

The factor Cdep is calculated by the following equation:

$$Cdep = [(Dep)\ (IF)/(k)\ (Y)] \times (1-e^{-kT}) \qquad \text{(Eq. 7-3)}$$

where:
- Cdep = amount of toxicant depositing on the vegetation per kg crop (μg-toxicant / kg-crop)
- Dep = deposition rate on impacted vegetation (μg/m^{2}day)
- IF = interception fraction
- k = weathering constant (d^{-1})
- Y = crop yield (kg/m^2)
- e = base of natural logarithm (~2.718)
- T = growth period (days)

The variate, Dep, is a function of the modeled (or measured) ground level concentration, and the vertical rate of deposition of emitted materials, and is calculated as follows:

$$Dep = GLC \times Dep\text{-}rate \times 86{,}400 \qquad \text{(Eq. 7-4)}$$

where: GLC = ground level concentration of contaminant in air ($\mu g/m^3$)
Dep-rate = vertical deposition rate (m/sec)
86,400 = seconds per day (sec/day)

The ground level concentration is calculated in the air dispersion modeling (see Chapter 2). The deposition rate is assumed to be 0.02 meters per second for a controlled source and 0.05 meters/second for an uncontrolled source (see Chapter 2).

The interception fraction in Eq. 7-3 above is crop specific. The work of Baes et al. (1984), examining the transport of radionuclides through agriculture, describes interception fraction as a factor which accounts for the fact that not all airborne material depositing in a given area initially deposits on edible vegetation surfaces. That fraction will be somewhere between zero and one.

There are no data on interception fraction for leafy and exposed produce but interception fractions for these produce categories were modeled by Baes et al. (1984). Baes et al. used assumptions based on typical methods of cultivating leafy and exposed produce in the U.S., and on the following equations:

$$If_e = 1 - e^{(-0.0324Y_e)}$$
$$If_l = 1 - e^{(-0.0846Y_l)}$$

where:
If_e = interception fraction for exposed produce
If_l = interception fraction for leafy produce
Y = yield of exposed produce (kg/m^2, dry)
Y = yield of leafy produce (kg/m^2, dry).

Baes et al. calculated an average interception fraction of 0.15 for leafy produce and 0.052 for exposed produce. For these guidelines, the interception fractions were rounded off to 0.2 and 0.1 for leafy and exposed produce, respectively.

Some information is available from studies of radioactive isotopes for pasture grasses. The empirical relationship for grasses is given by:

$$IFpg = 1\text{-}e^{-2.88\,Y} \qquad \text{(Eq. 7-5)}$$

where: IFpg = interception fraction for pasture grasses
Y = yield in kg/m^2 (dry)

Assuming that the wet yield is 2 kg/m^2, and 80 percent of the wet weight is water, then the IFpg is approximately 0.7 (Baes et al., 1984). This value compares well with the Baes modeled interception fractions for leafy and exposed produce since grasses are

more densely packed into a given area relative to home grown leafy and exposed produce.

For protected and root produce, there are no known interception fractions (modeled or empirical) and it is difficult to arrive at a wet yield value. OEHHA recommends that the 2 kg/m^2 wet yield value be used for the protected and root categories of produce.

Additional default values for variates in Eq. 7-3 are obtained from *Multi-pathway Health Risk Assessment Parameters Guidance Document* prepared for South Coast Air Quality Management District (Clement Associates, 1988). The weathering constant, k, is based on experimental observations from studies of particulate radionuclides on plant surfaces. This weathering constant does not include volatilization from the leaf surface since the radionuclides used were not volatile, nor does it include biotransformation or chemical transformation on the leaf surface. Baes et al. (1984) describe particulate half-lives ranging from 2.8 to 34 days with a geometric mean of 10 days for radionuclides depositing on plants. OEHHA proposes using a weathering constant of 10 days based on Baes et al. (1984).

The growth period, T, in Equation 7-3 above is based on the time from planting to harvest. OEHHA recommends a value of 45 days for leafy and root crops and 90 days for exposed and protected produce (time from fruit set to harvest). The assumptions in the interception fraction include the issue of increasing surface area with growth. Therefore, no additional adjustment is necessary.

7.~~4~~5.1.3 Translocation from the Roots

The variate, Ctrans, in Equation 7-6, represents the amount of contaminant that is translocated, or absorbed, from the soil into the roots of homegrown crops that are food sources for humans. Once absorbed, the contaminant may accumulate in edible roots (e.g., carrots) and be translocated to other parts of the plant that are consumed including the leaves and fruit. The equation for calculating concentration in the plant from root uptake is as follows:

$$Ctrans = Cs \times UF \qquad \text{(Eq. 7-6)}$$

Where: Cs = concentration in the soil (see Chapter 6)
UF = soil-to-plant uptake factor

The soil-to-plant uptake factor (UF) is the ratio of the fresh weight contaminant concentration in the edible plant or plant part over the total concentration of the contaminant in soil wet weight. The UFs (Eq. 7-6) recommended by OEHHA are from the scientific literature. Due to the large volume of studies investigating metal concentrations in edible plants grown in contaminated soils, OEHHA created a database to assemble the data and calculate UFs. The database and methods used to estimate the UFs are described in Appendix H.

The concentration in the soil (Cs) is calculated as described in Chapter 6 using air dispersion and deposition modeling. The UF for specified metals can then be applied in Eq. 7-6 in order to estimate Ctrans.

Due to lack of root absorption and translocation, the soil-to-plant uptake of organic compounds under the "Hot Spots" program (e.g., dioxins and PCBs) is considered not to be a pathway of contamination. Therefore, the soil-to-plant UFs are currently limited to the inorganic metals and metalloids.

The soil-to-plant UFs of edible plants, shown in Table 7.14~~45.1~~, are divided into four types: leafy, root, protected, and exposed. The foods in each of these produce categories are presented in Appendix D. The classification of edible plants into these four groups reflects the potential differences in contaminant concentrations that may occur in the plant parts resulting not only from soil-to-plant uptake, but also from airborne deposition.

Table 7.~~45.1~~14 Soil-to-plant uptake factors for inorganic metals and metalloids in edible crops[a]

Element	Leafy	Exposed	Protected	Root
Arsenic	1×10^{-2}	2×10^{-2}	7×10^{-2}	8×10^{-3}
Beryllium	2×10^{-4}	8×10^{-3}	3×10^{-4}	5×10^{-3}
Cadmium	1×10^{-1}	2×10^{-2}	1×10^{-2}	8×10^{-2}
Chromium (VI)	3×10^{-1}	2×10^{-2}	7×10^{-2}	3×10^{0}
Fluoride	4×10^{-2}	4×10^{-3}	4×10^{-3}	9×10^{-3}
Lead	8×10^{-3}	7×10^{-3}	3×10^{-3}	4×10^{-3}
Mercury	2×10^{-2}	9×10^{-3}	1×10^{-2}	2×10^{-2}
Nickel	1×10^{-2}	3×10^{-3}	3×10^{-2}	6×10^{-3}
Selenium	6×10^{-2}	4×10^{-2}	3×10^{-1}	7×10^{-2}

[a] Soil-to-plant UFs represent the fresh weight concentration of a contaminant in the plant part over the wet weight concentration of contaminant in the soil.

7.~~4~~5.2 Algorithms used to Estimate Dose to the Food Animal

The general formula for estimating concentrations of contaminants in animal products is as follows:

$$Cfa = [Dinh + Dwi + Dfeed + Dpast + Dsi] \times Tco \qquad \text{(Eq. 7-7)}$$

where:
- Dinh = dose through inhalation (μg/day)
- Dwi = dose through water intake (μg/day)
- Dfeed = dose through feed consumption (μg/day)
- Dpast = dose through pasturing/grazing (μg/day)
- Dsi = dose through soil ingestion (μg/day)
- Tco = transfer coefficient from consumed media to meat/milk products

Ideally, the Tco values would be evaluated separately for the inhalation and oral routes but the data do not exist to separately evaluate the inhalation route. The Tco values are based on oral studies, and are presented in Appendix K, and summarized in Table 7.16 and 7.17~~45.2 and 7.45.3~~.

7.~~4~~5.2.1 Dose via Inhalation

The dose via inhalation is proportional to the concentration of the contaminant in the air and the amount of air breathed by the animal in a single day. It is assumed that 100 percent of the chemical is absorbed. The dose via inhalation is calculated as follows:

$$Dinh = BR \times GLC \qquad \text{(Eq.7-8)}$$

where: Dinh = dose to the animal via inhalation (μg/day)
BR = daily breathing rate of the animal (m^3/day)
GLC = ground level concentration (μg/m^3)

7.4~~5~~.2.2 Dose via Water Consumption

Airborne contaminants depositing in surface water sources of drinking water for food animals can end up in the human food chain. The dose to the food animal from water consumption is proportional to the concentration of the contaminant in the drinking water and the amount of water consumed by the animal daily. In addition, the fraction of the water consumed daily that comes from a contaminated body of water is used to adjust the dose to the food animal. That fraction is a site-specific value that must be estimated for the site. The dose via water consumption can be calculated as follows:

$$Dwi = WI \times Cw \times Fr \qquad \text{(Eq. 7-9)}$$

where: Dwi = dose to the food animal through water intake (μg/day)
WI = water intake rate (L/day)
Cw = concentration of contaminant in water (μg/L)
Fr = fraction of animal's water intake from the impacted source

Cw is calculated as in Chapter 8. Water consumption rates for food animals are shown in Table 7.15~~45.2~~. The fraction of the animals' water intake that comes from the source impacted by emissions is a site-specific variable.

7.4.2.3 Dose from Feed Consumption, Pasturing and Grazing

Airborne contaminants may deposit on pastureland and on fields growing feed for animals. The default assumption is that the feed is not contaminated because most feed would be purchased from offsite sources. However, if feed is produced onsite, the dose from contaminated feed should be determined. Deposited contaminant contributes to the total burden of contaminants in the meat and milk. The dose to the animal from feed and pasture/grazing can be calculated as follows:

$$Dfeed = (1 - G) \times FI \times L \times Cf \qquad \text{(Eq. 7-10)}$$

where: Dfeed = dose through feed intake (μg/day)
G = fraction of diet provided by grazing
FI = feed consumption rate (kg/d)
L = fraction of feed that is locally grown and impacted by facility emissions
Cf = concentration of contaminant in feed (μg/kg) (calculated in Eq. 7-2)

$$Dpast = G \times Cf \times FI \qquad \text{(Eq. 7-11)}$$

where: Dpast = dose from pasture grazing (μg/day)
G = fraction of diet provided by grazing
FI = pasture consumption rate (kg/day)
Cf = concentration of contaminant in pasture (μg/kg)

DMI, kg dry matter intake (feed), is given for food animals in Table 7.15~~45.2~~. The percent of the diet that comes from pasture and feed, and the fraction of feed that is locally grown and impacted by emissions are site-specific variables and values for these variables need to be assessed by surveying farmers in the impacted area. Concentration in the feed and pasture are calculated as in Equations 7-10 and 7-11 above. It is considered likely that feed will come from sources not subject to contamination from the stationary source under evaluation.

Table 7.15~~45.2~~ Point Estimates for Animal Pathway

Parameter	Beef Cattle	Lactating Dairy Cattle	Pigs	Meat Poultry	Egg-laying Poultry
BW (body weight in kg)	533	575	55	1.7	1.6
BR (inhalation rate in m^3/d)	107	115	7	0.4	0.4
WI (water consumption in kg/d)	45	110	6.6	0.16	0.23
DMI (kg/d)[1]	9	22			
Feed Intake			2.4	0.13	0.12
%Sf (soil fraction of feed)	0.01	0.01	NA	NA	NA
%Sp (soil fraction of pasture)	0.05	0.05	0.04	0.02	0.02

[1] Dry matter intake

7.4.2.4 Transfer Coefficients from Feed to Animal Products

The derivation and use of transfer coefficients for specific chemicals is explained in Appendix K. Tables 7.16~~45.3~~ and 7.17~~45.4~~ contain the recommended values for persistent organic chemicals and metals, respectively.

Table 7.~~45.3~~16 Food Animal Transfer Coefficients for Persistent Organic Chemicals

Organic Chemical	**Tcos (d/kg)[a]**				
	Cow's Milk	**Chicken Egg**	**Chicken Meat**	**Cattle Meat**	**Pig Meat**
Diethylhexylphthalate	9×10^{-5}	0.04	0.002	6×10^{-4}	5×10^{-4}
Hexachlorobenzene	0.02	20	10	0.2	0.08
Hexachlorocyclohexanes	0.01	7	5	0.2	0.09
PAHs	0.01	0.003	0.003	0.07	0.06
Polychlorinated biphenyls					
Congener 77	0.001	6	4	0.07	0.4
81	0.004	10	7	0.2	0.4
105	0.01	10	7	0.6	0.7
114	0.02	10	7	0.9	0.7
118	0.03	10	7	1	0.7
123	0.004	10	7	0.2	0.7
126	0.04	10	7	2.	0.7
156	0.02	10	8	0.9	2
157	0.01	10	8	0.5	2
167	0.02	10	8	1	2
169	0.04	10	8	2	2
189	0.005	10	8	0.2	1
Unspeciated	0.01	10	7	0.2	0.5
~~Unspeciated (TEQ-adjusted)~~	~~0.01~~	~~20~~	~~10~~	~~0.7~~	~~0.3~~
PCDD/Fs					
Congener 2378-TCDD	0.02	10	9	0.7	0.1
12378-PeCDD	0.01	10	9	0.3	0.09
123478-HxCDD	0.009	10	6	0.3	0.2
123678-HxCDD	0.01	10	6	0.4	0.1
123789-HxCDD	0.007	7	3	0.06	0.02
1234678-HpCDD	0.001	5	2	0.05	0.2
OCDD	0.0006	3	1	0.02	0.1
2378-TCDF	0.004	10	6	0.1	0.02
12378-PeCDF	0.004	30	10	0.1	0.01
23478-PeCDF	0.02	10	8	0.7	0.09
123478-HxCDF	0.009	10	5	0.3	0.1
123678-HxCDF	0.009	10	6	0.3	0.09
234678-HxCDF	0.008	5	3	0.3	0.06
123789-HxCDF	0.009	3	3	0.3	0.03
1234678-HpCDF	0.002	3	1	0.07	0.06
1234789-HpCDF	0.003	3	1	0.1	0.02
OCDF	0.002	1	0.6	0.02	0.03
Unspeciated	0.001	6	5	0.03	0.09
~~Unspeciated (TEQ-adjusted)~~	~~0.005~~	~~10~~	~~7~~	~~0.2~~	~~0.09~~

[a] All Tco values were rounded to the nearest whole number.
[b] NA – no data available or not applicable

Table 7.~~45~~.~~4~~17 Food Animal Transfer Coefficients for Inorganic and Organic Metals

Inorganic and Organic Metals	Tcos (d/kg)[a]				
	Cow's Milk	Chicken Egg	Chicken Meat	Cattle Meat	Pig Meat
Arsenic	5×10^{-5}	0.07	0.03	2×10^{-3}	0.01[b]
Beryllium	9×10^{-7}	0.09	0.2	3×10^{-4}	0.001
Cadmium	5×10^{-6}	0.01	0.5	2×10^{-4}	0.005
Chromium (VI)	9×10^{-6}	NA[c]	NA	NA	NA
Fluoride	3×10^{-4}	0.008	0.03	8×10^{-4}	0.004[b]
Lead	6×10^{-5}	0.04	0.4	3×10^{-4}	0.001[b]
Mercury ~~Hg(II) only in diet:~~ ~~Inorganic mercury~~ ~~Methyl mercury (MeHg)~~ ~~MeHg only in diet:~~ ~~Inorganic mercury~~ ~~Methyl mercury~~	 7×10^{-5} ~~NA~~ ~~NA~~ ~~7×10^{-4}~~	 0.~~3~~8 ~~0.5~~ ~~NA~~ ~~10~~	 0.~~02~~1 ~~0.09~~ ~~NA~~ ~~10~~	 4×10^{-4} ~~NA~~ ~~NA~~ ~~NA~~	 0.002[b] ~~NA~~ ~~NA~~ ~~NA~~
Nickel	3×10^{-5}	0.02	0.02	3×10^{-4}	0.001
Selenium	0.009	3	0.9	0.04	0.5

[a] All Tco values were rounded to the nearest whole number.
[b] The meat Tco was estimated using the metabolic weight adjustment ratio of 4.8 from cattle to pig
[c] NA – no data available or was not applicable

7.~~5~~6 Default Values for Calculation of Contaminant Concentration in Animal Products

7.~~5~~6.1 Body Weight Defaults

Cows used for milk production will be adults (i.e., full body weight) and females, so only adult female weights should be used for the home produced milk pathway. OEHHA recommends the central tendency weight of 575 kg for the home raised milk cow (midpoint of the adult cow range). A cow or bull raised for home produced beef may be of any age, gender or strain. We recommend 533 kg (midpoint of the beef cattle range) for the home produced beef pathways (National Research Council, 2000). Beef cattle are growing while being raised and thus transitioning through lower body weights to reach the mature body weight. We therefore propose a default central tendency value. Mean pig body weights of 30.9-80 kg at age 13-23 weeks have been reported (Agricultural Research Council, London, 1967). The 4H club encourages children to participate in the home raising of pigs. The 4H club recommends that the pigs weigh between 200 and 240 pounds (90.9 and 109 kg) at the end of the project (http://www.goats4h.com/Pigs.html#weight). OEHHA recommends half of 240 pounds, 120 pounds or 55 kg, as the average weight of the pig while being raised.

The National Research Council (1994) in Table 2.5 lists the weight of broiler chickens by week up to 9 weeks. The weight for the males is 3.5 kg after 9 weeks. The average weight over the 9-week period is 1.7 kg, which is the OEHHA's recommendation for a default body weight for chickens raised for meat. The OEHHA recommends the average weight of white and brown egg laying chickens at 18 weeks to first egg laying (1.5 kg) in Table 2-1 National Research Council (1994) .

7.~~5~~6.2 Breathing Rate Defaults

Animal breathing rate defaults were calculated based upon a relationship of tidal volume to body weight. Each pound of body weight has been reported to correspond to approximately 2.76 ml of tidal volume (2.76 ml/lb ≅ 6.07 ml/kg body weight) (Breazile, 1971). Using this relationship, the default animal body weight, and breathing cycle frequencies provided in Breazile (1971), we generated breathing rates. Reported breathing frequencies for cattle, pigs, and poultry were 18-28, 8-18, and 15-30 respirations per minute, respectively. The body weight defaults described above were used in the calculations. Use of these values generated a range of breathing rates and the default value was derived as the average of the range limits. Default breathing rates for dairy cattle, beef cattle, pigs, and poultry are 116, 107, 6.2, and 0.33 m^3/day, respectively. The default value for cattle falls within the range of that reported by Altman et al. (1958).

7.~~5~~6.3 Feed Consumption Defaults

Backyard farmers could raise cattle, swine, and chickens from birth to early adulthood for meat. There is a large change in body weight that correlates with feed-consumption rates during that period of the animal's life. For meat animals, the OEHHA attempted to identify the consumption rate at the mid-point of the meat animals' pre-slaughter life span. In contrast, the adult cows and chicken that produce milk and eggs have relatively constant feed-consumption rates and body weights. For these cows and chickens, OEHHA attempted to identify the consumption rate of the fully-grown adult.

OEHHA's risk assessment model assumes that the source contaminates the pasture or hay from that pasture. A regulated source could contaminate a pasture that provides a cow with 100 percent of its nutrition. In contrast, homeowners usually procure feed for backyard swine and chicken that is produced off-site. Therefore, the default assumptions are that the regulated source contaminates 0 percent of the swine or chicken feed, and 100 percent of cows' feed. Site-specific conditions may require that different percent contamination be used.

7.~~5~~6.3.1 Bovine Feed Ingestion

Most published literature on bovine feed ingestion is on commercial production. While the backyard and commercial animals are the same breeds, the feeding patterns can be different. It is likely that home raised cattle will be fed a higher percentage of forage, for example. DMI is the feed consumption rate with the units of kilograms feed per day

(kg/d). Feed is dried before it is weighed to obtain a DMI because water content varies. The NRC identifies several factors that affect DMI (NRC, 2001). These include fiber content of the forage, initial size of the animal, and time preceding parturition. Two types of feed are reported in the literature: forage (grass, hay, alfalfa, etc.) and concentrate (high-energy feeds like corn, soybean or oats). As concentrate increases, consumption of forage decreases.

As the animal gets larger, it eats more food; therefore, DMI is correlated with body weight. Body weight does not change greatly during the majority of the milk producing years of dairy cows. Therefore, we assume the backyard dairy cow consumes the same amount as those in the studies described below. In contrast, the body weight of beef cattle varies greatly as they grow from calves to adults. Papers often report the starting body weight for beef cattle. OEHHA selected peer-reviewed papers in which DMI was reported with adequate description of the methods. DMI was measured in these studies but was not necessarily the objective of the study.

Cows eat about as much pasture as they do hay or silage. Holden et al. (1994) compared DMIs of pasture, hay, and silage in three non-lactating, non-pregnant dairy cows. The pasture was identical to that used for the hay and silage. The cows ate pasture, hay, and silage in sequential 19-day exposures. Chromium oxide, an indigestible component of vegetation, was used to estimate consumption. This study showed that fecal chromium oxide accurately predicts DMI of hay and silage. More importantly, intake rates (kg/d) showed no difference among pasture, silage or hay using fecal chromium oxide estimates. Therefore, OEHHA selected studies that measured silage or hay consumptions assuming they are the same as pasture consumption.

Britt et al. (2003) measured DMI in 13 herds of lactating Holstein dairy cows in Kentucky, Tennessee, and Mexico at different times throughout the year. The mean ± standard deviation of 34 measurements is 21.8 ±1.6 kg/day with a range of 16.8 to 24.5. Holcomb et al. (2001) reported an average DMI for 40 Holsteins of 21.6 kg/day. Rastani et al. (2005) measured DMI for 20 weeks around birth. Ten weeks prior to birth, the DMI was 20 kg/day and gradually decreased to 10 kg/day at birth, and then it gradually increased to 23 kg/day ten weeks post-partum. The OEHHA recommendation for DMI for dairy cows is 22 kg/day, the mean of these three reports.

As described in the Bovine section above, a number of factors influence the uncertainty and variability of pasture DMI of backyard dairy cows. As Rastani et al. (2005) show, lactating cows consume about twice as much as cows not lactating. We did not consider non-lactating cows since milk is the vehicle of human exposure. Cows fed supplements such as corn, soybean, or oats would eat less pasture.

The NRC (2000) has developed an equation predicting DMI based on the energy content in mega-calories per kg of dry matter of the forage (Mcal/kg). A graph of DMI vs. energy content using this equation peaks at about 9 kg/d with cows fed medium energy content forage. The DMI gradually decreases to about 7.6 kg/day with both high

and low energy content forages. A second graph in the NRC report shows DMI plotted against initial body weight. The smallest steers (200 kg) ate the least (4 kg/d) and larger animals ate the most (12 kg/d for 350 kg steers). Burns et al. (2000) reported DMI in six Angus steers (initial mean BW = 334 kg) fed with an average DMI of 9.7 kg/d. Stanley et al. (1993) measured DMI in four Hereford x Angus cows at seven time points. The total duration was 83 days during which there was a linear increase in DMI from 8.8 to 14.9 kg/day. Unfortunately, the authors did not report body weights at the seven time points. OEHHA recommends a default DMI of 9 kg/day for cattle home raised for beef to estimate average food consumption during the home raising period.

The uncertainties described for dairy cows apply to beef cattle. In addition, DMI correlates with body weight and the body weight varies greatly in beef cattle grown from calves to young adults for slaughter. The OEHHA value is an average over this period. It could over-estimate intake if calves are slaughtered for veal or under-estimate intake of cattle slaughtered long after reaching maturity.

7.~~5~~6.3.2 Swine Feed Ingestion

Since it is likely that most backyard swine would eat feed produced off-site, this exposure pathway to the swine should be included only when feed is grown on-site. OEHHA assumes people obtain backyard swine as weanlings and slaughter them at early adulthood when they weigh about 110 kg. The food consumption varies with body weight and calorie density of the feed. The NRC has developed a mathematical model from simultaneous observations of body weight and feed intake of a nutritionally adequate corn/soybean mix to over 8,000 swine. The model (NRC, 1998) predicts the digestible energy requirement (in kcal/day) as a function of body weight (from 10 to 120 kg). The equation predicts that swine at the average body weight of 55 kg would require about 8000 kcal/d. Corn has a digestible energy content of about 3,300 kcal/kg (Feoli et al.(2007). Thus, a 55 kg swine would consume about 2.4 kg/d.

Generally, backyard swine consume restaurant waste or other feed not produced on-site. Therefore, risk assessors should assume the amount of contaminated feed consumed by backyard swine is zero, as the default. If the dry weight digestible energy content of this feed is known, it can be used to convert 8,000 kcal into kg of feed consumed per day. When swine eat supplements not raised on-site, the risk assessor will need to determine the fraction of feed raised on-site.

7.~~5~~6.3.3 Chicken Feed Ingestion

Since most backyard chickens would eat feed produced off-site, this exposure pathway for chickens should be included only when chickens' feed is known to be grown on-site. Chicken feed consumption from onsite could contaminate the meat and/or eggs.

7.~~5~~6.3.4 Feed Ingestion by Chickens Raised for Meat

Ingestion of homegrown feed by chickens, which are home-raised for meat, is only an exposure pathway if the feed is also grown on site, which is unlikely. If the feed is grown on site then the following feed consumption value is provided. The National Research Council (1994) report in Table 2.5 of their document shows data on chicken food consumption for broilers from one to nine weeks of age. Males, the most likely to be eaten by homeowners, weigh 3.5 kg at 9 weeks and consume 0.23 kg/d of feed. Males at the midpoint, 4 weeks, weigh 1 kg and consume 0.132 kg/d. If only a fraction of the feed at a particular site is grown on site, this fraction should be used to reduce the consumption rate.

7.~~5~~6.3.5 Laying Hen Feed Ingestion

Ingestion of homegrown feed by chickens home raised for eggs is only an exposure pathway if the feed is grown on site, which is unlikely. If the feed is grown on site, then the following feed consumption value is provided. Table 2.2 of the NRC report (1994) shows consumption rates for laying hens from 2 to 20 weeks of age. At 20 weeks, the average weight of strains laying brown eggs and strains laying white eggs is 1.6 kg and the average food consumption at 20 weeks is 0.12 kg/d, which is recommended as the default for egg laying chickens. If only a fraction of the feed which chickens at a particular site ingest is grown on site, this fraction should be used to reduce the consumption rate.

7.~~5~~6.4 Water Consumption Defaults

Water consumption for home raised beef cattle, dairy cattle, pigs, and chickens would be an exposure pathway for these animals only if surface waters are used as a water source (e.g., a farm pond). If municipal or well water were used, the water supply would not be contaminated by the facility under evaluation under the assumptions of the Hot Spots risk assessment model.

7.~~5~~6.4.1 Bovine Water Consumption

Literature reported bovine water intake rates are generally expressed in relation to dry matter consumption on a weight basis. Water intake also generally increases with increasing temperature. Water intakes for cattle of 3.1-5.9 kg/kg dry matter at temperatures ranging from 12°C to 29.4°C have been reported (Winchester and Morris, 1956, as summarized by the Agricultural Research Council, London, 1965).

Water intakes of 6.6-10.2 kg/kg dry matter consumed for shorthorn cows at 27°C and 3.2-3.8 kg/kg dry matter consumed at 10°C have been reported (Johnson et al., 1958). Water intake for shorthorn cows at 18-21°C of 4.2-5.0 kg/kg dry matter consumed have also been reported (Balch et al., 1953). Water intake at lower temperatures (-18 to 4°C) of 3.5 kg/kg dry matter consumed has also been reported (MacDonald and Bell, 1958).

Friesian cattle water intake was estimated at 3.3-4.3 kg/kg dry matter consumed (Atkeson et al., 1934).

The National Research Council (2001) has several equations for calculating water intake of dairy cows that take into account ambient temperature, sodium intake, DMI, and milk production to produce a refined estimate of water intake. Given the feed intake for both non-lactating and lactating cattle as described above, a reasonable default estimate of water consumption is approximately 5-fold the dry matter consumption. If this exposure pathway to beef cattle or dairy cows is applicable, the resulting default water consumption rates for beef cattle and lactating dairy cattle are 45 and 110 kg/day, respectively.

7.~~5~~6.4.2 Swine Water Consumption Rates

Water consumption has been estimated for pigs at 1 kg/day for 15 kg pigs, increasing to 5 kg/day at 90 kg body weight (Agricultural Research Council, London, 1967). Non-pregnant sow water consumption was estimated at 5 kg/day, pregnant sows at 5-8 kg/day, and lactating sows at 15-20 kg/day. The National Research Council (1998) estimates 120 mL water/kg BW day for growing (30 to 40 kg) nonlactating pigs and 80 mL water/kg BW-day for nonlactating adult pigs (157 kg). A default value of 6.6 L/day is recommended based on the 120 mL/kg BW day figure in the National Research Council (1998).

7.~~5~~6.4.3 Water Consumption Rates by Chickens

The water consumption exposure pathway would only be applicable as an exposure pathway for chickens if surface water were used as a drinking water source (e.g., a farm pond). If municipal water or well water is used as the water supply for home raised chicken, the water is assumed uncontaminated from airborne emissions of a facility. Water consumption by chickens has been reported to fall in the range of 1-3 times the food consumption on a weight basis (Agricultural Research Council, London, 1975). They established a 2:1 ratio of water to feed consumption as the default value. Given a daily feed consumption rate of 0.1 kg/day, the resulting daily water consumption rate for chickens is 0.2 kg/day.

The National Research Council (1994) estimated water consumption over an eight-week period for broilers and brown egg layers. The average water consumption rate is 0.16 L/day for broilers. The daily water consumption rate is 0.23 L/day for brown egg layers at 20 weeks (National Research Council, 1994). A default water consumption rate of 0.16 L/day is recommended for broilers and 0.23 L/day is recommended for egg laying chickens, if the water exposure pathway is applicable to chickens.

7.~~5~~6.5 Soil Ingestion Defaults

Soil ingestion was estimated for dairy cattle based upon fecal titanium content (Fries et al., 1982). Among yearling heifers and non-lactating cattle receiving feed (vs. pasture),

soil ranged from 0.25 to 3.77 percent of dry matter ingested, depending on the management system used, with those cattle with access to pasture having the greatest soil ingestion. For cattle on feed, a reasonable estimate of 1 percent soil ingestion was made. For cattle grazing pasture, soil intake estimates of 4-8 percent dry matter ingestion have been made for cattle receiving no supplemental feed (Healy, 1968).

Soil ingestion varies seasonally, with the greatest soil ingestion during times of poor plant growth (14 percent) and the least soil ingestion during lush growth (2 percent). In a study of several farms in England, beef and dairy cattle were found to have soil ingestion rates ranging from 0.2 to 17.9 percent of dry matter consumed, depending both on the location and the time of year (Thornton and Abrahams, 1983). The two largest sets of data evaluated showed a range of soil ingestion of 1.1-4.4 percent dry matter consumed. Thus, a reasonable estimate of soil ingestion by beef and dairy cattle as percent of pasture consumed is 5 percent.

Soil ingestion estimates have been made for pigs (Healy and Drew, 1970). A mean weekly soil ingestion estimate of 1 kg soil/week was made for pigs grazing swedes (rutabaga), corresponding to 0.014 kg soil/day. Other estimates for animals grazing swedes, swedes with hay, and pasture only were 0.084, 0.048, and 0.030 kg soil/day, respectively. Assuming total feed ingestion of 2 kg/day, the soil ingestion as percent of grazed feed (pasture) ranged from 1.5 to 7 percent, with a best estimate of 4 percent. In the absence of information concerning soil content of feed for pigs, no estimate has been made for soil ingestion from feed. For risk assessment purposes, pigs are assumed to consume 4 percent soil from pasture ingestion.

As a digestive aid, chickens normally consume approximately 2 percent grit in their diet (McKone, 1993). This value was used as an estimate of the fraction of soil ingestion for chickens with access to pasture. Chickens were assumed to have access to pasture/soil and therefore, no estimate was made for soil ingestion strictly from feed.

7.~~6~~7 Fraction of Food Intake that is Home-Produced

The Child-Specific Exposure Factors Handbook (USEPA, 2008) has information on the fraction of food intake that is home produced (Table 13.6). This information is from a U.S. EPA analysis of the 1987-1988 National Food Consumption Survey. The Table contains information on a number of specific home produced items as well as broad categories such as total vegetables and fruits.

Table 7.18~~67.1~~ Fraction of Food Intake that is Home-Produced

	All Households	Households that Garden	Households that Farm
Total Fruits	0.04	0.101	0.161
Total Vegetables	0.068	0.173	0.308
Avg. Total Veg & Fruits	0.054	0.137	0.235
	All Households	Households that Raise Animals/Hunt	Households that Farm
Beef	0.038	0.485	0.478
Pork	0.013	0.242	0.239
Poultry	0.011	0.156	0.151
Eggs	0.014	0.146	0.214
Total Dairy	0.012	0.207	0.254

The data on the fraction of food intake that is home produced are older than would be considered optimal and there is no data on variability in percent consumption in the populations of concern. There are many factors that could affect the percent of home-produced fruits and vegetables. These may include lot size, employment status, avidity and income. As a default for home-produced leafy, exposed, protected and root produce, OEHHA recommends 0.137 as the fraction of produce that is home raised (Table 7.18~~67.1~~). The households that grow their own vegetables and fruits are the population of concern. In rural situations where the receptor is engaged in farming, OEHHA recommends 0.235 as the default value for fraction of leafy, exposed, protected and root produce that is home produced.

OEHHA recommends the fraction home-raised under “Households that raise animals/hunt” (Table 7.18~~67.1~~) for beef, pork, poultry (chicken), eggs and dairy (milk), with the exception of rural household receptors engaged in farming. OEHHA recommends that the fractions listed under “Households that farm” be used for the rural household receptors.

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8. Water Intake Exposure Pathway

8.1 Introduction

Surface water can serve as a source of domestic water in some locations, particularly rural areas. Airborne contaminants from facilities can deposit directly on surface water bodies, thus exposing humans to contaminants through water consumption. Hot Spots facilities having non-municipal surface bodies of water, which are within the facility's zone of impact and which are used as a source of drinking water, need to include the water pathway in their risk assessments. Note that this pathway is rarely invoked for typical facilities in the Air Toxics Hot Spots program. Hot Spots risk assessments do not include municipal or commercial water sources. Municipal water is excluded because surface reservoirs are generally so large that contaminants from a single source become highly diluted once they enter the surface water body. Further, the level of some contaminants in municipal water may be reduced by water treatment processes typically used for municipal water supplies.

OEHHA does not recommend water pathway algorithms for municipal water source evaluation because the simple model used in the Hot Spots program is not adequate for this purpose. In these guidelines, the algorithm for calculating the water concentration of contaminants only includes that amount of chemical that directly deposits onto the surface of the water and not amounts that deposit in the soil and then enter the water body via runoff. It is assumed that contaminants initially deposited onto the water body surface remain suspended in the water column.

Water can be consumed by individuals through various forms of foods and beverages. For Hot Spots program risk assessments we will only consider plain drinking water, water added for reconstituting foods and beverages, and water absorbed by food during cooking. This is because these foods and beverages could be made with water from a non-municipal surface water body. We will not consider water from commercial food or drink, or water that occurs naturally in fresh foods (e.g., water in an apple). The reasons for these exclusions are given in the paragraph above.

8.2 Recommendations [This section was moved from the back of the chapter to the front.]

8.2.1 Point Estimate Approach

Currently there are no water intake distributions specific for California residents. However, OEHHA's derived water intake rate distributions provide a reasonable basis for exposure assessments of the California population. Chemical specific properties such as volatility may influence alternate route exposures via tap water, e.g., by bathing, showering, flushing toilets, etc. In the Air Toxics "Hot Spots" program, these exposure routes are currently not considered. However, they are treated in Superfund risk assessments where ground water contamination is a larger issue. The following recommendations are based on currently available data. Depending on the nature of

the analysis one or more of the recommendations may apply.

For ages involving infants, OEHHA recommends using intake rates based on reconstituted formula intake. This is to protect the sizable subpopulation of infants who typically receive significant amounts of water through reconstituted formula. Breastfed infants, particularly during the first 6 months of age, are essentially non-consumers of water, and should not be included in the derivation of water intake rates designed to protect exposed infants.

For cancer risk assessment, the cancer risk estimates for exposures in the third trimester and from 0<2 years are weighted by an age sensitivity factor of 10 and exposures for the 2<16 year age groups are weighted by an age sensitivity factor of 3 (OEHHA, 2009). These age groups do not completely fit the 0-9, 0-30, and 0-70 year exposure duration scenario age groups. In order to properly weight for these periods and evaluate risk over each of the exposure duration scenarios, water intake rates specific for the third trimester, 0<2, 2<9, 2<16, 16-30, and 16-70 year age groups are needed. For example, for the 0-9 year scenario, intake rates are needed for the third trimester and the period from 0<2 year (for which the cancer risk will be weighted 10X), and intake rates are needed for the 2-9 year period (for which the cancer risk will be weighted 3X). Likewise, for the 0-30 year scenario, rates are needed for the third trimester, and 0<2 year, 2<16 year, and 16-30 year periods, while for the 0-70 year scenario, rates are needed for the 0<2, 2<16, and 16-70 year periods. OEHHA has derived water intake rates for these additional age groups using the steps and methods outlined in Section 8.2.9 ("OEHHA Derived Water Intake Rates") below.

Table 8.1 presents recommended point estimate water intake rates for Air Toxics Hot Spots risk assessments. The derivation is described below in section 8.4.13.

Table 8.1 Recommended Point Estimate Tap Water Intake Rates (ml/kg-day)

Point Estimates				
Using Mean Values	**For the Age Period**	**9-year scenario**	**30-year scenario**	**70-year scenario**
	3rd trimester	18	18	18
	0<2 years	113	113	113
	2<9 years	26	-	-
	2<16 years	-	24	24
	16-30 years	-	18	-
	16-70 years	-	-	18
Using 95th-percentile values	**For the Age Period**	**9-year scenario**	**30-year scenario**	**70-year scenario**
	3rd trimester	47	47	47
	0<2 years	196	196	196
	2<9 years	66	-	-
	2<16 years	-	61	61
	16-30 years	-	47	-
	16-70 years	-	-	45

8.2.2 The Stochastic Approach

When using distributions it is appropriate to truncate them to avoid impossibly large or small values. For drinking water ingestion, the minimum should be set to zero while the maximum should be set to the maximum value listed in Table 8.11.

Recommended water intake rates for stochastic analyses are presented in Table 8.2.

Table 8.2 Recommended Distributions of Tap Water Intake Rates (ml/kg-day) for Stochastic Risk Assessment

	9-year scenario	30-year scenario	70-year scenario
0<2 years	**Max Extreme** Likeliest = 93 Scale = 35	**Max Extreme** Likeliest = 93 Scale = 35	**Max Extreme** Likeliest = 93 Scale = 35
2<9 years	**Weibull** Location = 0.02 Scale = 29 Shape = 1.3		
2<16 years		**Gamma** Location = 0.19 Scale = 15.0 Shape = 1.6	**Gamma** Location = 0.19 Scale = 15.0 Shape = 1.6
16-30 years		**Gamma** location=0.49 scale=13.6 shape=1.26	
16-70 years			**Beta** min=0.17 max=178 alpha=1.5 beta= 12.9

8.2.3 Recommended Water Intake Rates for ~~Pregnant and~~ Lactating Subpopulations

OEHHA also recommends water intake rates specific ~~for pregnant and~~ for lactating subpopulations. These recommendations are presented in Table 8.18 in Section 8.5.2. In the point estimate approach, the mean and 95th percentile intake rate for lactating women should be used for the drinking water exposure of a mother when evaluating contaminant concentrations in breast milk. For stochastic analyses, OEHHA recommends using the percentile data for ~~the pregnant and~~ the lactating subpopulations in Table 8.18 and fitting each to distributional models using the procedure outlined in Sections 8.4.13 and 8.4.14. Although the same study derived water intake rates for pregnant women, we utilized the water intake rates for adults ages for the third trimester as they were slightly more health protective than the values derived for pregnant women by U.S. EPA (2004) and presented in Section 8.5.2 below.

8.2.4 Recommended Water Intake Rates for High Activity Levels / Hot Climates

For groups who may be highly physically active or who may live or work in hot climates, OEHHA recommends using the 95th percentile value in Table 8.1 for the age group for which the sensitive endpoint has been identified. For stochastic analyses, OEHHA recommends using the distributions for 9-year or 30-year scenarios in Table 8.2.

8.3 Water Intake Algorithm

The equation to calculate contaminant concentration in surface water for the Air Toxics "Hot Spots" risk assessment model is:

$$Cw = GLC * Dep\text{-}rate * 86{,}400 * SA * 365 / (WV * VC) \qquad \textbf{(Eq. 8-1)}$$

where: Cw = Average concentration in water (µg/kg)
GLC = Ground-level concentration of the pollutant (µg/m^3)
Dep-rate = Vertical rate of deposition (m/sec) (0.02 meters/second for controlled, or 0.05 meters/second for uncontrolled, sources.)
86,400 = Seconds per day conversion factor (sec/d)
SA = Water surface area (m^2)
365 = Days per year (d/yr)
WV = Water volume (kg) (1L = 1 kg)
VC = Number of volume changes per year

Site-specific values for SA, WV, and VC are needed for evaluating the surface water exposure pathway and can be estimated from data collected on-site or public data sources. The equation assumes that all material deposited into the water remains in the water column and that the deposition rate remains constant for a 9, 30 or 70-year exposure duration.

Estimating the daily oral dose of contaminants via the water intake pathway requires information on typical daily water intake of individuals. Typical water intake varies among individuals. Characterizing this inter-individual variability allows more accurate estimates of average and high end intake as well as characterizing a range of exposures to the population.

Water intake can be classified as tap water or total water. Tap water is water consumed directly from the tap (i.e., plain drinking water) as well as water used to reconstitute beverages (e.g., coffee, OJ) or foods (e.g., baby cereal), and water absorbed during cooking of foods (e.g., cooked oatmeal) in the home or at a food service establishment (e.g., school, restaurant). "Total water" consists of tap water, plus water found naturally in foods (e.g., in a fresh apple), and water that is in commercial beverages (e.g., soft drinks) and foods (e.g., canned spaghetti). The term "direct" is used by the USEPA (2008) to describe tap water consumed from the tap. The term "indirect" is used to describe tap water used to make foods or beverages. Water in purchased items such as canned soup and intrinsic water in items such as lettuce were not included in the indirect category.

For the Hot Spots program, we are interested in tap water intake rates of consumers. We use tap water intake rates because tap water does not include water from commercial sources and from fresh foods. Commercial food and beverages are excluded because they are almost certainly prepared using water from municipal sources and because commercial food and drink are typically from diverse sources

resulting in minimization of the likelihood of a person being exposed from a single source (i.e., facility). Water in fresh foods is excluded because it does not come from a local water source. We use consumer-only data because consumers are the population being exposed. Thus, for example, data from non-consumers, such as individuals who exclusively drink bottled water, would be excluded from the data we use to quantify water intake rates.

The sources for tap water are municipal (public) water, household wells or cisterns, and household or public springs. The Hot Spots program water pathway risk assessments apply to water obtained from non-municipal surface water sources. Because non-municipal surface water is delivered via the tap (faucet) to consumers, and because most studies that have measured water consumption do not specify non-municipal surface water sources, we will use "tap" water data for the estimation of intake rates. For stochastic evaluation of exposures from the water pathway, probability distributions reflecting variability within the population are needed, where data permit. There are intake data that are available in ml/kg-day. By normalizing water intake by body weight, the variability associated with the correlation between water intake and body weight is reduced.

Historically, when estimating exposures via drinking water, risk assessors assumed that children ingest 1 liter/day of water, while adults ingest 2 liters/day (NAS, 1977). These values have been used in guidance documents and regulations issued by the U.S. Environmental Protection Agency (U.S. EPA). The purpose of this section is to briefly assess data on water intake rates for use in stochastic types of exposure assessments that employ distributions of water intake. In addition, point estimates of intake can be identified from the distribution and used in the point estimate approach of Tier 1 and 2.

The algorithm for determining dose from surface drinking water sources is:

$$DOSEwater = 1 \times 10^{-6} * Cw * WIR * ABS * Fdw * EF \cancel{* ED/AT} \qquad \textbf{(Eq. 8-2)}$$

where:
DOSEwater = daily oral dose of contaminant, mg/kg-d
1×10^{-6} = conversion factor (1 mg/1000 µg) (1L/1000 ml)
Cw = Concentration of contaminant in drinking water, µg/L
WIR = Water intake rate for receptor of concern in ml/kg BW-day
ABS = GI tract absorption factor (default = 100%)
Fdw = Fraction of drinking water from contaminated source (default = 100%)
EF = Exposure frequency (days/year)

In practice, the GI tract absorption factor (ABS) is only used if the cancer potency factor itself includes a correction for absorption across the GI tract. It is inappropriate to adjust a dose for absorption if the cancer potency factor is based on applied rather than absorbed dose. The Fdw variate is always 1 (i.e., 100%) for Tier 1 screening risk assessments. This variate may only be adjusted under Tier 2-4 risk assessments. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) following US EPA (1991).

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASF) and the chemical-specific cancer potency factor (POTENCY):

RISKwater = DOSEwater *POTENCY*ASF*ED/AT **(Eq. 8-3)**

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (see OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the DOSEwater and ED are different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = Exposure duration (years):

0.25 yrs for third trimester (ASF = 10)
2 yrs for 0<2 age group (ASF = 10)
7 yrs for 2<9 age group (ASF = 3)
14 yrs for 2<16 age group (ASF = 3)
14 yrs for 16<30 age group (ASF = 1)
54 yrs for 16-70 age group (ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKwater_{(lifetime)} = RISKwater_{(3rdtri)} + RISKwater_{(0<2\ yr)} + RISKwater_{(2<16\ yr)} + RISKwater_{(16\ yr\ onward)} \quad \textbf{(Eq. 8-4)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk for a 9 year residential exposure scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$RISKwater_{(9\text{-}yr\ residency)} = RISKwater_{(3rdtri)} + RISKwater_{(0<2\ yr)} + RISKwater_{(2<9\ yr)} \quad \textbf{(Eq. 8-5)}$$

For the 30-year residential exposure scenario, risk for the 2<16 and 16<30 age groups would be added to risks for exposures in the third trimester and ages 0<2 years.. For the 70 year lifetime risk, Eq 8-4 would apply.

~~BW = body weight (kg)~~
~~AT = averaging time (days), to assess carcinogenic risk:~~
~~90 days for third trimester~~
~~730 days for 0<2 yr age group~~
~~2554 days for 2<9 age group~~
~~5110 days for 2<16 yr age group~~
~~5110 days for 16<30 age group~~
~~19,711 days for 16-70 yr age group~~

8.~~2~~ 4 Water Intake Rate Studies

Water intake rates have been estimated through the collection of empirical (measured or self-reported) intake data. Some studies have modeled these data by fitting them to distributions. Both U.S. EPA and Cal/EPA (OEHHA) have reviewed and made recommendations for water intake rates in their exposure guidelines. In this section (8.~~2~~4) we will present background on the major studies that have collected or modeled water intake rate data as well as summarize U.S. EPA (Exposure Factors Handbooks) and OEHHA (Air Toxics "Hot Spots" Program Exposure and Stochastic guidelines) exposure guidelines. We review and present water intake values in ml/kg-day because these rates are needed for Equation 8.2 (above). The studies and guidelines are presented chronologically, below. We also describe and present the estimates derived by OEHHA for the current guidelines.

It is important to note that currently available water intake data were collected over short-term periods (one to three days). These data do not reflect long-term typical water intake rates because repeated measures are not available on the same individual over long periods. Therefore, the variability of currently available estimates includes both intra- and inter-individual variability. These two types of variability cannot be separately evaluated with the current data. The average long term intake is better estimated by such data than high end intake.

8.~~2~~4.1 Canadian Ministry of National Health and Welfare (1981)

The Canadian Ministry of National Health and Welfare (1981) study was conducted in the summer of 1977, the winter of 1978, and involved 970 individuals in 295 households. Interview and questionnaire techniques were used to determine per capita intake of tap water in all beverages (water, tea, coffee, reconstituted milk, soft drinks, homemade alcoholic beverages, etc.). Patterns of water intake were analyzed with respect to age, sex, season, geographical location, and physical activity. Average daily intake rates by age group are presented in Table 8.~~1~~ 3 (below). OEHHA did not use data from the Canadian study because the overall climate of Canada tends to be colder than California, the estimates are not likely representative of the current demographics of the U.S. population, and the raw data necessary to determine distributional characteristics were not available.

Table 8.3 Average Daily Water Intake (ml/kg-day) from the Canadian Ministry of National Health and Welfare (1981)

Age	Females	Males	Both sexes
<3 years	53	35	45
3-5 years	49	48	48
6-17 years	24	27	26
18-34 years	23	19	21
35-54 years	25	19	22
55+ years	24	21	22
All Ages	24	21	22

8.~~2~~4.2 Ershow and Cantor (1989), Ershow et al. (1991)

The Ershow and Cantor (1989) and Ershow et al. (1991) studies analyzed drinking water intake rates using the 1977-1978 Nationwide Food Consumption Survey (NFCS) data. Tap water intakes include tap water consumed as plain water and tap water added, while at home or at restaurants, in the preparation of food and beverages. There were approximately 20,000 study participants. Data were analyzed by age group, sex, season, and geographic region (including the Western Region), and separately for pregnant women, lactating women, and breast-fed children. Intakes were normalized to body weight using self-reported body weights. Because the Western Region estimates of the NFCS most closely reflect intake patterns of California, the Western Region estimates were recommended in the prior version of the Air Toxics Hot Spots Program Stochastic and Exposure guidelines (OEHHA, 2000).

The Western Region estimates are presented by age group in Table 8.~~2~~4. These estimates are based on about 16 percent of the total data set. Note that the traditional assumption of 2 liters daily water intake for a 70 kg body weight person corresponds to approximately the 75th percentile on Ershow and Cantor's distribution (28 ml/kg-day, see Table 8.~~2~~4). Table 8.~~3~~ 5 summarizes the intake estimates for pregnant women, lactating women, and breast-fed children of the Ershow and Cantor study. Though the Ershow and Cantor (1989) and Ershow et al. (1991) studies presented extensive analyses of the NFCS data, more recent intake data that more closely reflect current water intake patterns are now available.

Table 8.~~2~~ 4 Tap Water Intake Rates (ml/kg-day) of the Western Region, from Ershow and Cantor (1989) [1]

	Mean (SD)	50%	75%-ile	90%-ile	95%-ile
All Ages	24 (17)	21	30	43	54
< 1 year	53 (51)	39	67	106	141
1-10 years	39 (24)	34	49	70	88
11-19 years	18 (11)	17	24	32	39
20-64 years	21 (12)	19	27	37	44
65+ years	23 (10)	21	28	37	42

[1] Pregnant and lactating women, and breast-fed children excluded

Table 8.~~3~~ 5 Tap Water Intake Rates (ml/kg-day) for Control, Pregnant and Lactating Women, and Breast-fed Children, from Ershow et al. (1991) [1]

	Mean (SD)	50%	75%-ile	90%-ile	95%-ile
Control [1]	19 (11)	17	24	33	29
Pregnant	18 (10)	16	24	35	40
Lactating	21 (10)	21	27	35	37
Breast-fed	22 (25)	12	38	56	60

[1]Control = women 15-49 years age who were not pregnant or lactating

8.~~2~~4.3 Roseberry and Burmaster (1992)

Roseberry and Burmaster fit lognormal distributions to the datasets of Ershow and Cantor (1989) (discussed above). In tabulating the data they adjusted the data that were originally collected in 1977-78 to better represent the U.S. age group distribution of 1988. Although this study provided distributions of water intake, which is an essential component of stochastic analyses, OEHHA chose to not use these estimates because more recent water intake data are available. Further, the estimates are not normalized to body weight so they cannot be used or compared to the water estimates recommended in this document.

8.4.4 Levy et al. (1995)

Levy et al. (1995) evaluated fluoride intake of infants at 6 weeks, and 3, 6, and 9 months of age. At 6 weeks age, the sample size was 124, while at 9 months of age it was 77. Mothers were asked to record the average number of ounces of water per day over the past week that the infant consumed as plain water or that were used to make formula, juices and other beverages, baby food, cereal, and other foods consumed by the infant. These amounts were used to determine water intake. However, we did not use data from this study because only the mean and range were reported and because results were given as ounces per day (i.e., intake rates were not normalized to body weight).

8.~~2~~4.5 Exposure Factors Handbook (U.S. EPA, 1997)

The U.S. EPA's Exposure Factors Handbook (EFH) (U.S. EPA, 1997) reviewed water intake studies conducted before 1997 and made recommendations for water intake rate values in U.S. EPA risk assessments. The EFH (1997) used three key studies as the basis for their water intake recommendations: Canadian Ministry of National Health and Welfare (1981), Ershow and Cantor (1989), and Roseberry and Burmaster (1992) (see above). These studies were selected based on the applicability of their survey designs to exposure assessment of the entire United States population. U.S. EPA recommended 21 ml/kg-day as the average tap water intake rate for adults. This value is the population-weighted mean of the data from the Canadian Ministry of National Health and Welfare (1981) and Ershow and Cantor (1989). For the high-end adult value, U.S. EPA averaged the 90th percentile values from the same two studies to obtain a value of 34.2 ml/kg-day. The U.S. EPA recommended using the estimates of Roseberry and Burmaster (1992) for a characterization of the lognormal distribution of water intake estimates. However, U.S. EPA cautioned against using Roseberry and Burmaster (1992) for post-1997 estimates since these distributions reflect 1978 data adjusted to the U.S. age distribution of 1988. In addition to intake rates for adults, U.S. EPA also provided a table of intake rates for children, by age category, also from Ershow and Cantor (1989) and the Canadian Ministry of National Health and Welfare (1981).

OEHHA chose to not use the U.S. EPA (1997) estimates for current Hot Spots Stochastic and Exposure Guidelines (the current document) because more recent data are available and different age groupings are needed for OEHHA's current guidelines.

It should be noted that the USEPA released an external review draft of an updated Exposure Factors Handbook in 2009. The final version of the Exposure Factors Handbook was released in October, 2011 (USEPA, 2011).

8.~~2~~4.6 OEHHA (2000) Exposure Assessment and Stochastic Analysis Guidance

The previous version of the Hot Spots Exposure and Stochastic guidance (2000) recommended the "Western Region" water intake values of Ershow and Cantor (1989), which are presented in Table 8.~~2~~ 4 (above). The Western Region was considered more applicable to California than the entire U.S. due to climate and lifestyle (e.g., physical activity) factors.

OEHHA (2000) provided point and distributional recommendations for the 9-, 30-, and 70-year exposure durations used with that guidance. For the 9-year scenario, OEHHA simulated a distribution using the tap water distributions presented by Ershow and Cantor (1989) for children <1 year of age and for children 1 to 10 years of age using Crystal Ball®. This distribution is presented below in Table 8.~~4~~6. The distribution was fit to a lognormal parametric model with an arithmetic mean and standard deviation of 40.3 ±□21.6, μ ± is exp(3.57 ±0.50). The Anderson Darling Statistic is 0.65.

Table 8.6 OEHHA (2000) Tap Water Intake Rates Fit to a Lognormal Model for the 9-year Scenario (ml/kg-day) [1]

mean	SD	Percentiles										
		5	10	20	30	40	50	60	70	80	90	95
40	22	16	19	23	27	31	35	40	46	54	68	81

[1]Derived by OEHHA from data of ages 0-10 years from Ershow and Cantor (1989) fit to a lognormal distribution. Results presented in OEHHA Exposure Assessment and Stochastic Analysis Guidelines (2000)

For the 30- and 70-year scenarios, OEHHA used data for all ages of females from Ershow and Cantor (1989) to fit to a lognormal distribution with a mean of 24.0 and standard deviation (SD) of 17.2. The female mean was chosen because it is slightly higher than the male mean. Estimates of the fit to a lognormal model distribution are presented in Table 8.~~5~~7, below.

Table 8.~~5~~ 7 OEHHA (2000) Tap Water Intake Rates Fit to a Lognormal Distribution for the 30- and 70-year Scenarios (ml/kg-day) [1]

mean	SD	Percentiles										
		5	10	20	30	40	50	60	70	80	90	95
24	17	7	9	12	14	17	20	23	31	34	45	56

[1]Derived by OEHHA using data of females of all ages from Ershow and Cantor (1989) fit to a lognormal distribution. Results presented in OEHHA Exposure Assessment and Stochastic Analysis Guidelines (2000)

The OEHHA (2000) Exposure and Stochastic Guidance recommended using the mean and 95th percent-ile values from Table 8.6 and 8.7 (above) for each of the 9-, 30-, and

70-year scenarios. These recommended point values are presented in Table 8.~~6~~8, below.

Table 8.~~6~~ 8 Previously Recommended Point-Value Estimates for Daily Water Intake Rates (ml/kg-day) for the Exposure and Stochastic Guidelines of OEHHA (2000)

	9-year scenario (children)	**30- and 70-year scenario**
Average	40	24
High-end	81	54

For stochastic analyses using the OEHHA (2000) Exposure and Stochastic Guidance, the distributional values presented in Tables 8.~~4~~ 6 and 8.~~5~~ 7 (above) and fit to a lognormal distribution were recommended.

8.~~2~~4.7 U.S. EPA Office of Water (2004)

The Office of Water, U.S. EPA, derived estimated water intakes using data from the Continuing Survey of Food Intake of Individuals (CSFII) 1994-1996, 1998 dataset. The CSFII 1994-1996, 1998 (hereafter referred to as CSFII) is a nationwide survey that collected data on food and beverage intakes for two 24-hour non-consecutive periods, 3-10 days apart, on approximately 20,000 individuals during the years 1994-1996 and 1998. The Office of Water estimated the amount of water consumed by each individual, including both direct and indirect water intake. Direct water intake is water consumed as plain water from the tap, while indirect water intake is water used to prepare beverages and foods, either at home or at a food service establishment.

Two-day average water intakes for each participant were used in the analyses. Results are presented by water source (tap, bottled, other sources, or all water sources), type of water (direct, indirect or both), consumption type (consumer-only or combined consumer plus non-consumer ("per capita")), and in units of L/day or L/kg-day. Fine and broad age groups were analyzed. This report provides the most recent published analysis of water intake rates that are representative of the U.S. population. The report includes results for both combined and separate analyses of direct and indirect water intakes. However, the Office of Water (2004) intake estimates are from data that is the average of two non-consecutive days of intake and thus do not reflect a person's long-term typical intake. The combined direct plus indirect, community water intake rates by age group from the Office of Water (2004) report are presented in Table 8.~~7~~9, below. For all ages, the mean and 95th percentile water intake rates were 17 and 44 ml/kg-d.

Table 8.~~7~~ 9 Direct + Indirect, Community Water Intake Rates From U.S. EPA (2004) Table IV-8 (ml/kg-day)

			Percentiles							
Age in Years	**Sample Size**	**Mean**	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**
0<0.5	414	95	5	7	37	91	133	184	221	294
0.5<0.9	534	53	3	5	12	47	81	112	129	186
0<2	1828	44	2	4	11	28	62	109	137	215
1-3	3230	26	2	4	9	20	35	53	68	110
4-6	2715	22	1	3	8	18	31	47	63	91
0<6	6410	30	2	4	9	21	38	67	93	162
7-10	956	16	1	3	6	13	22	33	40	59
11-14	736	13	1	2	5	10	17	27	36	54
15-19	771	12	1	1	4	9	16	26	32	62
20+	8459	16	1	3	7	13	22	32	39	62
20-24	637	15	1	2	5	11	18	31	39	80
25-54	4512	16	1	3	7	13	21	32	40	65
55-64	1383	17	1	3	8	14	23	32	38	58
65+	1927	18	2	5	10	16	24	32	37	53
All Ages	17,815	17	1	3	7	13	22	33	44	77

8.~~2~~4.8 U.S. EPA Child-Specific Exposure Factors Handbook (2008)

The U.S. EPA Child-Specific Exposure Factors Handbook (CEFH) provides statistical exposure factor recommendations, including recommended water intake rate values for exposure assessments that are specific for infants and children.

The CEFH (2008) undertook an analysis of the CSFII 1994-1996, 1998 dataset to derive water intake rates specific for the CEFH age groups. CEFH (2008) defined direct water as water consumed as a beverage. They defined indirect as water used to make beverages or foods. In their analysis, the CEFH did not differentiate between direct and indirect water resulting in intake estimates for combined direct plus indirect water.

The CEFH (2008) presented separate analyses of water intake by water source (i.e.,

community, bottled, other sources, and all sources). The U.S. EPA CEFH (2008) presented both ml/day and ml/kg-day intake rate values, and mean, minimum, maximum, and eleven percentile bins of intake estimates. No recommendations for fitted distributions for water intake rates were made in the CEFH (2008). Both per capita and consumer only water consumption rates were presented.

8.~~2~~4.9 CEFH Table 3-19

Of the tables in CEFH (2008), Table 3-19 provides water intake estimates that were of the most relevance to OEHHA because these rates are for combined direct plus indirect community water intake. The table includes percentile values for consumer-only rates. Table 3-19 is presented in Table 8.~~8~~10, below. OEHHA chose to use the estimates for some of these age groups in deriving OEHHA-specific age group water intake rates (see Section 8.~~2~~4.13, below). This information is also published in Kahn and Stralka (2009).

Table 8.~~8~~ 10 Table 3-19 U.S. EPA CEFH (2008). Consumer-only, Direct plus Indirect, Community Water, Intake Rates By Age Group for U.S. Infants and Children (ml/kg-day)

	Sample Size	Mean	50th	90th	95th	99th
0<1 month	37	137	138	235	238	263
1<3 months	108	119	107	228	285	345
3<6 months	269	80	77	148	173	222
6<12 months	534	53	47	112	129	186
1<2 years	880	27	20	56	75	109
2<3 years	879	26	21	52	62	121
3<6 years	3703	24	19	49	65	97
6<11 years	1439	17	13	35	45	72
11<16 years	911	13	10	26	34	54
16>18 years	339	12	9	24	32	58
18<21 years	361	13	10	29	35	63

* Source of Data: USDA Continuing Survey of Food Intakes by Individuals (CSFII), 1994-96, 1998

8.~~2~~4.10 Michaud et al. (2007)

Michaud et al. (2007) investigated the relationship between total fluid intake and bladder cancer. Participants were asked via questionnaire about the volume and frequency of specific beverages during the 5 years prior to the study interview. The researchers calculated total fluid intake by multiplying the volume and frequency of each beverage and summing the result. Because the fluid intake included fluids from commercial beverages, and because water absorbed into foods during cooking was not included, we did not use these intakes. Further, intakes were only given as ml/day and results were reported as quintiles so only intervals of intake were reported (e.g., 29 ml/day, 29-40 ml/day, 41-55 ml/day, etc.).

8.4.11 Barraj et al. (2008)

Barraj et al. (2008) collected drinking water consumption data over a 7-day period on a nationwide sample of persons of all ages during two 'waves' (survey periods meant to represent winter and summer seasons). Diaries were used to record frequency and amounts of plain drinking water consumed. The final dataset contained data from 4198 individuals from 2154 households. The response rate was 33 percent and 36 percent for wave 1 and wave 2, respectively. The proportion of study participants by age-sex groups and U.S. region was comparable to those of the U.S. 2000 census, with the exception of women over 50 years of age. The proportion of whites in the study was greater than the U.S. census. Results included 24-hour drinking water consumption rates, number of occasions of drinking water, amount per occasion, and inter- and intra-individual variability in water consumption patterns. Because this study was restricted to plain drinking water, while we are interested in water used for reconstituting food and beverages and water absorbed during cooking, in addition to plain drinking water, we cannot use these data to quantify water intake rates. Nonetheless, the study did evaluate inter- and intra-individual variability in daily water intake (ounces per day) and found that inter-individual variability was greater than intra-individual variability. There were significant day-to-day differences in water intake (ounces per day) in "wave 1" (summer) for women 13-49 years of age and men 20-49 years of age, and in "wave 2" (winter/early spring) for children 0-5 and boys 13-19 years of age. There was also a significant weekend effect.

8.~~2~~4.12 Kahn and Stralka (2009)

Kahn and Stralka (2009) published in a peer-reviewed journal the water intake rates that they had derived for the U.S. EPA, Office of Drinking Water (2004) report. This publication will not be discussed here because the methodology and results are presented in Section 8.~~2~~4.7, above. However, we make note of this publication and that it has been reviewed for these guidelines.

8.~~2~~4.13 OEHHA Derived Water Intake Rates for Hot Spots Program Age Groups and Exposure Duration Scenarios

OEHHA chose to use water intake estimates from the Office of Water, U.S. EPA (2004) and U.S. EPA CEFH (2008) Table 3-19 as the basis for OEHHA's water intake rate recommendations (with the exception of the infant age group, see below). Both the Office of Water (2007) and U.S. EPA CEFH (2008) Table 3.19 intake estimates are representative of demographics (e.g., age, sex, income, etc.) of the U.S. population because they have been weighted using the data-specific sample and variance weights. The rates are in ml/kg-day, which is the unit of measure specified for the current Hot Spots program guidance (see Equation 8.1, above). The Office of Water report and U.S. EPA CEFH (2008) Table 3.19 include consumer-only tap (community) water intake rates, which are of particular relevance for OEHHA because water consumed from local surface water bodies is likely to be made available to consumers via the tap available at home. Though more recent water intake data are now available (NHANES 1999-2004), the NHANES water intake data are limited because information on whether the water was from the tap or not was not collected, the water source (e.g., municipal, bottled, etc.) is not specified for several of the years, and intake data were collected on two days per individual. Further, although direct intake rates are in the NHANES dataset, to obtain the indirect intake rates that OEHHA needs would require calculations using recipe code books and other data manipulation. Thus, the Office of Water and U.S. EPA CEFH (2008) Table 3.19 rates, which are based on 1994-1996 and 1998 data, are the most recent derivation of direct and indirect water intake rates that are representative of the population.

It should be noted, though, that the Office of Water (2004) and U.S. EPA CEFH (2008) Table 3.19 intake rates are not available on a state-by-state basis. Thus, the rates used by OEHHA are not specific to California and therefore may differ from those of the California population due to different climate and lifestyle factors. However, it is likely that the rates would not be substantially different overall since there are other areas of the U.S. with climate and lifestyle patterns similar to those of California. Further, the California population represents a significant fraction (over 10%) of the national population and thus would have contributed a substantial weight to the CSFII survey.

Because the age groups in the Office of Water report (2004) and U.S. EPA CEFH (2008) Table 3.19 differ from the age groups and exposure duration scenarios to be used for the current Hot Spots risk assessments, OEHHA derived water intake rates specific for the Hot Spots program ages. Table 8.~~9~~11, below, lists the data sources used to derive water intake rates for the Hot Spots program.

Table 8.11 Data Used to Derive Water Intake Rates for Hot Spots Program Age Groups and Exposure Duration Scenarios

Hot Spots Age Group	Derived by OEHHA [1]	CEFH Revised Table 3-19 (2008)	Office of Water (2004)
0<2 years	0<1 year [1]	1<2 years	
2-9 years		2<3 years 3<6 years 6<11 years	
2<16 years		2<3 years 3<6 years 6<11 years 11<16 years	
16-30 years		16<21 years	20-24 years 25-54 years [2]
16-70 years		16<21 years	20-24 years 25-54 years 55-64 years [3]
>=16 years		16<21 years	20-24 years 25-54 years 55-64 years 65+ years
Hot Spots Exposure Duration	**Derived by OEHHA [1]**	**CEFH Table 3-19 (2008)**	**Office of Water (2004)**
9-year	0<1 year [1]	1<2 years 2<3 years 3<6 years 6<11 years	
30-year	0<1 year [1]	1<2 years 2<3 years 3<6 years 6<11 years 11<16 years 16<21 years	20-24 years 25-54 years [2]
70-year	0<1 year [1]	1<2 years 2<3 years 3<6 years 6<11 years 11<16 years 16<21 years	20-24 years 25-54 years 55-64 years [3]

[1]Using intakes of water in reconstituted formula consumed by infants in CSFII 1994-1996, 1998
[2]Because intake rates are relatively stable after 16 years of age, the 25-54 year age group was used to represent the 25-30 year age group but with population size adjusted to the 25-30 year age group
[3]Because intake rates are relatively stable between the 55-64 year and 65+ year age groups (mean of 17 vs. 18 and 95%-ile of 38 vs. 37, for the 55-64 and 65+ year age groups, respectively), OEHHA chose to use the 55-64 year age group to represent the 65-70 year age group and adjust for the additional 65-70 years of age population.

For the derivation of Hot Spots program age groups and exposure duration scenarios, OEHHA used Crystal Ball version 7.2 (Oracle, 2008) to find the best fit for distributions, to simulate values of distributions, and to identify distributional parameters (mean, scale, location, etc.). Crystal Ball was also used to derive percentiles and summary statistics. In identifying the best fit for a distribution, the Anderson-Darling test, one of three goodness-of-fit tests available in Crystal Ball, was used because it gives extra weight to the tails of the distribution, which the other goodness-of-fit tests do not. The tails of the distribution are of particular interest to OEHHA because the right tail defines high-end intake rates.

OEHHA did not use the Office of Water (2004) or U.S. EPA CEFH (2008) Table 3.19 water intake estimates for infant (0<1 year of age) intake rates. Instead, OEHHA derived water intake rates of infants consuming reconstituted formula. The reasons for this are described below in Section 8.~~3~~5.1, "Infants." OEHHA used data from the CSFII 1994-1996, 1998 dataset to derive infant water intake rates. To identify infants who received reconstituted formula, the food description provided for the formula consumed by each infant was reviewed. Breast-fed infants were excluded from analysis. To calculate the amount of water consumed by each infant, the amount of reconstituted formula consumed was multiplied by the percent of indirect water in each type of reconstituted formula (these values were obtained from Appendix-D of the U.S. EPA Office of Drinking Water report (2004)). Two outliers were identified and excluded from analyses. Sample weights were available in the dataset in order to weight each individual's intake according to the number of infants in the population that he/she represented (see USDA, 2000 for a more detailed description). Each infant's water intake was paired with her/his sample weight in Crystal Ball (version 7.2) to derive a distribution of intakes representative of the population. The Anderson-Darling goodness-of-fit test was used to find the best fit distribution for the weighted data. This weighting and best fit procedure was conducted for each infant age group (0<1, 1<2, 0<3, 3<6, and 0<12 months of age).

The OEHHA–derived water intake rates for these infant age groups will be used in conjunction with other data to derive Hot Spots program age group and exposure duration scenario water intake rates (as outlined in Table 8.~~9~~11, above). By doing so, the Hot Spots program water intake rates will reflect intake rates of the truly exposed infants (those receiving reconstituted formula). The results are presented in Table 8.~~10~~12, below, along with the Office of Water (2004) or U.S. EPA CEFH (2008) Table 3.19 estimates (direct plus indirect consumer-only community water intake rates) for comparison.

Table 8.~~10~~ 12 Water Intake Rates of Infants by Age Group (ml/kg-day) – Derived by OEHHA (2008) or U.S. EPA (2004 or 2008)

Study	Age in Months	Sample Size	Mean	50%-ile	90%-ile	95%-ile	99%-ile
OEHHA CSFII [2]	0<1	45	184	171	253	300	466
U.S. EPA Table 3-19 [3]	0<1	37	137	155	236	269	269
OEHHA CSFII [2]	1<2	61	134	113	294	301	375
OEHHA CSFII [2]	0<3	137	122	113	206	294	375
U.S. EPA Table 3-19 [3]	0<3	108	119	107	247	289	375
OEHHA CSFII [2]	0<6	467	127	123	200	237	333
U.S. EPA (2004) [3]	0<6	414	95	91	184	221	294
OEHHA CSFII [2]	0<12	906	142	148	213	228	276
U.S. EPA (2004) [3]	0<12	948	71	62	145	185	261

[1]N = sample size. However, results have been weighted to adjust sample to the population.
[2]OEHHA analyses include water intake only from reconstituted formula
[3]U.S. EPA (2008) includes any direct or indirect intake of community water by consumers-only

A limitation of using intake data from infants receiving reconstituted formula is that the intakes do not include water added to food and non-formula drink, which results in possible underestimation of water intake. This limitation is likely only applicable to the second half of infancy when infants typically receive supplemental food and drink in addition to formula. A second limitation to the OEHHA derived infant intake rates are that the source of water (e.g., tap) used to reconstitute the formula is unknown. However, it is probable that a large fraction of infants are fed reconstituted formula prepared with tap water (see Section 8.~~3~~5.1, below, for results of Levallois et al. 2007).

The Office of Water (2004) mean estimates are lower than the OEHHA mean estimates because they include data from infants who may have been almost exclusively (i.e., received an insignificant amount of calories from other non-milk food or drink), or exclusively, breast-fed but received a small amount of water. The 90th-, 95th-, and 99th-percentile estimates are similar among the analyses because these values likely represent infants who are exclusively fed formula reconstituted

with water. These values support the consistency of results among analyses, and that some infants consuming reconstituted formula may have very high water intake rates.

To estimate intake rates for the Hot Spots 0<2 year age group, the percentiles of the distribution and associated intake values for the 0<1 year age group (OEHHA derived, see Table 8.~~10~~12, above) were entered into Crystal Ball and used to characterize the probability distribution of the intake rates. The best fit for the distribution was identified using the Anderson Darling goodness-of-fit test. The parameters for the modeled distribution were then derived using the empirical minimum and maximum to truncate unrealistically low and high values. This process (characterizing the probability distribution) was repeated for the water intake values of the 1<2 year age group of the CEFH Table 3-19 (2008). Table IV-8 of the Office of Water (2004) provided data on the population size of each age group (0<1 year and 1<2 years) relative to the full age group (0<2 years).

The population proportion was multiplied by 60,000 to give the number of infants for each age group in a hypothetical population of 60,000 infants. The Latin Hypercube method of Monte Carlo simulation in Crystal Ball was then used to generate simulated values for the 0<1 year age group based on the calculated number of infants in the hypothetical population. The same simulation procedure was applied to the 1<2 year age group distribution. The simulated values were then combined into one dataset. The best fit for the distribution of the combined values was characterized using the empirical minimum and maximum values for truncation to eliminate potentially unrealistic extreme values. The parameters of the combined (0<2 year age group) distribution were identified and summary statistics calculated.

To derive distributions for the other Hot Spots age groups and exposure duration scenarios, the above described procedure was also used. That is, using the data outlined in Table 8.~~9~~ 11 for each Hot Spots program age group and exposure duration scenario, the probability distribution was characterized, population proportions were calculated (using Office of Water Table IV-8), and values proportional to population size were simulated. The simulated values were then combined, the best fit for the resultant distribution was identified, and parameters and summary statistics for the distribution were found. It may be noted that when calculating population proportions, the age groups of Table IV-8 of the Office of Water (2004) did not always fit the CEFH Table 3-19 age groups. In these cases, some approximations were required.

Values for the OEHHA derived Hot Spots age groups and exposure duration scenarios are presented in Table 8.~~11~~13, below.

Table 8.13 OEHHA Derived Consumer-only Water Intake Rates (ml/kg-day) for Hot Spots Program Age Groups and Exposure Duration Scenarios[1]

Age	Mean	50th	Variance	90th	95th	99th	Max
Third Trimester	18	14	218	38	47	67	117
0<1 year [2]	143	149	3240	213	228	276	491 [5]
0<2 years [2]	113	106	1915	172	196	247	491 [4]
2-9 years [3]	26	22	414	54	66	92	190 [5]
2<16 years [3]	24	19	362	49	61	88	152
>=16 years [3]	19	16	208	38	47	67	135 [5]
16-30 years [3]	18	14	218	38	47	67	117
16-70 years [3]	18	15	191	37	45	62	116
Duration							
0-9 year [2]	45	25	3052	102	152	288	491
0-30 year [2]	28	15	1219	59	87	177	450
0-70 year [2]	23	14	886	51	73	141	442

[1]OEHHA recommends the mean and 95th percentiles as the average and high end point estimate values.
[2]Includes the OEHHA derived 0<1 year of age group water intake rates derived from the water in reconstituted formula for infants in CSFII
[2]OEHHA derived – data sources are **c**onsumer-only, direct + indirect, community water intake rates from Office of Water (2004) and U.S. EPA CEFH (2008) Table 3.19.
[4]Right tail outliers deleted
[5]fit distribution has maximum of infinity

8.~~2~~4.14 Fitted Distributions of OEHHA Derived Water Intake Rates

The steps involved in deriving water intake rates specific for the Hot Spots program age group and exposure duration scenarios are described above, and briefly discussed here. OEHHA characterized the probability distributions for certain age group datasets from the Office of Water (2004) or Table 3-19 (2008) using Crystal Ball version 7.2 (Oracle, 2008). The best fit distributional type (e.g., gamma) was then found using the Anderson-Darling goodness-of-fit test. The parameters of the best fit distribution were then determined. Distributions were combined as listed in Table 8.~~9~~ 11 to provide age groups matching the age groups needed for the Air Toxics Hot Spots program. The distributions were combined proportionate to population size which was approximated using the population numbers in U.S. EPA (2004). The mean and percentiles were calculated for the combined age group distributions using Crystal Ball 7.2 (Oracle, 2008) and the results are presented in Table 8.~~11~~13, above. The combined age group distributions were characterized using Crystal Ball to find the best fit distribution, the Anderson-Darling statistic for that fit, and the parameters that fit that distribution. The distributional characteristics and values are presented in Table 8.~~12~~14, below.

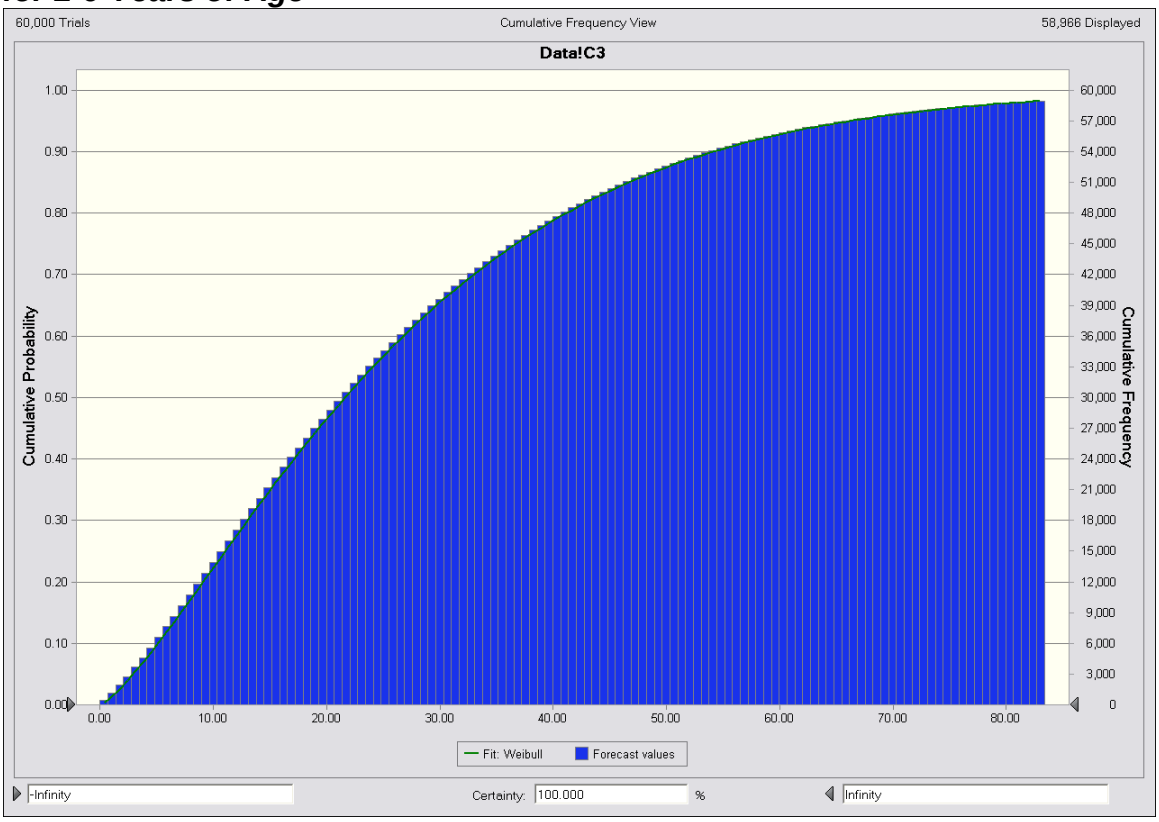
Table 8.~~12~~ 14 Recommended Distributions of OEHHA Derived Water Intake Rates for Stochastic Analysis (ml/kg-day)

Age	Best Fit [1]	A-D statistic [2]	Parameters of Distribution [3]
0<1 year	Beta	23.2	Min = 60 Max = 264 Alpha = 4.1 Beta = 2.5
0<2 years [5]	Max Extreme	1.06	Likeliest = 93 Scale = 35
2<9 years	Weibull	0.01	Location = 0.02 Scale = 29 Shape = 1.3
2<16 years [6]	Gamma	0.11	Location = 0.19 Scale = 15.0 Shape = 1.6
≥16 years [6]	Gamma	0.52	Location = 0.17 Scale = 10.7 Shape = 1.8
16-30 year[7]	Gamma	10.6	location=0.49, scale=13.6, shape=1.26
16-70 year	Beta	1.09	min=0.17, max=178, alpha=1.5beta= 12.9
Duration			
0-9 year scenario	Lognormal	2.7	Mean = 45 SD = 70
0-30 year scenario	Lognormal	0.31	Mean = 26 SD = 39
0-70 year scenario	Lognormal	0.04	Mean = 23 SD = 29

[1]Best Fit refers to the distribution found to best fit the empirical data according to the Anderson-Darling goodness-of-fit test
[2]A-D statistic = Anderson-Darling statistic
[3]Parameters of Distribution refers to the parameters of the best fit distribution
[4]Taken directly from U.S. EPA CEFH (2008) Table 3.19.
[5]0<2 year age group derived by combining water in reconstituted formula only for 0<12 month ages from CSFII and the 1<2 year age group from U.S. EPA CEFH (2008) Table 3.19
[6]OEHHA analyses that derived alternate age groups using U.S. EPA (2004) and U.S. EPA CEFH (2008) Table 3.19.
[7]This distribution is recommended for the third trimester also.

To give a graphical example of the OEHHA derived distributions, the cumulative probability of the 2-9 year of age distribution (best fit) is shown below, in Figure 8.1.

Figure 8.1. Cumulative Probability Distribution for Water Intake Rates (ml/kg-day) for 2-9 Years of Age



8.~~3~~ 5 Special Subpopulations of Concern

8.~~3~~5.1 Infants

Infants may be more sensitive and exposed (on a body weight basis) to some toxicants than non-infant children and adults. Further, infants have unique nutritional needs, necessitating the feeding of milk or milk substitutes through at least three, and more commonly through four to six months of age. For the first 4-6 months, infants who are fed breast milk typically receive little, if any, other fluid. This is primarily because continued lactation is dependent on continued nursing. If nursing is reduced or discontinued for any length of time, the milk production quickly ceases. Thus, breast-fed infants tend to receive breast milk as their sole source of fluid and nutrition during the first half of infancy.

On the other hand, infants who are not breast-fed receive formula. The Ross Mothers Survey (Ross Products Division, Abbott, 2003) reported that in 2003, 44 percent, 18 percent, and 10 percent of infants were exclusively breastfed (no other liquids) in the hospital (i.e., soon after birth), at 6 months of age, and at 12 months of age, respectively. This suggests that the percent of infants who receive formula may be up to 56 percent soon after birth and 82 percent at 6 months of age.

Formula can be bought ready-to-feed or in a form requiring the addition of water before it can be fed to the infant (i.e., powder or concentrated liquid). OEHHA analyzed the CSFII 1994-1996, 1998 and NHANES (National Health and Nutrition Examination Survey) 1999-2004 dataset to assess the proportion of infants who received reconstituted formula, relative to all types of formula. The food code descriptions were reviewed to identify the type of formula each infant received, including reconstituted formula. The results are presented in Table 8.~~13~~15, below. These results provide evidence that a large fraction of formula-fed infants receive reconstituted formula, especially so for the youngest ages. These results also suggest that there may be a trend over time toward greater consumption of reconstituted formula relative to ready-to-feed formula.

Table 8.~~13~~ 15 Percent of formula-fed infants consuming reconstituted formula

Age	CSFII	NHANES
0 < 1 month	82% (45 / 55) [1]	94% (31 / 32)
0<6 months	71% (467 / 658)	87% (398 / 457)
0<12 months	75% (906 / 1201)	87% (886 / 1013)

[1] ( ) = # receiving reconstituted formula / # receiving any type formula

Additionally, a study of 2-month old infants in rural Canada (with a sample size of approximately 300) found that 91 percent of formula-fed infants received formula reconstituted with water (Levallois et al., 2007). This is consistent with the results in Table 8.~~13~~15, above. Because OEHHA is particularly interested in tap water intake rates, it is important to note that, of the Canadian infants receiving reconstituted formula, 60 percent received formula reconstituted with tap water.

Because the majority of formula-fed infants receive formula that has been reconstituted with water, which is often tap water (60 percent per Levallois et al., 2007), during the first half of infancy, the infant population is dichotomized into infants who receive little, or no, tap water (breast-fed infants) and infants who receive significant amounts of tap water every day (reconstituted formula fed infants).

While the infant's diet during first half of infancy typically consists almost exclusively of breast milk or formula, infant diet during the second half is much more varied and includes the gradual introduction of food and non-milk beverages. (The term 'second half of infancy' is used loosely here because the age at which food and non-milk drink is introduced varies but is typically between 4-6 months of age). Nonetheless, during this second half of infancy, the dichotomization of infants into two groups based on water intake rates continues, though the difference between the groups may be somewhat less pronounced.

The American Academy of Pediatrics (AAP, 1997) recommends that infants be exclusively breast-fed through 6 months of age and continue to receive breast milk as their sole source of milk while being introduced to solid food through 12 months. Thus, breast-fed infants may begin to receive some food and drink prepared with water but often not until at least 6 months of age. Further, breast-fed infants

frequently continue to receive breast milk as a significant source of fluid and nutrition for several months past the introduction of supplemental food and drink. For formula-fed infants, because the accepted medical recommendation is to not feed cow's milk until at least 12 months of age, formula-fed infants typically continue to receive formula as their sole milk source. Like breast-fed infants, formula-fed infants may increase their intake of food and non-formula drink prepared with water during this period. Both breast-fed and formula-fed infants tend to decrease their consumption of breast milk or formula, respectively, while their consumption of food and drink prepared with water is likely to increase. Thus, during the second half of infancy, overall water intake of breast-fed infants likely increases, though probably not dramatically, while intake of formula-fed infants likely varies considerably between infants but with the potential for some infants to have even greater intake rates than during the first half of infancy.

The above information supports the existence of a sizable subpopulation of infants who are exclusively (or almost exclusively) fed formula reconstituted with water, which is often tap water, for the first 4-6 months and thereafter receive significant quantities of tap water through 12 months of age. These infants could receive significant tap water intake over the first year of life. In the past few years, there has been heightened awareness of the probable increased susceptibility of infants and children to some environmental toxicants. Therefore, it is prudent to identify subpopulations of infants who may be the most highly exposed. For the water pathway, reconstituted formula-fed infants can have a very high rate of tap water intake over the first year of life. Thus, water intake rates representative of this subpopulation (reconstituted formula fed infants) should be used for assessments of infants to exposures via the water pathway.

In risk assessment, we are interested in the dose to those who are exposed; in the case of the water pathway, those who consume water. With water intake, some individuals may not consume water on one or more days, or consume insignificant amounts of water (e.g., breast-fed infants). For the 'consumer-only' groups of infants in the Office of Water report, (U.S. EPA, 2004), only mean (average) values were given and these were only for the 0<6 and 0<12 month ages (i.e., relatively broad age groups for infants). In Table 3-19, consumer-only rates include percentiles of the distribution and the ages are stratified into narrower age groups (i.e., 0<1, 1<3, 3<6, and 6<12 months of age).

Of interest to OEHHA are rates of direct plus indirect community water intakes for narrow age groups of consumer-only infants. With such rates, both central tendency plus high-end rates of potentially more susceptible and exposed infants can be identified. U.S. EPA CEFH (2008) Table 3.19 provides these estimates. The U.S. EPA CEFH (2008) Table 3.19 infant estimates are presented in Table 8.~~14~~16, below. However, the data used to derive these estimates included infants who were breast-fed. Therefore, these values do not represent the high-end exposure subpopulation of formula-fed infants.

Table 8.~~14~~ 16 Infants Only -- U.S. EPA (2008), Child-Specific Exposure Factors Handbook Table 3-19. Estimates of Direct + Indirect, Consumer-only, Community Water Intake By Age Group (ml/kg-day)

Age (years)			Percentiles (ml/kg-day)								
	Mean	**Min**	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**	**Max**
0<1 month	137	5	11	11	67	155	198	236	269	269	269
1<3 months	119	3	9	12	72	107	153	247	289	375	375
3<6 months	80	1	3	7	28	77	118	149	174	224	288
6<12 months	53	0	3	5	12	48	81	112	130	186	254

8.~~3~~5.2 Pregnant and Lactating Women

Pregnant and lactating women have greater water requirements than non-pregnant or non-lactating women. A pregnant woman requires increased water intake in order to support fetal circulation, amniotic fluid, and a higher maternal blood volume, while a lactating woman requires increased water to replace the water excreted in breast milk. Values from the literature support this hypothesis. OEHHA (2000) Exposure Assessment and Stochastic Analysis Guidelines presented a table based on Ershow and Cantor (1989) that compared water intake rates of pregnant and lactating women with 'control' (not lactating, not pregnant) women of the same ages (see Table 8.~~15~~17, below). These estimates demonstrate that lactating women consume significantly more water than non-lactating, and even pregnant, women. More recent data are available than the values in Table 8.~~15~~17. Therefore the values from Table 8.~~15~~ 17 will not be used for Hot Spots guidance values.

Table 8.~~15~~ 17 Water Intake Estimates For Pregnant and Lactating Women from Ershow and Cantor (1989*) (ml/kg-day) – *Tap Water

Group	**N**	**Mean**	**50th**	**75th**	**90th**	**95th**
Control	6201	19	17	24	33	39
Pregnant	188	18	16	24	35	40
Lactating	77	21	21	27	35	37

*Data from Ershow et al. 1991 based on data from the USDA Nationwide Food Consumption Survey (NFCS 1977-78)

The Office of Water, U.S. EPA (2004) report presented estimates of water intake rates for pregnant and lactating women. These rates are derived from CSFII 1994-1996, 1998 data. The consumer-only intake rates of direct plus indirect community water intakes are presented in Table 8.~~16~~ 18 below.

Table 8.~~16~~ 18 Water Intake Rates of Direct + Indirect Community Water for Consumers-only (ml/kg-day) for Pregnant, Lactating, and Non-pregnant / Non-lactating Women 15-40 Years of Age

Group	Sample size	mean	Percentiles				
			50th	75th	90th	95th	99th
Pregnant	65	14	9	22	33	43	47
Lactating	33	26	20	41	54	55	57
Non-pregnant, non-lactating, aged 15-44 yrs	2028	15	12	21	32	38	68

- From Part IV Table A3 of U.S. EPA (2004)
- Data used were from CSFII 1994-1996, 1998

8.~~3~~5.3 High Activity Levels / Hot Climates

In the Exposure Factors handbook (1997), the U.S. EPA also addresses the issue of water consumption for those individuals performing strenuous activities under various environmental conditions, including desert climates (U.S. EPA, 1997). Data on these intake rates are very limited, and since the populations in the available studies are not considered representative of the general U.S. population, U.S. EPA did not use these data as the basis of their recommendations. Instead, they used the data from two studies to provide bounding intake values for those individuals engaged in strenuous activities in hot climates (McNall and Schlegel, 1968; U.S. Army, 1983).

McNall and Schlegel (1968) measured water intake of adult males working under varying degrees of physical activity, and varying temperatures. The results of this study indicate that hourly intake can range from 0.21 to 0.65 L/hour depending on the temperature and activity level.

U.S. EPA notes that these intake rates cannot be multiplied by 24 hours/day to convert to daily intake rates because they are only representative of water intakes during the 8-hour study periods of the test protocol. Intakes of the subjects for the rest of the day are not known.

The U.S. Army has developed water consumption planning factors to enable them to transport an adequate amount of water to soldiers in the field under various conditions (U.S. Army, 1983 and 1999). According to their estimates, intake among physically active individuals can range from 6 L/day in temperate climates to 11 L/day in hot climates. The Army's water consumption planning factors are based on military operations and may over-estimate civilian water consumption.

8.~~5~~ 6 References

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9. Fish Consumption

9.1 Introduction

The "Hot Spots" (AB-2588) risk assessment process addresses contamination of bodies of water near facilities emitting air pollutants. The consumption of fish from contaminated bodies of water can be a significant exposure pathway for persistent bioaccumulative organic compounds and some heavy metals. Sport fishing in freshwater lakes and ponds is the primary concern for this exposure pathway, as deposited contaminants have the greatest potential to concentrate in these types of water bodies. Although regional air contaminants depositing into the ocean, bays and estuaries are a significant problem, the risks predicted from a single source are expected to be relatively insignificant due to tidal flows and dilution. Possible exceptions could be estuaries, salt marshes or sloughs with very low tidal flow that lead to accumulation of pollutants from nearby emission sources.

Commercial store-bought fish generally come from a number of sources. Consequently, the health risks of concern are due to noncommercial, or sport, fishing. The sport fish consumption rate is a critical variate in the assessment of potential health risks to individuals consuming fish from waters impacted by facility emissions. Other synonymous terms used for sport fishing include "self-caught fish" and "wild-caught fish". The term "angler" or "sport fisher" refers to persons who catch sport fish or shellfish. These groups may include subsistence fishers.

Estimates of sport fish consumption by fishers tend to be greater than estimates of commercial fish consumption rates for the general population (Puffer et al., 1982a; Puffer et al., 1982b; SCCWRP and MBC, 1994; OEHHA, 2001). The higher intake rate of sport fish consumption by fishers creates a sensitive subpopulation relative to the general population when a facility's emissions impact a fishable body of water. For this reason, consumption rates that apply to the general sport fisher population, rather than per capita estimates of fish consumption, are used here to characterize fish consumption by the subpopulation that is at risk from consuming fish contaminated by air emissions from stationary sources.

Sport fish consumption rates may also vary by geographic location and for specific subpopulations. The U.S. EPA recommends using data on local consumption patterns and population characteristics whenever possible (U.S. EPA, 2000). For instance, subsistence fishers, as well as certain cultural groups, can have particularly high consumption rates relative to the general population (Harnly et al., 1997; SFEI, 2000; U.S. EPA, 2000). Use of national averages can seriously underestimate risks to these subpopulations.

Because freshwater bodies ~~including~~ such as lakes and~~,~~ ponds ~~and reservoirs~~ have the greatest potential for concentrating deposited contaminants, the ideal fish consumption study to use for the Hot Spots program would be a study of California freshwater sport fish consumption. Unfortunately, there are no such studies available. However,

comprehensive studies have been conducted in California surveying consumption rates of saltwater or Central Valley Delta fishers (Puffer et al., 1982a; Puffer et al., 1982b; SCCWRP and MBC, 1994; Wong, 1997; SFEI, 2000; Shilling et al., 2010). One strength of the California marine surveys is that the survey population is ethnically diverse, which may better approximate the consumption patterns for the California population, relative to studies that surveyed more homogeneous populations.

The application of the results of an ideal single fish consumption study conducted elsewhere to an impacted water body will always be uncertain because factors such as individual water body productivity, size, and local angler water body preferences will influence fish consumption. Conducting a site-specific sport fish consumption survey, in most cases, would not be a cost-effective alternative to use of the values presented in this chapter. Thus, OEHHA encourages the description of factors in the risk assessment which might significantly reduce or increase the estimated quantity of sport fish consumed for the consideration of the risk managers.

9.2 Recommendations for Angler-Caught Fish Consumption Rates

[note: this section moved (and slightly reworded) from the back to the front]

Recommended point estimates for angler-caught fish consumption rates are shown in Table 9.1. The fish consumption estimates are used to calculate individual cancer risk and noncancer chronic risk to those who eat sport (angler-caught) fish. Under the "Hot Spots" program, these values apply principally for risks to the general freshwater fishing population from consumption of all sport fish species at a given location.

The risks should be presented using the high-end estimate in Tier 1 risk assessments, if the fish ingestion pathway is a dominant pathway. As noted in Chapter 1, dominant pathways are defined as the two pathways contributing the most to cancer risk when high-end estimates of intake are used in the risk calculation. The risks estimated from the average value would be used where fish ingestion is not a dominant pathway and may also be presented for comparison in assessments where fish ingestion is a dominant pathway.

However, if high fish-consuming groups including ethnic groups and/or subsistence fishers are known to be present, OEHHA recommends that the intake rate at the 95th percentile be used to reflect the upper bound estimate of consumption rates for these subpopulations, and when characterizing and aiming to protect the target population as a whole.

Table 9.1 Point Estimate Values for Sport Fish Consumption by Age Group

	Third Trimester	0 <2 Years	2<9 Years	2<16 Years	16<30 Years	16-70 Years
	Consumption rates in g/day					

Average	-	2.1	7.9	13.3	28.8	28.8
High End[a]	-	6.6	25.4	42.9	92.4	92.4
	Consumption rates normalized by body weight, in g/kg-day					
Average	0.38	0.18	0.36	0.36	0.38	0.36
High-End[a]	1.22	0.58	1.16	1.16	1.22	1.16

[a] High end fish consumption values are the 95th percentiles. OEHHA recommends using the g/kg-day values.

Distributional analysis rather than single point estimates of fish consumption rates may be used to describe exposure within a population. Using a stochastic analysis will allow a more complete characterization of the variability in consumption in a population.

OEHHA is recommending the avidity-bias corrected distribution derived from the San Francisco Bay study (see Section 9.5) be used in Tier 3 and 4 risk assessments. The data in Table 9.2, expressed in g/kg-d, were obtained by dividing the adult fish consumption lognormal distribution data (in g/day) in Table 9.6 by the mean body weight of 80.0 kg derived in Section 10 for adults age 16-70 years. This was necessary because individual body weights were not collected in the fish consumption surveys.

Table 9.2. Empirical Distribution for Avidity Bias Adjusted Sport-Caught Fish Consumption Expressed in g/kg-day

Mean	p10	p20	p30	p40	p50	p60	p70	p80	p90	p95
Third trimester, 2<9, 2<16, 16<30 and 16-70-year age groups										
0.36	0.06	0.09	0.12	0.16	0.21	0.28	0.36	0.50	0.79	1.16
0<2-year age group										
0.18	0.03	0.05	0.06	0.08	0.11	0.14	0.18	0.25	0.40	0.58

As discussed below, there were no data available to clearly ascertain sport fish consumption rates of children. Estimates from studies for children in households of anglers indicate both potentially higher consumption rates than the anglers themselves (Mayfield et al., 2007; Shilling et al., 2010), and lower consumption rates than the anglers themselves (US EPA, 2002). We therefore assumed that sport fish consumption rate for adults 16-70 years of age would be proportional to body weight for the child age groupings of 2<9 and 2<16-year olds. Multiplying the adult consumption rate point estimates in g/kg-day by the time-weighted average body weight of 21.9 kg from Section 10 for the 2<9 year olds yields a mean and high-end fish consumption rate of 7.9 and 25.4 g/day, respectively. Performing the same calculation for the 2<16 age group with an average body weight of 37.0 kg results in a mean and high-end fish consumption rate of 13.3 and 42.9 g/day, respectively.

For the 0<2 age group, no fish consumption is expected in the first year, and fish consumption during the second year was assumed proportional on a gram per kg body weight basis to that of older children and adults. Thus, the fish consumption rate is

based on the mean body weight of children during the second year (11.4 kg for 1<2 year age group) and divided by two to represent the first 2 years after birth. The resulting mean and high-end fish consumption rates are 2.1 and 6.6 g/day, respectively (See Table 9.1 above).

Fetal exposure via the mother's consumption of fish during the third trimester is represented in g/kg-day only; no estimate was determined based on g/day. To account for the third trimester of fetal exposure we assumed sport fish consumption for both the fetus and the mother will be the same during this three-month period using the sport fish consumption rate of 0.38 g/kg-day for adults age 16<30 years.

9.~~2~~3 List of "Hot Spots" Chemicals for Which Evaluation of the Fish Pathway Is Recommended

The subset of organic and metal compounds that exhibit multipathway exposure are semi-volatile or nonvolatile, and are therefore partially or wholly in the solid or liquid phase and subject to deposition on water bodies. Fate and transport of the deposited chemical are estimated in order to assess the impact on fish that humans may catch and consume. The basis for the selection of these compounds as Hot Spots multipathway substances can be found in Appendix E. If the chemical has a long half-life and accumulates in fish, the multipathway analysis becomes more important. Below are the compounds on the Air Toxics "Hot Spots" list for which evaluation of the fish pathway is recommended:

Organic Compounds

Diethylhexylphthalate
Hexachlorobenzene
Hexachlorocyclohexanes
Polychlorinated biphenyls
Polychlorinated dibenzo-p-dioxins and dibenzofurans
Polycyclic aromatic hydrocarbons

Inorganic and Organic Metals

Arsenic & arsenic compounds
Beryllium & beryllium compounds
Cadmium & cadmium compounds
Soluble compounds of hexavalent chromium
Lead & inorganic lead compounds
Inorganic mercury and methylmercury
Nickel & nickel compounds
Selenium & selenium compounds

9.~~3~~4 Algorithm for Dose via Fish Ingestion

In the Air Toxics "Hot Spots" program, the concentration of a chemical in fish, Cf, is a product of the modeled concentration in water, Cw, and the bioaccumulation factor (BAF) for the chemical of concern.

$$Cf = Cw \times BAF \qquad \text{(Eq. 9-1)}$$

where: Cf = concentration in fish (μg/kg)
Cw = concentration in water (μg/kg)
BAF = chemical-specific bioaccumulation factor for fish

Bioaccumulation refers to the uptake and retention of a chemical by an aquatic organism such as fish from all surrounding media (e.g., water, food, sediment). A BAF is the ratio of the chemical concentration in the fish tissue to the concentration in water, taking into account uptake through contaminated food, sediment and water. There are a number of factors that can affect the BAF of a chemical in fish. Appendix I summarizes the concepts for BAFs in the "Hot Spots" program and presents the derivation of the BAF for each chemical. A brief discussion of the various factors influencing the BAF in fish is also presented.

Airborne contaminants can deposit directly into a body of water or be carried there by runoff. The current Air Toxics "Hot Spots" algorithm only considers direct deposition onto the surface of the water body. OEHHA has not currently endorsed a modeling approach for runoff. If runoff into a water body is thought to significantly impact risk from a particular facility, the risk assessor should include discussion of this problem. The concentration in the water in the model below is a function of what is directly deposited into the body of water. This is calculated as follows:

$$Cw = Dep\ (SA)\ (365) / (WV)\ (VC) \qquad \text{(Eq. 9-2)}$$

and

$$Dep = GLC \times \text{dep-rate} \times 86{,}400 \qquad \text{(Eq. 9.2a)}$$

where: Cw = concentration in water due to direct deposition (μg/kg)
Dep = amount deposited/day (μg/m^2/day) = GLC x dep-rate x 86,400
GLC = modeled ground level concentration (μg/m^3)
dep-rate = vertical rate of deposition (m/sec)
86,400 = seconds/day
SA = surface area of water body (m^2)
365 = days per year
WV = water volume (L = kg)
VC = number of volume changes per year

The deposition rate is assumed to be 0.02 m/sec for a controlled source and 0.05 m/sec for an uncontrolled source (see Chapter 2). The terms SA, WV, and VC are site-specific factors; values for these terms need to be ascertained by the risk assessor.

Calculating dose of contaminant via fish ingestion requires an estimate of the fish concentration and the amount of fish an individual consumes. The following equation can be used to calculate dose via ingestion of contaminated fish:

$$DOSEfish = (Cf \times I_{fish} \times GI \times Fsf \times EF \times \cancel{ED \times} (1 \times 10^{-6}) \cancel{/ (AT)} \qquad \text{(Eq. 9-3)}$$

where: DOSEfish = dose of contaminant via ingestion of fish (mg/kg BW-day)
Cf = concentration in fish (μg/kg)
I_{fish} = sport fish ingestion rate (g/kg BW-day)
GI = gastrointestinal absorption fraction, unitless
Fsf = fraction of sport fish caught at contaminated site, unitless
EF = exposure frequency (days/~~year~~365 days)
~~ED = exposure duration (years)~~
1×10^{-6} = conversion factor (μg/mg) (kg/gm)
~~AT = averaging time; time period over which exposure is averaged in days e.g., for carcinogenic risk calculations,~~
~~90 days for third trimester fetal stage~~
~~730 days for the 0<2 year age group~~
~~5110 days for the 2<16 year age group~~
~~19,711 days for the 16-70 year age group~~
~~25,550 days for the 0-70 year age group~~

The value of Cf is calculated using equations 9-1 and 9-2. The default gastrointestinal absorption fraction is 1. There are currently no data to support a value different from 1 for any of the chemicals that are evaluated for this pathway. The factor, Fsf, is a site-specific factor; the risk assessor must evaluate site-specific data to ascertain what fraction of the sport fish consumed by an individual comes from the impacted body of water. If such data are unobtainable, then Fsf should be set to 1. We provide both point estimates and a distribution of sport fish consumption rates normalized to body weight in this chapter. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) to allow for a two week period of time away from home (US EPA (1991).

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (CPF) expressed in units of $(mg/kg\text{-}day)^{-1}$.

$$RISKfish = DOSEfish * CPF * ASF * ED/AT \qquad \textbf{(Eq. 9-4)}$$

RISK is the predicted risk of cancer (unitless) over a lifetime as a result of the exposure, and is usually expressed as chances per million persons exposed (e.g., 5×10^{-6} would be 5 chances per million persons exposed).

The dose-response phase of a cancer risk assessment aims to characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. This is usually expressed as a cancer potency factor, or CPF, in the above

equation. The CPF is the slope of the extrapolated dose-response curve and is expressed as units of inverse dose $(mg/kg\text{-}d)^{-1}$.

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the ED is different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)
7 yrs for 2<9 age group	(ASF = 3)
14 yrs for 2<16 age group	(ASF = 3)
14 yrs for 16<30 age group	(ASF = 1)
54 yrs for 16-70 age group	(ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$RISKfish_{(lifetime)} = RISKfish_{(3rdtri)} + RISKfish_{(0<2\ yr)} + RISKfish_{(2<16\ yr)} + RISKfish_{(16\text{-}70yr)} \quad \textbf{(Eq. 9-5)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential exposure scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$RISKfish_{(9\text{-}yr\ residency)} = RISKfish_{(3rdtri)} + RISKfish_{(0<2\ yr)} + RISKfish_{(2<9\ yr)} \quad \textbf{(Eq. 9-6)}$$

For the 30-year residential exposure scenario, the risk for the 2<16 and 16<30 age groups would be added to the risks from exposure during the third trimester and from ages 0<2 yr. For 70 year residency risk, Eq 9-5 would apply.

The fetus can be exposed via the mother's consumption of fish during the third trimester of pregnancy. Fetal exposure during the third trimester via fish consumption by the mother is taken into account in the final determination of the point estimate values presented in Section 9.2. For the 0<2 yr age group, no fish consumption by the infant is expected from birth to one year of age.

9.~~4~~5 Studies Evaluated for Sport Fish Consumption Rate

In order to determine the dose of a contaminant via ingestion of fish, reasonable point estimates and distributions for the rate of California sport fish ingestion are required.

The most comprehensive studies of noncommercial fish consumption in California are the Santa Monica Bay Seafood Consumption Study (SCCWRP and MBC, 1994) and the San Francisco Bay Seafood Consumption Study (SFEI, 2000). These studies were undertaken to describe the demographic characteristics of anglers that fish the Santa Monica Bay and San Francisco Bay, to assess their sport seafood consumption rates, and to identify ethnic subgroups that may have high rates of seafood consumption. Other California fish consumption studies that provide estimates of fish consumption rates are also reviewed here. Since comprehensive freshwater fish consumption rate studies in California are lacking, the best freshwater fish studies performed elsewhere in the U.S. are also summarized. Studies that discussed consumption of sport fish by household members are also summarized. Household members may represent a more sensitive subgroup of people consuming contaminated sport fish brought home by anglers. Sensitive household members include children and pregnant and breastfeeding women.

9.~~4~~5.1 Marine and Delta Fish Consumption Studies

9.~~4~~5.1.1 1998-1999 San Francisco Bay Seafood Consumption Study

Between July 1998 and June 1999, the California Department of Health Services conducted over 150 fishing site visits and approached over 1700 San Francisco Bay (SF Bay) anglers (SFEI, 2000). The sites chosen for interviews included public piers and adjacent beaches or banks, public boat launches, and party boats. Anglers were asked how many times they ate Bay fish in the four weeks prior to being interviewed - a time period within which anglers were assumed to have reasonably accurate recall. Anglers were also asked the portion size of the meal compared to a plastic model of an eight-ounce fish fillet. The portion size question was asked only once and was used to calculate all fish consumption rates. Angler fish-consumption rates were determined by multiplying the two variables, meal frequency and portion size, and converted to grams per day (g/d). Consumption rates are described primarily for two populations, consumers and recent consumers. Consumers are anglers who reported eating Bay fish. Recent consumers are a subset of consumers who reported consuming Bay fish in the last four weeks.

Of 1738 eligible (i.e., not previously interviewed) anglers interviewed, 501 individuals identified as recent consumers provided adequate information for deriving a consumption rate. The researchers had determined a sample size of 500 recent consumers would be needed to derive a reasonably precise mean consumption rate (i.e., 95% confidence interval of +/- 10% around the geometric mean consumption rate and 95% confidence interval of +/- 15% around the upper percentiles). The mean and 95th percentile for fish consumption rate among recent consumers based on 4-week recall was 28 and 108 g/d, respectively.

The SF Bay report also included a distribution of consumption rates for recent consumers adjusted for avidity bias (See section 9.~~7~~8.2.1 for discussion on avidity bias). In on-site surveys such as the SF Bay study, avid anglers may be over-represented in

the sample and infrequent anglers will be under-represented, resulting in avidity bias. This bias occurs because an individual who fishes frequently has a greater chance of being interviewed than a person who fishes infrequently. Thus the distribution will over-represent the consumption of frequent fishers. Further information about avidity bias is discussed below. The mean and 95th percentile for the avidity adjusted fish consumption rate among recent consumers based on 4-week recall was 23 and 80 g/d, respectively.

Although less reliable than the four week recall, consumers (n=1019) were asked to report the number of times they ate Bay fish in the past 12 months. The unadjusted mean and 95th percentile for fish consumption rate based on 12-month recall was 11 and 44 g/d, respectively. Consumption rates for the 12-month period prior to the interview could not be adjusted for avidity bias due to insufficient fishing frequency data over the same time period.

Due to historic mercury contamination in the region, the SF Bay report also surveyed angler households for pregnant or breastfeeding women. The developing fetus and infants are particularly sensitive to mercury contamination. The SF Bay report found that only 2% of anglers reported that pregnant or breastfeeding women in their household ate SF Bay sport-caught fish. However, 46% of anglers reported that women of childbearing age (18-45 years) in their household ate SF Bay sport-caught fish, and 13% reported that children younger than six years of age ate SF Bay sport-caught fish.

9.~~4~~5.1.2 1991-1992 Santa Monica Bay Seafood Consumption Study

For the Santa Monica Bay study, surveys were conducted at 29 sites on 99 days, from September 1991 to August 1992 (SCCWRP and MBC, 1994; Allen et al., 1996). Fishers on piers and jetties, private boats, party boats, and beaches were interviewed using a questionnaire. The fish consumption estimates applied only to consumption of Santa Monica Bay sport fish, and did not include consumption of fish from all sport and commercial sources. Anglers were questioned about consumption of eight commonly consumed species of fish as well as about fish they had in hand. Anglers were also asked to estimate how much fish he/she consumed per meal, compared to a wood model representing a 150 gram (0.33 pound) portion of a fish fillet. Similar to the SF Bay study, fishers were asked the number of times they had consumed sport fish in the 4 weeks prior to the interview, but unlike the SF Bay study, the frequency of fish consumption was increased by one meal to account for consumption of catch present at the time of the interview. Fishers who had eaten any of the 8 species in the survey in the 4 weeks prior to the interview were included in consumption rate estimates. Of the 1,243 fishers interviewed, 554 provided information that could be used for calculating consumption rates. Average daily sport fish consumption rates (g/day) were calculated by multiplying the fisher's estimate of the typical meal size relative to the model, by the frequency of consumption in the four weeks prior to the interview, divided by 28 days. The mean and 95th percentile consumption rates for the overall surveyed population were 49.6 and 161 g/d, respectively.

OEHHA utilized a basic inverse-weighting scheme to adjust the fish consumption rate data for avidity bias, resulting in a mean of 29.4 g/d (OEHHA, 2000). Additionally, the analysis adjusted for four separate factors producing potential bias in the sampling procedure (i.e., number of times fished, frequency of site selection, proportion of successful interviews, and week days versus weekend days sampled). The four-factor corrected mean was 30.5 g/d, and differed from the avidity-corrected mean by only 3%. The four-factor adjusted high end (95th percentile) fish consumption rate estimate was 85.2 g/d.

9.~~4~~5.1.3 1980 Los Angeles Metropolitan Area Survey

In 1980, an intercept survey was conducted in the Los Angeles metropolitan area (including Santa Monica Bay) to assess noncommercial fish and shellfish consumption rates by local fishers, and to identify subgroups that have significantly larger consumption rates (Puffer et al., 1982a; Puffer et al., 1982b). The intercept survey method surveys fishers at a fishing site or sites about fish consumption, catch or other questions of interest. During the one-year study period, a total of 1,059 fishers were interviewed at 12 sites, including piers, jetties, and party boats. Average daily consumption rates were estimated based on the number of fish in the catch, the average weight of the fish in the catch, the edible portion of the species, the number of fish eaters in the family and the frequency of fishing per year. The fish consumption rate data were presented as a cumulative percentile distribution, with a median of 37 g/d and 90th and 95th percentiles of 225 and 339 g/d, respectively. Mean estimates of fish consumption were not presented.

While this study was quite extensive, there were several limitations. Consumption data were collected from over 1,000 individuals representing various ethnic groups in the survey population (i.e., Caucasian, Black, Mexican-American, and Oriental/Samoan), but only English speaking fishers were included in the study. The Santa Monica and SF Bay Seafood Consumption Studies interviewed a number of different ethnic groups in their native languages. In addition, the survey did not ask fishers for direct estimates of the amount of fish they consumed, correction for avidity bias was not performed, and no recall was included of sport fish consumption over a previous period of time.
Price et al. (1994) attempted to correct for avidity bias using the general assumption that sampling probability is proportional to the inverse of fishing frequency. The adjusted consumption rate distribution was considerably lower than that obtained by Puffer et al. studies; the median and 90th percentile were estimated at 2.9 and 35 g/d, respectively. U.S. EPA (1997) notes that an avidity-correction assumption is not completely valid, as interviewers visited sites numerous times and anglers were not interviewed more than once. However, U.S. EPA (1997) does state that the estimates of Price et al. (1994) are probably better estimates of the fish consumption of the entire population that fishes the area than the nonadjusted survey results.

9.~~4~~5.1.4 1988-1989 San Diego Bay Health Risk Study

The San Diego Department of Health Services conducted a survey of fishers fishing the San Diego Bay (SDCDHS, 1990) to identify the demographics of this fisher population and to characterize their noncommercial fish consumption patterns. The authors derived an overall bay-wide fishing population mean of 31.2 g/d. Only 59 fishers provided all of the necessary data for calculating individual noncommercial fish consumption rates and subsets of the 59 interviews were used to calculate species and ethnic-specific rates. ~~The statistical power of the study was limited~~Thus, there is more uncertainty about the fish consumption values because of the small number of subjects in the study population, particularly for the subsets for specific species and influence of ethnicity. In addition, the consumption rate overestimates consumption in the general fishing population because the rate only includes fishers who were known to catch and consume fish year-round.

9.~~4~~5.1.5 1993 San Francisco Bay Seafood Consumption and Information Project

In an earlier study of fish consumption habits of people fishing in San Francisco Bay, Wong (1997) conducted personal interviews with approximately 200 people fishing or crabbing from ten public piers during September to November 1996. A fish fillet model, representing 150 grams, was used to assist with estimating the amount of fish consumed per meal. Sixty-two respondents (29 percent) reported consumption of SF Bay fish in the 7-day period preceding the interview. A calculated median consumption rate of 32 g/d was determined for anglers that ate fish and/or shellfish from SF Bay. This study was not corrected for avidity bias.

9.~~4~~5.1.6 2010 California Central Valley Delta Fish Consumption Study

A fish consumption survey was conducted in the California Central Valley Delta (including the Sacramento-San Joaquin Rivers Delta) where a high rate of subsistence fishing of potentially mercury-contaminated fish occurs (Shilling et al., 2010). This study reflects a region where both freshwater and anadromous fish are caught. Anglers were chosen for interviews as they were encountered along the riverbank by surveyors. Shore anglers (n=373) were interviewed during biweekly to monthly site visits between September 2005 and June 2008. Anyone reporting that they had been previously interviewed was not interviewed again. Fish consumption rates (g/d) were calculated for each individual based on 30-day recall of how much and how often individual types of fish were eaten. Fish fillet models were used representing 1.5, 4.5, and 7.5 oz cooked weights of fish fillet for the estimate of actual fish consumption rates.

The arithmetic mean and median consumption rates of locally caught fish were 27.4 and 19.7 g/day, respectively, for anglers. There were no statistically significant differences in consumption rates among age groups (18-34, 35-49, and >49 years of age). The 95th percentile rate of locally caught fish (126.6 g/d) was also determined to represent the majority of the fish consuming population. Note that this distribution is not normally distributed. The arithmetic mean and median consumption rates of locally caught fish for children (n=174, age unspecified) in households of anglers were 35.3 and 22.2 g/day, respectively. This study was not corrected for avidity bias.

In addition to interviewing shore anglers, interviews were conducted with selected members of the local South East Asian community in which it was known that a member of their extended family fished. The mean corresponding consumption rate for locally-caught fish from the community member survey was 55.2 g/day, which was higher than the corresponding rate for anglers in the field. Because this portion of the study was a community-based, rather than ~~an~~ angler-based, survey of an ethnic group known for high consumption of locally-caught fish, it does not represent an overall California fish consumption rate.

9.~~4~~5.2 Freshwater Fish Consumption Studies

9.~~4~~5.2.1 Washington King County Lakes Study

A survey was conducted at three Washington state freshwater lakes from June 2002 to May 2003 (Mayfield et al., 2007). A total of 212 anglers were interviewed and asked to estimate their typical meal size from a visual aid (6, 8, 10, and 12 oz. fillets) and how often they had consumed fish they caught from the lakes in the previous month. Surveyors also asked the anglers to provide the same information for any children (i.e., <18 years) who also consumed their catch. Forty-six percent of anglers reported sharing their catch with children. The mean consumption rate was 10 and 7 g/d for anglers and their children, respectively. The 95th percentiles were 42 and 29 g/d for anglers and the children of anglers, respectively. Although many anglers reported consuming fish from King County Lakes, many had not consumed any fish in the previous month. Therefore, the median consumption rate was zero.

9.~~4~~5.2.2 Michigan Freshwater Fish Consumption Studies

The University of Michigan conducted a stratified random mail survey of 2600 Michigan residents with annual fishing licenses during the period of January to June 1988 (West et al., 1989a; 1989b; 1989c). Those with one day fishing licenses from both in state and out of state were excluded thus eliminating some infrequent fishers. Fish meals included self-caught, market, restaurant, and gift fish. Fish consumption information was gathered from all members of the household for a 7-day recall period and included only those individuals who responded that they ate fish. However, all responses were tabulated in one of only three meal sizes, 5, 8, and 10 oz. Because the overall response rate was only 47.3 percent, the authors adjusted the population mean value of 18.3 g/d downward by 2.2 g/d to account for nonresponse bias, thus deriving a mean rate of 16.1 g/d. Derivation of the adjustment factor was based on a follow-up telephone survey of respondents and nonrespondents (West et al., 1989b). The researchers did not generate a distribution. The probability of being contacted in this study was not dependent on the frequency of fishing; therefore, the avidity bias found in intercept surveys is not present in the data. However, the authors noted that the sampled population may not have represented subsistence fishers because it was selected from licensed anglers only.

Murray and Burmaster (1994) used the raw data of West et al. studies to generate a distribution for total fish and self-caught fish among adults only, providing 12 empirical distributions for eight population subgroups. Fish consumption rate estimates were derived for persons who consumed self-caught fish during the recall period, resulting in a consumption rate based on a population that more frequently consumes fish. This study represents the most comprehensive analysis of freshwater sport fish consumption by anglers. Table 9.~~1~~ 3 includes empirical distribution data for average daily fish consumption rate in the four adult subgroups that are most relevant for the California "Hot Spots" program. The Great Lakes fish population groups refer to anglers and family members who only ate self-caught fish from the Great Lakes. These groups may be analogous to sport fishers in California that fish only from one or a few lakes in a defined area that are impacted by pollutants. The self-caught fish population groups refer to groups that caught and consumed fish caught anywhere in Michigan.

Table 9.~~1~~3. Average Daily Fish Consumption Rates in g/day of Adults for Four Subgroups from Murray and Burmaster (1994)

Population group[a]	Distribution for fish consumption type	N	Fraction as % of adults[b]	Mean	SD	P50[c]	P95[d]
Anglers/ate self-caught fish	Self-caught fish	191	0.08	45.0	23.7	32.7	98.0
All/ate self-caught fish	Self-caught fish	418	0.18	42.3	22.3	32.7	98.0
Anglers/ate Great Lakes fish	Great Lakes fish	89	0.04	40.9	19.9	32.7	81.6
All/ate Great Lakes fish	Great Lakes fish	188	0.08	38.5	19.0	32.7	81.6

[a] The first two rows refer only to fish consumption of self-caught fish for anglers only (anglers) or the anglers plus adult family members (all). The last two rows refer to fish consumption of only self-caught fish from the Great Lakes for anglers only (anglers) or the anglers plus adult family members (all).
[b] This column represents the percentage of general population (i.e., Michigan adults) that ate self-caught fish.
[c] 50th percentile
[d] 95th percentile

Murray and Burmaster (1994) found that a lognormal model fit the empirical data well and provided parametric compound distributions for use in Monte Carlo simulations.

9.~~4~~5.2.3 1992-1993 Freshwater Fish Consumption by Alabama Anglers

A statewide survey was conducted from August 1992 to July 1993 to estimate daily fish consumption of freshwater fish harvested by anglers fishing from 29 locations throughout Alabama, including tailwater sites, reservoirs, and river drainages (Meredith and Malvestuto, 1996). A total of 1,586 anglers were interviewed at the completion of fishing activity. Of the total anglers interviewed, 1,303 anglers reported consumption of fish from the study areas. Serving size was estimated by equating the entire surface

(palm side) of the flat open hand to a single 113 g (4 ounce) serving. To estimate fish consumption rates, anglers were asked to estimate the number of fish meals eaten in the past month consisting of fish caught at the study sites ("site meals") and those caught at all lakes and rivers in Alabama, including study sites ("all meals"). Only anglers indicating they consumed fish from the study sites were included in the analysis. The mean annual consumption rate estimated by this method was 30.3 g/d for site meals and 45.8 g/d for all meals.

9.~~4~~5.3 Studies of Household Members Who Eat Sport-Caught Fish

Determining the consumption rate of sport fish eaten by others in angler households was beyond the scope of most studies summarized above. Some studies have shown that people who do not go fishing eat sport-caught fish given to them by friends and family, but possibly at reduced rates compared to the anglers themselves (Toth and Brown, 1997; Burger, 2000; Nadon et al., 2002; Mayfield et al., 2007). The household members of anglers are of particular interest because the anglers are predominantly male, and may bring home fish to household members that are at higher risk from consuming contaminated sport-caught fish (i.e., pregnant and breastfeeding women, women who are of childbearing age, and children). Table 9.~~2~~ 4 below presents the data from studies that did estimate consumption rates for household members that eat freshwater sport-caught fish.

Table 9.~~2~~4. Freshwater Sport Fish Consumption Rates by Household Members of Anglers

Group	N	Consumption rate (g/day)	Consumption rate (g/kg-day)	Reference
Children		Arithmetic Means	Arithmetic Means	U.S. EPA (2002) [a]
1-5 yrs	121	5.63	0.369	
6-10 yrs	151	7.94	0.276	
11-20 yrs	249	7.27	0.123	
<18 yrs	81	7	0.19	Mayfield et al. (2007)
[b]	174	35.3	0.95[c]	Shilling et al. (2010)
Women				
All ages (<17-50+)	80	10.5 [d]	0.14 [d]	Silver et al. (2007)
<17 yrs	5	13.9		
Pregnant	6	12.8		
Breastfeeding	11	10.2		
18-49 yrs	217	33.0	0.44	Shilling et al. (2010)

[a] U.S. EPA values are based on treatment of data from West et al. (1989a)
[b] Child age range not specified, but can be inferred from the study to mean <18 years of age.
[c] Based on average body weight of 37.0 kg for children 2<16 years of age from Table 10.~~8~~?

[d] Only geometric mean consumption rates were available for women in the Silver et al. study .

9.~~4~~5.3.1 U.S. EPA analysis of West et al. (1989a) child fish consumption data subset

The U.S. EPA (2002) child fish consumption rates presented in Table 9.~~2~~ 4 were obtained from the raw data by West et al. (1989a) to estimate freshwater recreational fish consumption rates for household members of anglers, based on the 7-day recall data. The household members were divided into three age groups, age 1-5, 6-10, and 11-20 years. The analysis was restricted to individuals who ate fish and who resided in households reporting some recreational fish consumption during the previous year. Since the study was a stratified random mail survey of Michigan residents with annual fishing licenses, the study was not dependent on the frequency of fishing and did not need to be corrected for avidity bias.

Using an average adult body weight of 80.0 kg from Table 10.~~8~~ 1of this document, the average adult angler consumption rate on a per kg body weight basis is 0.56 g/kg-day (45.0 g/day from Table 9.1 ÷ 80.0 kg). Comparing the child consumption rates in Table 9.~~2~~ 4 to that of adult anglers who ate self-caught fish, this study suggests that the children in households of anglers eat less on a per body weight basis than the adult anglers.

9.~~4~~5.3.2 Child sport fish consumption rate for the Washington King County Lakes Study

The Washington state freshwater fish consumption study recorded a mean consumption rate of 7 g/day for children (<18 years) of anglers interviewed (Mayfield et al., 2007). However, this study was not corrected for avidity bias, and included persons who did not consume sport fish during the 30-day recall period. Not accounting for avidity may overestimate consumption, while including anglers and their children who did not consume sport fish in the last month may underestimate the consumption rate of persons who frequently consume sport fish.

Using a mean body weight of 37.0 kg for children age 2<16 years, and 80.0 kg (age 18<75) for the mean body weight of adults, the sport fish consumption rates on a per kg body weight basis are 0.19 g/kg-day for children (7 g/d ÷ 37.0 kg) and 0.13 g/kg-day for adults (10 g/d ÷ 80.0 kg). The Washington state freshwater fish consumption data suggest that, if corrected for differences in body weight, children of anglers may consume as much fish, or more, on a per kg body weight basis as the anglers themselves. However, when compared to avidity-adjusted average adult angler consumption rates corrected for body weight from the S.F. Bay study (0.36 g/kg-day, see Table 9.~~5~~1), the child consumption rate from the Washington study is only about half that of the adult S.F. Bay anglers.

9.~~4~~5.3.3 California sport fish consumption survey among low-income women

The only study that investigated sport-caught fish consumption rates among a California population at increased risk (and presumably household members of an angler) was a survey of low-income women at a Special Supplemental Nutrition Program for Women, Infants and Children (WIC) clinic in the California Sacramento-San Joaquin Delta region (Silver et al., 2007). Of 500 eligible women participating in the survey, 80 (16%) reported eating sport fish in the last 30 days. These participants were asked about consumption frequency, portion size of cooked meals, and source of the fish. To assist with recall of portion size, fish fillet "portion models" were shown corresponding to 1.5, 3.0, 4.5, and 7.5 oz weight. The geometric mean sport fish consumption rate among this group was 10.5 g/d. Hmong and Cambodian women consumption rates showed a higher consumption trend but were not statistically significantly different.

Comparison of this geometric mean sport fish consumption rate for women in angler households with the geometric mean sport fish consumption rate among anglers in the SF Bay and Santa Monica Bay studies suggests household members eat less sport-caught fish than the anglers themselves. The unadjusted geometric mean sport fish consumption rate for the SF Bay study and Santa Monica Bay study were 16.5 and 23.6 g/d, respectively. However, these consumption rates did not account for gender body weight differences and the predominance of male anglers in surveys (e.g., 92% of interviewed anglers in the SF Bay study were male), which would bring sport fish consumption rates among anglers and women household members closer together. Using mean body weight data by gender summarized in Table 10.2, the SF Bay and Santa Monica Bay mean consumption rates were divided by the average body weight of adult males (88.3 kg, age 20 yrs and above) and the WIC mean consumption rate divided by the average body weight for adult females (74.7 kg, age 20 yrs and above). Consumption rates on a per body weight basis yields values of 0.19, 0.27 and 0.14 g/kg-day for the SF Bay, Santa Monica Bay and WIC fish consumption studies, respectively.

9.~~4~~5.3.4 California Central Valley Delta study of household fish consumption

The household consumption rates of women and children in the study by Shilling et al. (2010) are considerably higher compared to the household members in other studies. This may be due to the high number of subsistence fishers in this study, and that a majority of the anglers reported catching fish in order to feed their families. This study did not correct the consumption rate for avidity bias, so consumption rate may be overestimated.

Comparing the anglers with their family members, the consumption rates of children and women in households of anglers were not statistically significantly greater than the anglers themselves ($P < 0.05$, *t*-test). The study reported average consumption rates of 26.4, 33.0, and 35.1 g/day for male anglers, women in households of anglers, and children in households of anglers, respectively. However, when OEHHA divided the consumption rates by average body weights for men (88.3 kg), women (74.7 kg) and children (37 kg for 2 to <16 yrs), the fish consumption on a per body weight basis was 0.30, 0.44, and 0.95 g/kg-day, respectively. The results from this study suggest that

household members of anglers, many of which are subsistence fisherman that fish mainly to feed their families, have a greater fish consumption rate than the anglers themselves.

9.~~4~~5.3.5 Household sport fish consumption frequency surveys

A nationwide telephone survey of fish consumption patterns found that the presence of a fishing license in the home was a significant predictor of sport-caught fish ingestion by family members, including children and their mothers (Imm et al., 2007). Families with a fishing license in the home were more likely to eat sport-caught fish than families without a fishing license in the home. Forty-seven percent of children (2-17 years of age) who lived with a licensed angler ate sport-caught fish, with an average of 16 sport-caught fish meals (median = 8 meals; maximum = 240 meals) per year. A nationwide survey of 3015 women of childbearing age (ages 18-45) reported that 29% of participants had consumed sport fish in the previous 12 months (Anderson et al., 2004). Among those reporting sport fish consumption, the median and mean number of sport-caught fish meals for the past 12 months were 6 and 16, respectively. Neither study collected data on portion sizes of fish meals to estimate consumption rate.

9.~~5~~6 Comparison of Marine Fish Consumption Rates among California Studies

Fish consumption rates for four California fish consumption studies, the SF Bay study, the Santa Monica Bay study, the Save the Bay Study (Wong, 1997), and the Central Valley Delta study (Shilling et al., 2010) are shown in Table 9.~~3~~ 5 for comparison. The data from the SF Bay and Santa Monica Bay studies are presented both adjusted and unadjusted for avidity bias as discussed under section 9.~~7~~8.2.1. Differences among the consumption rates could be explained by the different study methodologies used by the studies.

For example, the unadjusted geometric mean consumption rate from the Santa Monica Bay study is about 50 percent higher than the unadjusted rate derived from the SF Bay study, and the difference was found to be statistically significant. In the Santa Monica study, the frequency of consumption was increased by one to account for consumption of any fish in hand at the time of the interview. Fish in hand at the time of interview was not included in the SF Bay consumption rate estimates. This factor was thought to explain the higher consumption rates of the Santa Monica Bay study (SFEI, 2000). Another difference between the two studies was that the Santa Monica Bay study used a 5.3 ounce (150 g) portion model while the SF Bay study used an 8 ounce (227 g) portion model. The model size appears to have influenced the responses in both studies. Whether the different model sizes would widen or narrow the consumption rate difference between the two studies is not known.

In the Save the Bay study, the median consumption rate (32 g/d) was considerably higher than the unadjusted consumption rates of the other two California studies. However, only 7-day recall of fish consumption was surveyed among interviewed anglers. This short recall period creates an even smaller subset of all anglers

compared to the 4-week recall used in the California studies, and also selectively includes anglers with the highest consumption rates.

Other factors unrelated to methodologies that may contribute to consumption rate differences among studies include differences in climate, fishery production, year of study, and demographic characteristics. As noted in Section 9.~~4~~5.3.4, the California Central Valley Delta study by Shilling et al. (2010) contained a high number of subsistence anglers that reported catching fish in order to feed their families. This study also did not correct the consumption rate for avidity bias. Even so, consumption rates among the Central Valley Delta anglers are similar to avidity-adjusted rates in Table 9.3. This study suggests that a greater proportion of this population of subsistence anglers gives the fish they catch to their families, and this may account for the high consumption rate of household family members shown in Table 9.~~2~~4.

Table 9.~~3~~ 5 Comparison of Consumption Rates (in g/day) for the San Francisco Bay Seafood Consumption Study, Santa Monica Bay Study, Save the Bay Study and the Central Valley Delta Study[a]

	Adjusted SF Bay Study[b]	**Adjusted Santa Monica Study[c]**	**Unadjust-ed SF Bay Study[b]**	**Unadjust-ed Santa Monica Study[c]**	**Save the Bay Study[d]**	**Central Valley Study[e]**
Respondents	n=1152	[f]	n=1331	n=1244	n=222	[f]
Population used to derive consumption rate (% of respondents)	n=465 (40%)	[f]	n=501 (38%)	n=555 (45%)	n=62 (27%)	n=373 ([f])
	4-week recall	4-week recall	4-week recall	4-week recall	7-day recall	4-week recall
Mean (Standard Deviation)	23.0 (32.1)	30.5 (45)	28.0 (39.5)	49.6 (111.1)	[f]	27.4 ([f])
Geometric Mean	14.0	[f]	16.5	23.6	[f]	[f]
50th Percentile	16.0	15.0	16.0	21.4	32	19.7
90th Percentile	48.0	62.4	56.0	107.1	[f]	[f]
95th Percentile	80.0	85.2	108.0	161	[f]	126.6

[a] Table modified from SFEI (2000)
[b] SFEI, 2000; [c] Allen et al. (1996); [d] Wong, 1997; [e] Shilling et al. (2010)
[f] Not reported

9.~~6~~7 Comparison of Freshwater and Marine Fish Consumption Rate Studies

Although the California fish consumption rate studies are derived from a population fishing from marine water bodies, a similar distribution of consumption rates also

occurred from data obtained of populations fishing from freshwater bodies. For example, Murray and Burmaster (1994) calculated mean rates for non-avidity-biased consumption of Michigan sport-caught freshwater fish by anglers as 45.0 g/d for self-caught fish in general, and 40.9 g/d for anglers consuming fish from the Great Lakes, in particular. Meredith and Malvestuto (1996) reported an avidity-biased consumption rate of 30.3 g/d for specific study sites in Alabama, and 45.8 g/d for all sport-caught meals caught in the state. These mean values fall between the adjusted mean for the SF Bay study (23.0 g/d) and the unadjusted mean for the Santa Monica Bay study (49.6 g/d) shown in Table 9.~~1~~5. These saltwater and freshwater studies were comparable in many study parameters and in analytical evaluation and, thus, can be reasonably used to support angler-caught freshwater fish consumption estimates in California.

The Washington King County Lakes study (Mayfield et al., 2007) exhibited a lower mean angler consumption rate of 10 g/day for freshwater fish compared to the Alabama and Michigan studies. The lower consumption rate in the Washington study is likely due to differences in methodology. Anglers that had not eaten sport fish in the previous month were included in the consumption rate analysis, whereas the Alabama and Michigan studies excluded anglers who had not eaten sport fish in the previous month. Thus, the Alabama and Michigan studies target the angler population that are the most frequent consumers of sport fish.

A more analogous comparison to the Washington King County Lakes study might be made with the unadjusted mean fish consumption rate based on 12-month recall in the SF Bay study. A lower mean consumption rate of 11.0 g/d was recorded for this group, which includes frequent (i.e., consumed sport fish in the last 4 weeks) and infrequent (i.e., consumed sport fish in the previous year, but not in the previous 4 weeks) anglers. The Washington King County Lakes mean consumption rate of 10 g/d is similar, using the assumption that this consumption rate includes both frequent and infrequent anglers that probably consumed sport fish in the previous year.

9.~~7~~8 Determination of Fish Consumption Distribution

9.~~7~~8.1 Choice of Study

The data from the San Francisco Bay ~~Sea~~ Seafood Consumption Study (SFEI, 2000) were determined to be the most comprehensive and appropriate report for our estimation of average daily sport fish consumption in California. The SF Bay study was chosen over the other major California fish consumption studies in Table 9.~~3~~ 5 because it represents the most recent well-conducted study of a California population. The SF Bay study applies to salt water sport-caught fish, whereas the “Hot Spots” program primarily applies to consumption of contaminated fresh water sport fish. However, as discussed above, comparable fish consumption rates have been observed for both marine and fresh water angler populations. If comprehensive and reliable data become available which describe consumption of freshwater sport fish in California, the current consumption rate values will be revised

The Central Valley Delta fish consumption study by Shilling et al. (2010) was ~~also~~ considered. This study contained a high number of subsistence anglers and did not correct for avidity bias. However, the consumption rate of 27.4 g/day for all anglers, and the body weight adjusted value of 0.33 g/kg-day compared well to the SF Bay study avidity-corrected average consumption rates of 28.8 g/day and 0.36 g/kg-day, respectively, for adults (see Table 9.~~5~~ 1).

9.~~7~~8.2 Statistical Correction for Unequal Sampling Probabilities

Samples obtained from on-site surveys, such as the SF Bay and Santa Monica Bay fish consumption rate studies, can provide estimates of the distribution of fish consumption rates for the total angler population being sampled. In order to obtain unbiased estimates for the total angler population in the SF Bay study, the estimates were (1) adjusted for sources of unequal sampling probabilities in fishing frequency, leading to avidity bias, and (2) examined for the effect of interview decliners on the consumption rate estimate.

9.~~7~~8.2.1 Avidity Bias

How frequently anglers go fishing (i.e., their avidity) can vary widely among anglers. Some may fish daily while others may fish only once per year. In on-site surveys, how often an angler goes fishing determines how likely he or she will be included in the survey. Generally, avid anglers will be over represented in the sample and infrequent anglers will be under represented, resulting in avidity bias (Price et al., 1994; U.S. EPA, 1997; OEHHA, 2001).

Avidity bias presents a concern when an angler's avidity is correlated with important parameters that are being studied, such as consumption rate. If no correlation exists, there is no bias and data adjustments will not change the results. However, if correlation exists, the sample will not accurately reflect the overall angler population. Adjusting for avidity bias allows for the results to more closely reflect general exposure of the target population of the study (i.e., San Francisco Bay anglers), and to determine a point estimate for the California fish consumption rate.

In the SF Bay study, sample data were adjusted for avidity bias by weighting the respondents in proportion to the inverse of their sampling probability during the four weeks prior to the interview. The algorithm for the statistical adjustment for avidity bias can be found in the report. For cases where the target population is the general fishing population and fish is not a major exposure pathway, as can be expected in most cases under the "Hot Spots" program, the adjusted (weighted) results that correct for avidity bias are recommended. However, if the target fishing population are fishers that consume sport fish on a regular and frequent basis (i.e., at least once per month), the unadjusted values are considered most relevant (OEHHA, 2001). For risks associated with a single fish species from a water body (i.e., single pathway exposures where fish consumption is a major pathway), it has been recommended that the unadjusted values

representing the median and the 90th percentile be used to characterize the population at risk (SCCWRP and MBC, 1994; OEHHA, 2001)

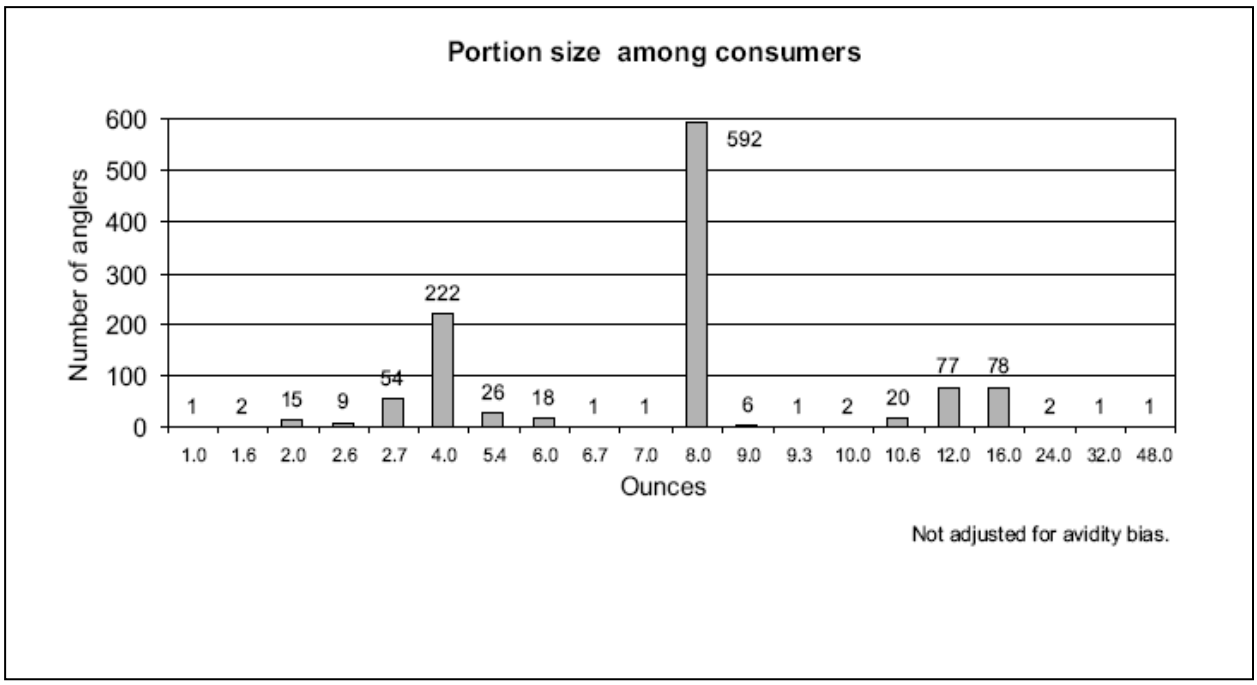
9.~~7~~8.2.2 Influence of Interview Decliners on the Fish Consumption Rate

Anglers who declined to be interviewed for the SF Bay study represented 23% (n=407) of the net attempted interviews. Lacking data on nearly one fourth of the sample may have introduced some bias. As a worst-case scenario, it was assumed that all decliners had recent consumption (in the last four weeks) of Bay fish, to ensure that the influence of decliners did not result in an underestimation of overall consumption rates of recent consumers. Because ethnicity was the only demographic variable that showed a significant influence on consumption rate, the sample was adjusted to account for ethnic differences between the decliners and interviewed anglers. This was done by assuming that decliners of a certain ethnic group had the same consumption rate as recent consumers interviewed in the same ethnic group. Although any bias associated with anglers who declined to be interviewed is not quantifiable, the analysis using reasonable assumptions about this group revealed that the 23% of anglers from whom the researchers could not directly obtain consumption data were unlikely to influence the overall derived consumption estimates.

9.~~7~~8.3 Graphical and Statistical Presentation of Consumption Rate Distributions

Figure 9-1 shows the portion size responses among consumers from the SF Bay study (SFEI, 2000) as a distribution. Portion size responses for consumers and recent consumers (i.e., anglers who reported consuming SF Bay fish in the last four weeks) were similar. In general, anglers gave portion size responses in multiples or fractions of the 8-ounce fish fillet model they were shown during the interview. Just over half of consumers reported that the 8-ounce model was equal to the amount they eat at one time, and the overall mean portion size for consumers was 7.7 ounces.

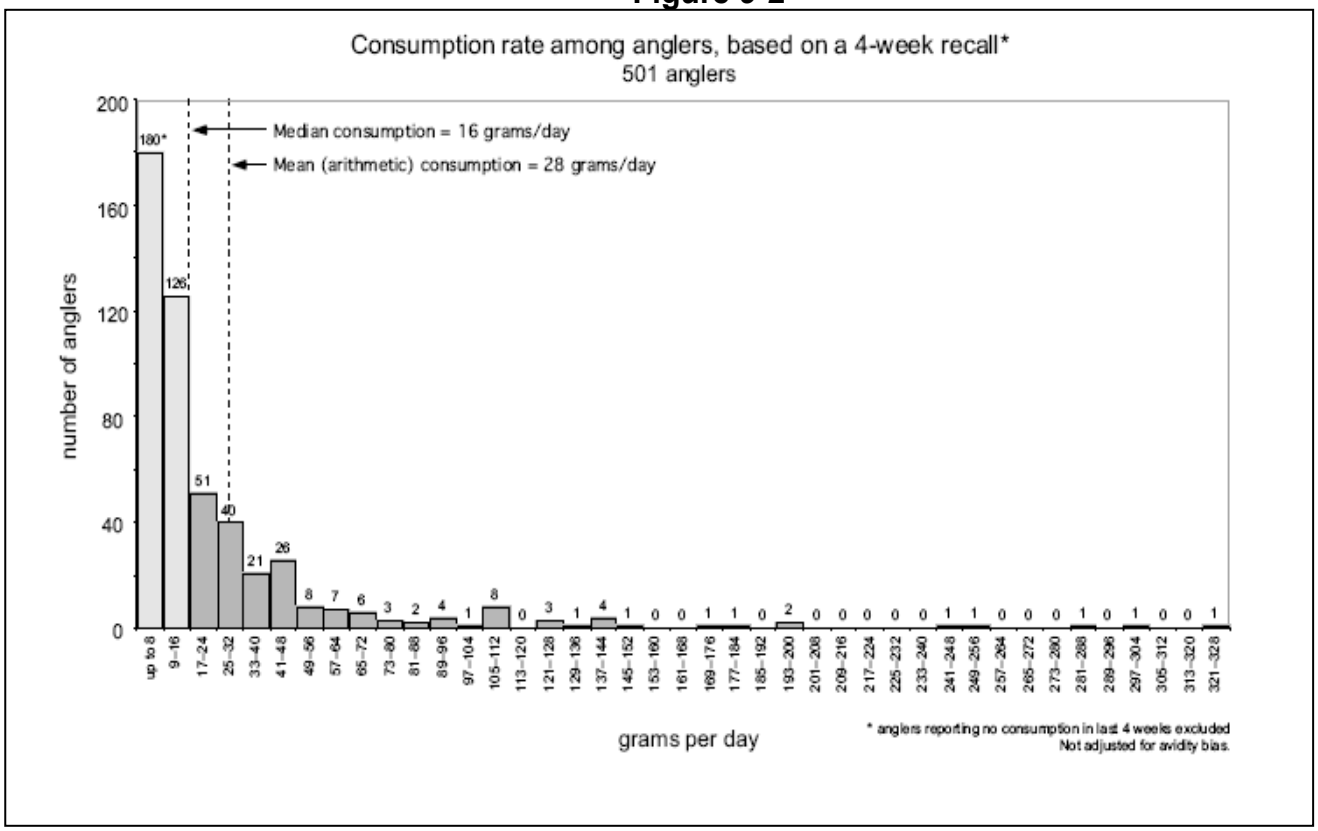
Figure 9-1



(Reprinted from SFEI, 2000))

Multiplying portion size by meal frequency responses provided by the anglers during the interview gives the consumption rate. Figure 9-2 shows the raw (untransformed) data for consumption rate distribution for recent consumers.

Figure 9-2



(Reprinted from SFEI, 2000)

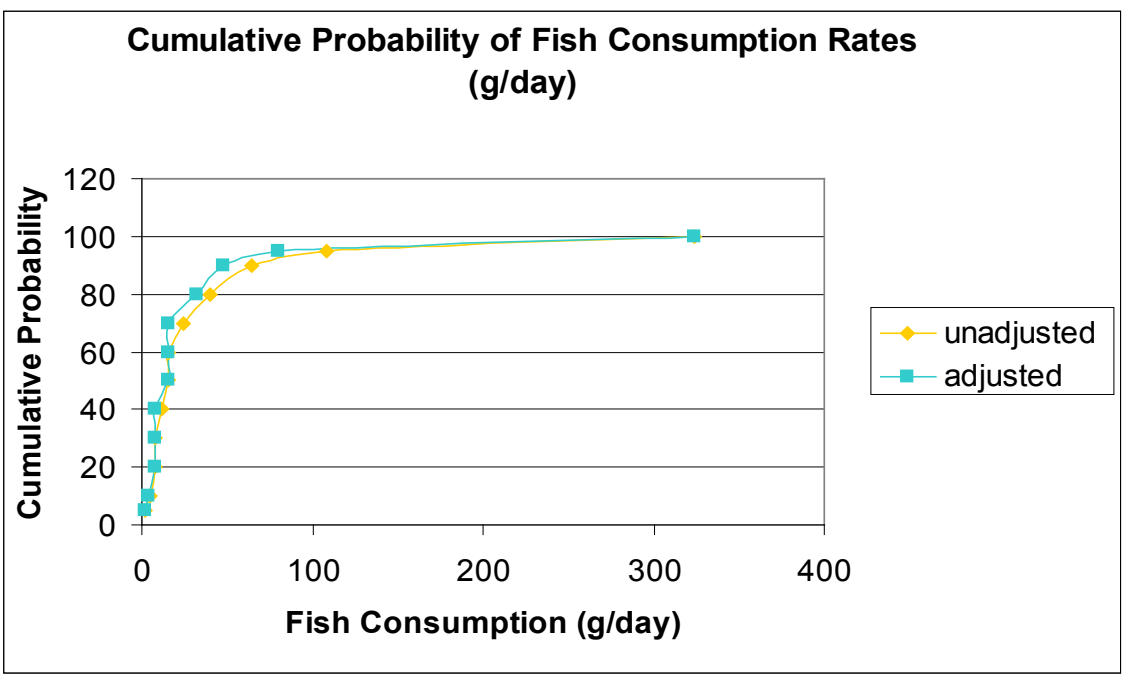
The cumulative empirical distribution curves for the rate of fish consumption for all anglers who caught Bay fish in the SF Bay survey, both unadjusted and adjusted for avidity bias, are shown in Fig. 9-3. The fish consumption rate distribution is highly skewed to the right with a long upper tail, characteristic of a lognormal distribution. The skewness and kurtosis, shown in Table 9.~~4~~6, are positive. A positive skewness indicates a distribution with a tail to the right. In other words, skewness is an indicator of the lack of symmetry of the distribution. The kurtosis indicates heaviness of the tails. Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak.

The best fit for the empirical distribution of avidity adjusted fish consumption rates was checked using Crystal Ball (Decisioneering, 2008). The best fit was the lognormal distribution based on the Anderson-Darling, Chi-square, and Kolgomorov-Smirnov goodness of fit tests. The Anderson-Darling test was the most important for our

purposes because it gave greater weight to the tails of the distribution. The right tail represents the most highly exposed in the population so it is important to properly characterize this region of the distribution. Because the lognormal distribution was found to be the best fit, Crystal Ball was also used to fit a lognormal parametric model to the avidity-adjusted data.

Moments and percentiles of the empirical distributions (unadjusted and adjusted for avidity) and of the lognormal fitted avidity adjusted fish consumption rates are presented in Table 9.~~4~~6. Figure 9-4 depicts the cumulative probability distribution of the lognormal fitted data. The lognormally fit distribution is slightly more skewed to the right than the original empirical distribution. Nonetheless, the empirical avidity adjusted distribution was non-continuous, as evidenced by the somewhat staircase appearance of its graphs (Figs 9-2 and 9-3). The 20th, 30th, and 40th cumulative percentiles all had the same consumption rate value (i.e., 8 g/day) (Table 9.~~4~~6). Likewise, the 50th, 60th, and 70th percentiles had a 16 g/day value. Fitting a lognormal distribution to the empirical data smoothes the choppy empirical distribution. Though the empirical distribution was appropriate for the sample, the lognormally fit distribution is likely more realistic for the population. For the empirical data, the unadjusted values are higher than the adjusted values because the correction for avidity bias is crucial to compensate for the increase of fish consumption rates with increased frequency (i.e., avidity) of fishing.

Figure 9-3



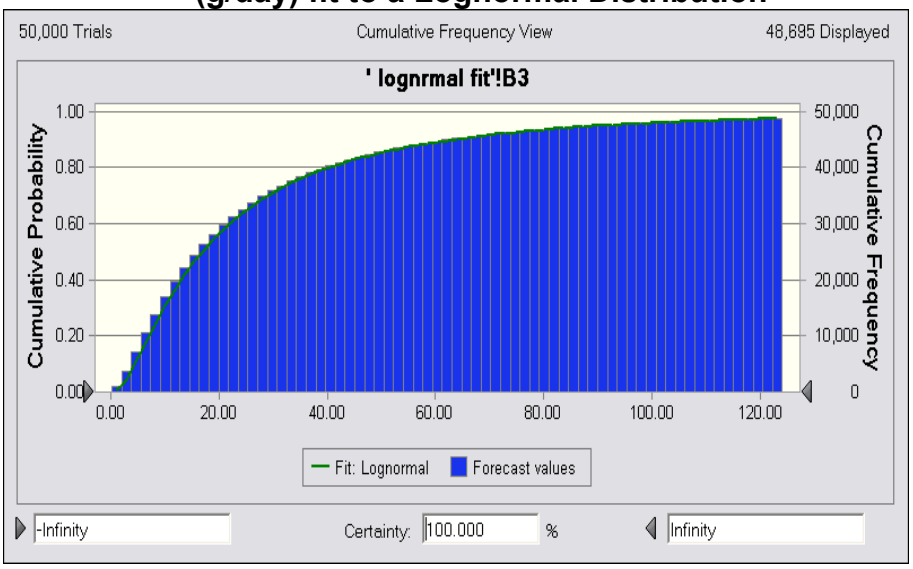
Data source: SFEI (2000)

Table 9.~~4~~6. Comparison of Empirical Distributions and the Recommended Lognormal Model of Fish Consumption Rates for Stochastic Analysis

	Moments and Percentiles (g/day)		
	Empirical Distribution Unadjusted[a]	**Empirical Distribution Avidity-Bias Adjusted[a]**	**Lognormal Parametric Model Fit to Avidity-Bias Adjusted Data**
Geometric Mean	16.55	13.97	[b]
Arithmetic Mean	28.08	23.02	28.8
Standard Deviation	39.63	32.05	39.6
Skewness	3.9	[b]	6.7
Kurtosis	19.9	[b]	140.3
PERCENTILES			
Sample Minimum	2.00	2.00	0.0
10	5.33	4.00	4.5
20	8.00	8.00	7.1
30	8.00	8.00	9.9
40	12.00	8.00	13.0
50	16.00	16.00	16.9
60	16.00	16.00	22.0
70	24.00	16.00	29.0
80	36.00	32.00	40.3
90	56.00	48.00	63.4
95	108.00	80.00	92.4
99	[b]	[b]	177.0
Sample Maximum	324.00	324.00	[c]

[a] Data from SFEI (2000), Appendix K, Table K29
[b] Not Reported
[c] Not Applicable

Figure 9-4 Cumulative Probability of Avidity Adjusted Fish Consumption Rates (g/day) fit to a Lognormal Distribution



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10. Body Weight

10.1 Introduction

Body weight is an important variate in risk assessment that is used in calculating dose (mg/kg body wt). ~~Some~~ Many of the point estimates and distributions of exposure variates are based on studies that ~~OEHHA used to generate distributions and point estimates for variates~~ collected body weight data on individual subjects. For example, the food consumption rate data for each subject collected in the Continuing Survey of Food Intake Among Individuals (USDA, 2000) was divided by the body weight of that subject, and distributions of consumption per unit body weight per day were generated. However, a few of variates (i.e., fish consumption and soil ingestion)~~the studies used by OEHHA, such as the one used to determine fish consumption rate distributions and point estimates,~~ are based on studies that did not collect body weight information on the individual subjects. Therefore a review of the body weight literature was conducted and appropriate body weight defaults were selected to use to calculate the dose in mg/kg body weight in risk assessments for exposure via fish consumption and soil ingestion. Note that the fish consumption pathway has been very rarely invoked in the Hot Spots program.

10.2 Recommended Point Estimates for Body Weights

[Note: This section was moved from the back to the front]
Recommended body weight point estimates in Table 10.1 for specific age groupings are based on raw data for age-specific body weights of U.S. residents collected in the National Health and Nutrition Examination Surveys (NHANES) discussed below in Section 10.3. The measured NHANES-derived body weight data likely represent most accurate estimates of body weight for Californians and U.S. citizens.

In the interest of simplicity males and females are averaged. Little gender-based data is available for the two variates in which these body weight information is used, namely soil ingestion and angler-caught fish consumption. OEHHA concluded that the additional level of refinement by gender for body weight to use in these two exposure pathways does not add enough useful information to a risk assessment to warrant the increased complexity of the assessment. If a toxicant affects only one or predominantly one gender, the assessor may want to adjust point estimates and distributions of intake parameters to reflect body weight of the gender in question. However, such an adjustment will not result in a significant change in the results of the risk assessment.

Table 10.1. Mean Point Estimates for Body Weight (Kg)

Age Range (years)	Mean
0<2	9.7
2<9	21.9
2<16	37.0
16<30	75.9

16-70	80.0

Although body weight data of Californians are available, the data are self-reported (See Section 10.4, The California Health Interview Survey). Comparison of the NHANES and California Health Interview Survey datasets presented in Tables 10.4 and 10.7, respectively, shows that California body weight values are similar to the NHANES body weights, but consistently lower in most age groups by <1 to 12%. These generally small differences could mean that self-reported body weights are often underestimated by the CHIS participants. Another possibility is that Californians have body weights that are lower compared to the rest of the U.S. Obesity trends in the U.S. show a lower prevalence for obesity in California compared to many other states (CDC, 2009). However, because the California body weight data was self-reported and NHANES body weight data was not, we chose to utilize the NHANES data.

OEHHA is not recommending body weight distributions for a stochastic approach because most of the consumption rate distributions that we derive from raw data, or recommend from the literature already incorporate subject body weight. It may be appropriate to use body weight distributions when the correlation between body weight and the consumption rate of interest is known. For the fish consumption distribution we have chosen to divide the consumption distribution by a point estimate of body weight because the correlation is not known. If body weight distributions are used without the appropriate correlation, broad distributions are generated that may overestimate the variability in the parameter of interest. We do not have enough information to derive appropriate soil ingestion distributions; thus, use of a point estimate for body weight is appropriate.

10.~~2~~3 Body Weights Derived from the National Health and Nutrition Examination Surveys (NHANES)

The data collected by NHANES includes detailed anthropometric measurements such as body weight for assessments on the health and nutrition status of U.S. residents (CDC, 2006). The most comprehensive surveys (NHANES II, and III) for body weight were conducted periodically by the National Center for Health Statistics (NCHS) since the 1970s. However, NHANES became a continuous survey in 1999. As anthropometric reference data collection for children and adults is ongoing, 2-year data sets are released as more data become available. The survey samples are nationally representative, from birth to 80+ years of age, from the civilian, non-institutionalized population of the United States. Body weights were recorded for individuals wearing disposable gowns and socks to the nearest 0.1 kg. Some subpopulation subgroups (low income, preschool children, elderly) were oversampled to ensure that sufficient numbers of subjects are available to support estimation to the specified level of precision.

NHANES body weight data represent the most current information on body weight of the U.S. population. NHANES has a large sample size and provides raw data from which interindividual variability can be assessed and categorized by specific age

groupings. The body weights recorded for the NHANES reports also have the advantage of being directly measured rather than self-reported.

The most current information on body weights is preferred and summarized in this document because of the rapid increase in obesity incidence in U.S. residents over the last 30 years (Portier et al., 2007). Thus, earlier studies of body weight distributions derived from the NHANES II, including Brainard and Burmaster (1992), Burmaster and Hull (1997), Burmaster and Crouch (1997), and Finley et al. (1994), are not summarized here but can be found in the first edition of this document (OEHHA, 2000).

10.~~2~~3.1 NCHS Analysis of NHANES 2003-2006 body weight data

The most recently published study by the NCHS that presented NHANES-generated body weight distributions used a combined 4-year dataset based on 2003-2004 and 2005-2006 data (McDowell et al., 2008). A 4-year dataset improves the stability and reliability of the statistical estimates for subgroup analysis. Adolescents 12-19 years of age, persons 60 years of age or older, Mexican Americans, black persons, and low-income persons were oversampled to improve the precision of the statistical estimates for these groups. The 2003-2006 analytic sample was based on 19,593 persons and excluded pregnant females from body weight tabulations. Mean, standard error, and selected percentiles by age group and sex are shown in Table 10.~~1~~2.

Table 10.~~1~~2. Body Weight in Kg for Children and Adults Derived by NCHS From NHANES 2003-2006

Age Category	Body Weight Means and Percentiles in Kg									
	Males [a]					Females [b]				
	Mean	SE	50th	90th	95th	Mean	SE	50th	90th	95th
0-2 mo	5.2	0.12	5.2	[c]	[c]	4.9	0.10	4.9	[c]	[c]
3-5 mo	7.3	0.08	7.2	8.2	[c]	6.8	0.10	6.6	[c]	[c]
6-8 mo	8.4	0.13	8.4	9.9	[c]	8.1	0.13	8.0	[c]	[c]
9-11 mo	9.7	0.15	9.7	[c]	[c]	9.2	0.11	9.0	[c]	[c]
1 yr	11.6	0.12	11.5	13.8	14.4	10.9	0.11	10.9	13.0	13.4
2 yr	14.1	0.14	13.9	16.4	16.9	13.4	0.13	13.1	16.1	16.8
3 yr	15.8	0.16	15.3	18.7	[c]	15.8	0.20	15.5	18.5	[c]
4 yr	18.6	0.31	18.1	22.7	[c]	17.9	0.21	17.5	20.8	[c]
5 yr	22.1	0.49	21.0	26.9	[c]	20.5	0.37	19.6	25.5	[c]
6 yr	24.2	0.33	23.7	29.5	[c]	23.4	0.49	22.1	29.7	[c]
7 yr	26.6	0.58	25.6	33.9	[c]	27.3	0.62	25.7	35.5	[c]
8 yr	31.4	0.90	29.0	41.9	[c]	30.7	0.94	28.2	42.1	[c]
9 yr	34.6	0.71	32.3	44.1	[c]	36.7	0.99	34.0	50.7	[c]
10 yr	40.1	0.86	37.3	56.8	[c]	42.4	1.07	40.5	58.5	[c]
11 yr	46.8	1.62	44.2	67.0	[c]	49.2	1.31	47.3	68.2	[c]
12 yr	50.8	1.23	46.9	72.8	82.9	52.9	1.31	49.5	76.2	[c]
13 yr	57.8	1.37	55.6	81.0	90.9	57.4	0.98	54.4	76.0	88.5
14 yr	63.1	1.73	59.8	84.3	99.1	58.8	1.75	54.4	81.0	[c]
15 yr	70.2	1.36	66.3	89.9	100.4	60.9	0.76	57.6	81.0	[c]
16 yr	76.1	1.50	70.7	101.9	116.1	61.5	0.95	58.8	79.6	[c]
17 yr	75.0	1.30	70.6	101.3	111.0	66.0	1.66	60.6	87.3	[c]
18 yr	77.2	1.67	72.7	105.8	110.4	67.6	2.15	63.0	92.1	[c]
19 yr	80.2	1.69	76.5	107.3	117.3	67.4	1.79	63.0	92.7	[c]
20-29 yr	85.4	1.06	81.1	111.5	122.6	70.7	1.03	65.3	98.6	110.7
30-39 yr	88.1	0.80	85.9	109.6	120.8	74.7	1.06	70.2	101.7	114.2
40-49 yr	91.8	0.83	88.9	114.0	124.7	77.7	1.03	72.9	106.6	116.9
50-59 yr	90.2	0.95	88.7	113.1	124.4	78.0	1.15	73.7	106.3	117.8
60-69 yr	90.0	0.98	88.0	112.9	121.3	77.3	0.91	74.0	102.0	112.9
70-79 yr	85.0	0.92	83.8	104.5	116.7	70.6	1.07	68.3	91.2	98.9
20 yrs and over	88.3	0.46	85.6	111.5	122.6	74.7	0.53	70.7	101.8	113.6

[a] For male children age groups, n ranged from 101 to 360; for male adult 10-year age groups, n ranged from 555 to 811.
[b] For female children age groups, n ranged from 81 to 335; for female adult 10-year age groups, n ranged from 468 to 779.
[c] Figure does not meet standards of reliability or precision.

In Table 10.~~1~~2, estimation of some of the higher percentiles (90th and 95th) did not meet standards of reliability or precision. The reliability of the estimates was evaluated using the relative standard error (RSE), which is calculated by dividing the standard error by

the estimate, and the minimum sample size criterion. NCHS recommends that an estimate with an RSE greater than 30 percent be considered unreliable.

10.~~2~~3.2 U.S. EPA Analysis of NHANES 1999-2006 body weight data

The U.S. EPA analyzed data from the 1999-2006 NHANES to generate distributions of body weight for various age ranges of children in their Child-Specific Exposure Factors Handbook (U.S. EPA, 2008). Because four NHANES datasets were utilized in the analysis (NHANES 1999-2000, 2001-2002, 2003-2004, and 2005-2006) containing approximately 20,000 children, sample weights were developed for the combined dataset in accordance with CDC guidance. Mean and selected percentile body weights for specified age groups derived from NHANES are presented in Table 10.~~2~~ 3 for males and females combined.

Table 10.~~2~~3. Body Weight For Children in Kg Derived by U.S. EPA (2008) From NHANES 1999-2006, Males and Females Combined

Age Group	N	Body Weight Means and Percentiles in Kg				
		Mean	50th	75th	90th	95th
Birth to < 1 mo	158	4.8	4.8	5.1	5.8	6.2
1 to <3 mo	284	5.9	5.9	6.6	7.1	7.3
3 to <6 mo	489	7.4	7.3	8.0	8.7	9.1
6 to <12 mo	927	9.2	9.1	10.1	10.8	11.3
1 to <2 yr	1176	11.4	11.3	12.4	13.4	14.0
2 to <3 yr	1144	13.8	13.6	14.9	16.3	17.1
3 to <6 yr	2318	18.6	17.8	20.3	23.6	26.2
6 to <11 yr	3593	31.8	29.3	36.8	45.6	52.5
11 to <16 yr	5297	56.8	54.2	65.0	79.3	88.8
16 to <21 yr	4851	71.6	67.6	80.6	97.7	108.0

For our objectives, the OEHHA stochastic risk assessment approach is focused on chronic exposure and on deriving parameter distributions for use in assessing cancer risk weighted by age-at-exposure. Thus, we need age groupings that represent 0<2, 2<9, 2<16, 16<30, and 16-70 yrs. The U.S. EPA's body weight data for specified age groups would be useful for assessing hazard for acute and subchronic exposures.

10.~~2~~3.3 OEHHA Analysis of NHANES 1999-2006 body weight data

The body weight estimates derived by OEHHA in this document consist of a combined 8-year NHANES dataset from 1999 to 2006, each one spanning 2 years (1999-2000, 2001-2002, 2003-2004, and 2005-2006) (NCHS, 2005; 2006; 2007). As of this writing, the 2007-2008 NHANES dataset results had not been finalized. The NHANES body weight data represent the most current information on body weight. NHANES has a large sample size and provides raw data from which OEHHA can assess interindividual variability and categorize by specific age groupings for the purposes of the "Hot Spots" program. Since the survey was meant to be representative of the U.S. population, the

raw data were weighted to reflect the age structure, sex and race of the population at the time of the survey.

The NHANES data included the body weight and age for each participant, so participants were placed into the age groupings consistent with OEHHA's "Hot Spots" program. The body weights for each age group were fit to a lognormal distribution using Crystal Ball® (Decisioneering, 2009). Crystal Ball® was also used to determine the best parametric model fit for the distribution of body weights for each age group. The Anderson-Darling goodness-of-fit test was chosen to determine the best fit distribution because this test specifically gives greater weight to the tails than to the center of the distribution. OEHHA is interested in the tails since the right tail represents the high-end (e.g., 95th percentile) body weights.

For each age group, males and females combined, the mean, and percentiles (50th, 75th, 90th, and 95th) of the body weight distributions are presented in Table 10.~~3~~4.

Table 10.~~3~~4. OEHHA-Derived Body Weight Distributional Results Based on the NHANES IV 1999-2006 Surveys, Males and Females Combined

Age Range (years)	N	Body Weight Mean and Percentiles (in kg)				
		Mean	50th	75th	90th	95th
0<2	3034	9.7	9.9	11.5	12.7	13.4
2<9	5626	21.9	20.3	25.5	32.7	36.8
2<16	12,352	37.0	32.1	50.1	64.3	74.8
16<30	8083	75.9	72.1	85.9	102.8	114.9
16-70	32,012	80.0	77.4	91.5	106.6	116.8

Directly measured body weights that are representative of the U.S. population and the large sample sizes are clear advantages for using these body weight distributions. The limitation for using NHANES body weight data is that it is not California-specific; the body weights collected from California participants could not be removed from the report and analyzed separately.

10.2.4 Analysis of NHANES data for body weight changes over time

Distributional changes in body weight over a 24-year period were investigated by Portier et al. (2007) based on NHANES data from three different surveys (II, 1976-1980; III, 1988-1994; IV 1999-2002). For each of the three body weight data sets, the weighted mean and standard deviation of natural log-transformed body weights were computed for single-year age groups and population-specific weight patterns further described using piece-wise polynomial spline functions and nonparametric age-smoothed trend lines.

The analysis demonstrated that there were changes in body weight as well as changes in age-specific distributions over the 24-year time period (Table 10.~~4~~5). However, the

changes were not constant for all ages. For the most part, mean body weights of children (1-6 yrs) did not change for males, and there was only about a 1 kg change in females from NHANES III to IV. Similarly, there was no change for adolescent males (7-16 years), but there was an upward change in female adolescent average body weight of about 4 kg from the NHANES II to IV surveys. The major differences occurred among adults, where mean body weight for males (18-65 yrs) showed an upward trend of about 3.5 to 4 kg between each survey with about a 4 to 5 kg increase for females (18-65 yrs). Percentile distributions by age group were not provided. This study demonstrates the changing nature of body weights in the U.S. population and the value of using the most recent data for risk assessment purposes.

Table 10.~~4~~5. Comparison of Body Weights in Kg for Selected Age Groupings from NHANES II, III AND IV Surveys

Age Range (years)	NHANES	Male		Female		Overall Male and Female	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1-6	II	17.04	4.58	16.34	4.70	16.66	4.47
	III	16.88	4.70	16.52	4.91	16.75	4.98
	IV	17.10	4.86	17.46	5.02	17.27	4.97
7-16	II	45.15	17.64	43.93	15.91	44.75	17.49
	III	49.34	20.94	46.77	18.02	47.76	18.40
	IV	47.86	20.10	47.87	19.19	47.73	19.13
18-65	II	78.65	13.23	65.47	13.77	71.23	11.97
	III	82.19	16.18	69.45	16.55	75.61	18.02
	IV	85.47	19.03	74.55	19.32	79.96	20.73
65+	II	74.45	13.05	66.26	13.25	69.56	12.20
	III	79.42	14.66	66.76	14.52	72.25	15.71
	IV	83.50	16.35	69.59	14.63	75.54	15.88

10.~~2~~3.5 Child Growth Charts Derived from NHANES data

Child growth charts, including weight-for-age data, were published by the Centers for Disease Control (Kuczmarski et al., 2002) using improved statistical smoothing procedures in conjunction with several national surveys (NHANES II and III, NHANES I, II and III). Growth charts and percentile distributions for weight by sex and age were presented in two sets of data: Birth to 36 months (infants) and 2 to 20 years (children and adolescents). The surveys were pooled because no single survey in the NHANES series had enough observations to construct growth charts. Sample sizes from 400 to 500 were required to achieve precision of the empirical percentiles at the specific ages for the curve fitting. The weight-for-age curves were smoothed using a 3-parameter linear model and locally weighted regression.

The evaluation of the growth charts found no large or systematic differences between the smoothed percentiles and the empirical data. Very low birth weight (VLBW) infants were excluded from the infant percentiles, but included in the older child percentile

where the effect of VLBW is diminished. The observed mean, standard deviation, and selected percentiles were presented in one month age intervals for infants (birth to 36 months), and 0.5-year intervals for children and adolescents ages 2-20 years.

More recent children body weight results derived from NHANES data have been published and presented above (McDowell et al., 2008; U.S. EPA, 2008), so the CDC growth charts are not reprinted here in this document. However, the growth charts can be downloaded from the website in the listed citation by Kuczmarski et al. (2002) below. The report did not address the upward trend in weight of female children over time noted by Portier et al. (2007), possibly because the later release of NHANES IV survey data (1999-2002) strengthened the observed trend that was not yet firmly established by the earlier surveys used in the CDC report.

10.~~3~~4 California Health Interview Survey

The California Health Interview Survey (CHIS) is conducted by the California Department of Health Services every two years, with the most recent published survey data collected in 2005 (CHIS, 2006). CHIS is the largest population-based state health survey including individual health information such as health conditions and limitations, health behaviors, and health care access and health insurance coverage information. The report used the same method to adjust for non-response as that used by NHANES, correcting for several factors (e.g., race, ethnicity, household income, etc.) in order to make the body weights more representative of the California population. The individual self-reported body weight information is available to researchers in a statistical program format.

Because body weight and age information was collected for each participant, OEHHA combined the data into the specified age groups and fit a lognormal distribution to their body weights using Crystal Ball® (Decisioneering, 2009), same as that performed for the NHANES body weight data. The best parametric model fit for the distribution of body weights was determined for each age group and the Anderson-Darling test was used for goodness-of-fit. For each age group, males and females combined, minimum and maximum values, mean, standard error of the mean, and percentiles of the body weight distributions are presented in Table 10.6.

Table 10.6. Body Weight Distributional Data from the California Health Interview Survey, Males and Females Combined

Age Group (years)	N	Body Weight Mean and Percentiles (in kg)						
		Min	Max	Mean	SEM	50%	90%	95%
0<2	1,927	3	32	9.4	0.07	10	13	14
2<9	6,022	9	79	21.4	0.095	20	31	36
2<16	11,719	9	145	36.6	0.176	32	62	71
16<30	6,367	41	150	72.1	0.22	68	95	107
16<70	37,108	41	150	76.0	0.095	73	100	109

Although the state-wide body weight database is specific for Californians, it is self-reported. Self-reported body weights are often underestimated by the participants. The survey, which was conducted by phone, reported a relatively low response rate of 29.2%. However, the report noted that this nonresponse rate was similar to the rate for other phone surveys, and the sampling weights used in the analysis would be expected to adjust much of the bias associated with the high nonresponse rate.

10.~~4~~5 Analysis of CSFII body weight data

The U. S. Department of Agriculture (USDA) conducts a continuing survey of the food intakes by individuals. Self-reported body weight data were collected during the USDA's 1994-1996 and 1998 Continuing Survey of Food Intake by Individuals (CSFII), which was a multistage probability sample survey of individuals within U.S. households. Distributions of body weights by different age categories from this survey were calculated by Kahn and Stralka (2009) and shown in Table 10.7.

Table 10.7. Body Weight Distrib~~t~~utions from the CSFII, Males and Females Combined

Age Group	N	Body Weight Mean and Percentiles (in kg)				
		Mean	50th	75th	90th	95th
<1 mo	88	4	3	4	4[a]	5[a]
1 to <3 mo	245	5	5	6	6	7[a]
3 to <6 mo	411	7	7	8	9	10
6 to <12 mo	678	9	9	10	11	12
1 to <2 yr	1002	12	11	13	14	15
2 to <3 yr	994	14	14	16	18	19
3 to <6 yr	4112	18	18	20	23	25
6 to <11 yr	1553	30	27	35	41	45
11 to <16 yr	975	54	52	61	72	82
16 to <18 yr	360	67	63	73	86	100[a]
18 to <21 yr	383	69	66	77	89	100[a]
≥21 yr	9049	76	74	86	99	107
≥65 yr	2139	72	71	81	93	100

[a] The sample size did not meet minimum reporting requirements

The CSFII body weight results have the same limitation as the CHIS body weight data, in that self-reported body weights are often underestimated by the participants. Also, more recent and comprehensive national body weight data are collected by NHANES.

10.~~5~~6 International Commission on Radiological Protection

The International Commission on Radiological Protection (ICRP) reviewed and compiled extensive data on anatomical measurements, elemental composition, and physiological values for the human body (ICRP, 2003). Weight (W), length (L), and surface area (SA) during prenatal life are presented as means +/- standard deviation (SD) as a function of gestational age. From the data, a number of allometric relations were derived which

relate gestational age to average length, and length to surface area and weight. Postnatal life data from a number of sources were reviewed. Charts presented in the report show mean body weight ± one SD from 0 to 15 years and adults by sex. However, the bulk of the body weight information is based on Western European data, and it was noted that in some age groupings, differences exist in body weight between North Americans and Europeans.

10.7 References

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11. Residential and Worker Exposure Duration, Individual vs. Population Cancer Risk, and Evaluation of Short Term Projects

11.1 Introduction

This chapter covers topics related to estimating cancer risk for facility-specific emissions under the Air Toxics Hot Spots program. The Hot spots statute mandates the assessment of cancer risks from airborne emissions of stationary sources to people living or working near a specific facility. The duration of exposure for residential and offsite worker receptors influences the estimate of cancer risk from a specific facility. In the past, cancer risk was estimated for the maximally exposed individual resident who was assumed to be at the point of highest exposure to emitted carcinogens 24 hours per day, 7 days per week for a lifetime. This is a health protective but not particularly realistic assumption. To address this problem, ARB and OEHHA evaluated information available on length of residence at a specific address to develop guidance on the duration of exposure for the residential exposure scenario.

Past risk assessments assumed a 40 year exposure duration for offsite workers based on little data. For the offsite worker exposure scenario, ARB and OEHHA evaluated information available on the length of time people work at the same location. Information on the percentage of time people are at home was also evaluated to provide an adjustment based on activity patterns for time away from home.

This chapter also discusses reporting and more explicitly considering population wide cancer risks separately from the traditional maximally exposed individual cancer risk estimate.

Finally, the chapter presents guidance to the Air Districts for evaluating cancer risks from short-term projects in their purview that are not Hot Spots facilities.

11.1.1 Residential Exposure Duration for Cancer Risk Assessment

An assumption of lifetime exposure duration (70 years) for the calculation of cancer risk is incorporated into the unit risk factors, inhalation cancer potency factors and oral cancer potency factors. The cancer potency factors and unit risk factors are estimated from data from long-term worker epidemiological studies or lifetime rodent studies. A lifetime cancer risk of 5×10^{-5} means that in a population of a million chronically exposed individuals ~~for 70 years~~, ~~it would be expected that~~ 50 excess cancer cases would ~~occur~~be predicted. Since the cancer potency factors and unit risk factors are based on lifetime or very long-term studies, there are uncertainties in calculating less than lifetime risk.

A complicating factor in estimating cancer risk is the greater impact of early-in-life exposure. ~~Over the last few years, an increasing number of studies~~Analyses of available data on the influence of age-at-exposure on potency of carcinogens by

OEHHA (OEHHA, 2009) and U.S.EPA (U.S.EPA, 2005, Barton et al., 2005) indicate that early in life exposures to carcinogens are more potent than later in life exposures. ~~There are a variety of reasons why this may occur. Cell division in the younger organism is much more rapid, thus, mutations become fixed before they can be repaired. Metabolism can be less or more efficient and occur through different pathways. Early-in-life cellular damage has a longer amount of time to progress through various stages to cancer. Epigenetic mechanisms may also play a role.~~This is discussed in detail in OEHHA (2009).

In order to address the issue of early-in life exposures, OEHHA has adopted a policy, based on the available scientific data, of weighting cancer risk from exposures from the third trimester to <2 yrs of age by a factor of ten, and exposures from age two to less than sixteen years by a factor of three (OEHHA, 2009). In addition to innate sensitivities to some carcinogens, c~~C~~hildren have greater exposures due to physiological and behavioral factors. As a result, a greater proportion of total lifetime risk is accrued by age 16 with lifetime exposure to a constant air concentration than was previously recognized.

Accumulation of risk over a lifetime is thus no longer assumed linear with increasing length of exposure to a constant dose, but depends on the age at exposure. To further complicate estimation of risk, exposure to a constant air contaminant concentration or soil contaminant concentration over time is also not linear. There are physiological and behavioral differences between adults and children, which results in children's doses (mg/kg body weight) being greater than adults at the same environmental contaminant concentration.

When estimating cancer risk from individual stationary facilities to nearby residents ~~from a stationary facility~~, exposure duration is an important determinant of cancer risk. Cancer risk for residents is also influenced by activity patterns. Exposure duration for the resident near a facility amounts to the time that resident lives in his or her house. Another important factor is the number of hours that the resident spends at his or her residence. This factor varies with age. Section 11.5 discusses available information to use in estimating exposure duration for residential exposure scenarios.

11.1.2 Offsite Worker Exposure Duration for Cancer Risk Assessment

Offsite workers near a stationary source of airborne emissions are treated as members of the public in the Hot Spots program. The length of time that a worker is on the job at a specific location determines the exposure duration and is directly proportional to the cancer risks estimated from a specific stationary source. In the past, OEHHA recommended a default of 40 years for employment tenure. OEHHA has examined the data on job tenure in the United States in order to develop a new data-derived high-end estimate of job tenure that would be public health protective without being unnecessarily conservative. These data are not perfect for this purpose but provide a useful basis for our new recommendation. Section 11.6 discusses available information to use in estimating exposure duration for offsite worker exposure scenarios.

The point estimate risk assessment approach (Tier 1 and 2) can be used with more than one estimate of resident chronic exposure duration to give multiple point estimates of cancer risk. For stochastic risk assessment (Tier 3 and 4), OEHHA recommends calculating separate cancer risk distributions for each fixed chronic exposure duration.~~there are two possible approaches to incorporating duration of exposure.~~ An alternative approach would be to express the variability in exposure duration as a distribution of residency times and equate residency time to exposure duration. The variance in residency times would be propagated through the model and contribute to the variance in the cancer risk. ~~The second approach would be to calculate separate cancer risk distributions for each fixed chronic exposure duration.~~

OEHHA does not recommend a distribution of residence times for our model (Tier ~~I~~II). Since each individual knows the length of time that he or she has resided near the facility, if the 9, 30 and 70-year cancer risks are presented the residents should have a better idea of his or her risk.

11.2 Recommendations *[This section has been moved to the front of the chapter from the back of the chapter; additional recommendations that were scattered in the chapter have been brought forward here]*

11.2.1 Exposure Duration for Estimating Cancer Risk in the Residential and Offsite Worker Exposure Scenarios

OEHHA is recommending that an exposure duration (residency time) of 30 years be used for individual cancer risk determination for the maximally exposed individual resident (MEIR) (Table 11.1). This should provide adequate public health protection against individual risk. Note that the 30 year exposure duration starts in the third trimester to accommodate the increased susceptibility of exposures in early life (OEHHA, 2009), and would apply to both the point estimate and stochastic approaches. Reducing the residency time assumption from 70 years to 30 years will however reduce the protection for the population. Thus, we have recommendations below (Section 11.1.3) for specifically evaluating population cancer risk from facility emissions.

As supplemental information in the risk assessment for the MEIR scenario, OEHHA is recommending that point estimate and stochastic risk estimates also be presented for 9 and 70-year exposure durations, both starting in the third trimester. This will help convey the message to the public that cancer risk is proportional to the duration of exposure (i.e., length of residency near the facility). Different communities may have different patterns of residency duration and the pattern within the community may need to be considered by the risk manager.

Although the data for determining residency duration is less than perfect, it is likely that 30 years is a reasonable estimate of the 90th or 95th percentile of residency duration in a population. Thus, a 30-year residency time is consistent with recommendations for other risk assessment variates in our model. In addition, it should be noted that

accounting for the greater potency of early-in-life exposure using the Age Sensitivity Factors (OEHHA, 2009) means that a smaller fraction of lifetime risk is incurred after age 30.

Note that there is an assumption that after the person moves, he or she is no longer significantly exposed to the emissions from the facility in question. However the larger the isopleths of cancer risks, the greater the probability that the person could be moving into a residence still impacted by the facility. As the size of the cancer risk isopleths increases, the probability that population risk will be more important in terms of public health increases (see discussion in Section 11.7).

OEHHA recommends, based on the available data, that 25 years be used as a reasonable estimate of the 95th percentile of employment duration for the Hot Spots program. Thus, for estimating cancer risk for the offsite worker scenario, a 25 year exposure duration should be used.

The time that a person is away from his or her residence can mean either no exposure to a small facility's emissions, or in the case of a facility with a large isopleth footprint, continuing significant exposure. The available California data do not determine distance from residence during time away from residence (Appendix L). This makes it difficult to come up with a general recommendation, protective of public health, for evaluating risk to the residential MEI during the time that a person is away from the residence. However, OEHHA notes it is appropriate to consider the fraction of time people spend at home as an adjustment for exposure to carcinogens (Table 11.2)

A large fraction of lifetime (70-year) cancer risk and an even larger fraction of the cancer risk for the first 30 years in life is incurred during the first 16 years of life because of the higher risk of early in life exposure. A good fraction of the time away from residence will be spent at school for the first sixteen years of life. Many California schoolchildren attend a local neighborhood school. Therefore, OEHHA is recommending that time away from residence be considered as away from facility emissions (no facility cancer risk) for facilities that do not have a school within the 1 X 10^{-6} or greater cancer risk isopleth. We recommend no adjustment for time away from residence when there are schools inside the 1 X 10^{-6} (or greater) cancer risk isopleth. The larger facilities with multiple emissions sources are most likely to have schools within the 1 X 10^{-6} isopleth and are more likely to cause significant exposure to people while they are away from their residences.

11.2.2 Activity Patterns and Time Spent at Home

OEHHA and ARB evaluated information from activity patterns databases to estimate the percentage of the day that people are home (discussed in Appendix L). This information can be used to adjust exposure duration and risk from a specific facility's emissions, based on the assumption that exposure to the facility's emissions are not occurring away from home. Table L.6 in Appendix L shows the number of minutes spent at home, statewide in California, and the percentage of total time spent at home as well. Ages 0 to 2 spend 85% of their time at home, ages 2 through 15 spend 72% of the their time at home, and ages greater than 15 spend 73% of their time at home (Table 11.2). The data used to determine these percentages were collected by the California Department of Transportation in 2000 and 2001 (Cal Trans, 2001). The time away from the home includes vacations.

11.2.3 Recommendations for Presenting Population Risks

Clear separation of individual risk and population risk and their separate evaluation will be helpful in risk communication and could result in better public health protection and more equitable risk management decisions (further discussed in Section 11.7). The cancer risk estimate based on a 70-year residential exposure does not account for an important aspect of population risk. In particular, large facilities with multiple stacks can dilute emissions over a large area that impact thousands of individuals and theoretically cause a large number of cancer cases, but because of the dilution, the cancer risk estimate for the maximally exposed individual resident, which is what most risk management decisions are based upon, is below a level of concern. A small facility with a single stack, impacting very few individuals due to more concentrated emissions can exceed individual risk limits set by the air districts, thus triggering notification and other measures. The large facility may in fact have a much greater public health impact (greater number of cancer cases) when population risk is considered. There are different methods that can be used as measure of population burden, based on a lifetime (70 year) cancer risk estimate. Calculating cancer burden as described ~~above~~ below is one method. The number of individuals residing within a 1×10^{-6}, 1×10^{-5}, and/or 1×10^{-4} isopleth is another potential measure of population burden (OEHHA, 2003). OEHHA recommends this latter approach for the Hot Spots risk assessments to more explicitly consider population-wide cancer risks from facility emissions. This metric is more easily understood, and provides a metric for population-wide cancer risks that can inform risk management decisions. Cancer burden can also be presented, based on a 70 year lifetime risk estimate.

11.3.3 Recommendations for Exposure Duration for Short-term projects

We recommend that exposure from projects less than 6 months be assumed to last 6 months (e.g., a 2-month project would be evaluated as if it lasted 6 months). Exposure from projects lasting less than two months would not be evaluated for cancer risk. We recommend that exposure from projects lasting more than 6 months be evaluated for the duration of the project. In all cases the exposure should be assumed to start in the

third trimester to allow for the use of the Age Sensitivity Factors (OEHHA, 2009). Thus, if the District is evaluating a proposed 5-year mitigation project at a hazardous waste site, the exposure duration for the residents would be from the third trimester through the first five years of life. The exposure duration for the offsite worker scenario would be five years in this case.

Table 11.1 Summary of Recommendations for Exposure Duration

Receptor	***Recommendation***
Resident	30 years[a]
Resident (supplemental Information)	9 years for central tendency; 70 years for maximum
Worker	25 years

a All durations start with exposure in the third trimester to accomodate use of the Age Sensitivity Factors for early life exposure to carcinogens

Table 11.2 Recommendations for Time Away from Residence for Evaluating Cancer Risk for Facilities Without A School Within the 1 X 10^{-6} (or greater) Cancer Risk Isopleth[1]

Age Range	Fraction of Time at Residence
3rd Trimester<2	0.85
2<16	0.72
16-30	0.73

1Facilities with a school within the 1 X10^{-6} (or greater) cancer risk isopleth should use 1 as the fraction of time at the residence for ages 3rd trimester to less than age 16.

11.4 Cancer Risk Algorithm and Exposure Duration

The following equations for ~~inhalation dose~~cancer risk can accommodate different exposure durations:

~~$DOSE = (C_{air} \times BR \times ED \times FAH \times EF \times 1 \times 10^{-6}) / [AT]$~~

9-year exposure duration - Calculation of Cancer Risk from the Third Trimester to Age Nine:

$$\text{Cancer Risk} = [(ADD_{\text{third trimester}} \times CPF \times 10) \times 0.3\ \text{yrs}/70\ \text{yrs}] + [(ADD_{0\ \text{to}\ <2\text{yrs}} \times CPF \times 10) \times 2\ \text{yrs}/70\ \text{yrs}] + [(ADD_{2 < 9\text{yrs}} \times CPF \times 3) \times 7\ \text{yrs}/70\ \text{yrs}] \times FAH$$

30-year exposure duration - Calculation of Cancer Risk from Third Trimester to Age 30:

$$\text{Cancer Risk} = [(ADD_{\text{third trimester}} \times CPF \times 10) \times 0.3\ \text{yrs}/70\ \text{yrs}] + [(ADD_{0\ \text{to}\ <2\text{yrs}} \times CPF \times 10) \times 2\ \text{yrs}/70\ \text{yrs}] + [(ADD_{2 < 16\text{yrs}} \times CPF \times 3) \times 14\ \text{yrs}/70\ \text{yrs}] +$$

[(ADD$_{16 < 30yrs}$ X CPF X 1) X 14yrs/70 yrs X FAH

Lifetime (70 year) exposure duration - Calculation of Cancer Risk from Third Trimester to Age 70:

Cancer Risk = [(ADD$_{third\ trimester}$ X CPF X 10) X 0.3 yrs/70 yrs] + [(ADD$_{0\ to\ <2yrs}$ X CPF X 10) X 2 yrs/70 yrs] + [(ADD$_{2 < 16yrs}$ X CPF X 3) X 14 yrs/70 yrs]+ [(ADD$_{16 < 70yrs}$ X CPF X 1) X 54 yrs/70 yrs X FAH

where:

ADD = Average Daily Dose, mg/kg-d, for the specified time period (estimated using the exposure variates presented in the TSD)
CPF = Cancer Potency Factor $(mg/kg\text{-}d)^{-1}$
Age Sensitivity Factor third trimester to less than 2 years = 10
Age Sensitivity Factor age 2 to less than 16 years = 3
Age Sensitivity Factor age 16 to less than 70 years = 1
FAH=Fraction of time at home
ED =Exposure duration, in years
1×10^{-6} =Conversion factor ($\mu g/m^3$) to (mg/L)
AT =Averaging time (period over which exposure is averaged, in years); for carcinogenic effects, the averaging time is 70 years = 25,500 days

~~where:~~

~~DOSE = Inhalation dose [(mg/kg body weight)/day]~~
~~C_{air} = Average annual air concentration of contaminant ($\mu g/m^3$)~~
~~BR = Average daily breathing rate (L/day*kg body weight)~~
~~EF = Exposure frequency, days/year~~
~~FAH= Fraction of time at home~~
~~ED = Exposure duration, in years~~
~~1×10^{-6} = Conversion factor ($\mu g/m^3$) to (mg/L)~~
~~AT = Averaging time (period over which exposure is averaged, in years); for carcinogenic effects, the averaging time is 70 years = 25,500 days~~

Adjustment for exposure less than 365 days/year (e.g., 350 out of 365 days a year to allow for a two week period away from home each year for the residential exposure scenario, or worker exposures of eight hours per day, 5 d/week for the offsite worker exposure scenario) can be factored into the equation using the EF term.

11.5 Available Studies for Evaluating Residency Time and Exposure Duration for the Residential Exposure Scenario

11.5.1 National Studies

Israeli and Nelson (1992) used information from the American Housing Survey (AHS) for the United States for 1985 and 1987 (Bureau of the Census, 1987; 1989) to develop a distribution of average total residence time for all U.S. residents. Finley et al. (1994) calculated more of the percentiles for the data presented by Israeli and Nelson (1992). The mean of the distribution presented by Israeli and Nelson (1992) is 4.6 years. In addition, distributions are presented for subpopulations such as renters and owners, and for regions of the country. The study clearly shows that homeowners have a much greater average residency time than renters and therefore may be a more at risk population from exposure to emissions of a nearby facility. The average residency time for the Western region was lower than for the entire U.S. population.

The authors note that with the methodology they used, there could be repeated sampling or over-sampling of a population of frequent movers. This methodology would also tend to overemphasize the more frequent short duration residency periods that have been found to occur from approximately age twenty to thirty by the Bureau of Census (1988). The Israeli and Nelson (1992) study has information on various categories such as renters, homeowners, farm, urban and rural populations, and large geographic regions such as the West. OEHHA staff did not consider the Israeli and Nelson (1992) study to be appropriate for determining an appropriate residency time to use in less-than-lifetime exposure scenarios in the Air Toxics "Hot Spots" program.

The Israeli and Nelson (1992) study does not examine the effect of socio-economic status on residency times. Many facilities in the Air Toxics "Hot Spots" program are located in areas surrounded by low socioeconomic status populations. OEHHA has published a framework for assessing cumulative impacts, *Cumulative Impacts - Building a Scientific Foundation* (2010), which established the need to take into account socioeconomic factors in risk assessment. As the methodology for doing so evolves, OEHHA will update the Exposure Assessment and Stochastic Analysis Technical Support Document as appropriate.

Johnson and Capel (1992) used a Monte Carlo approach for determining residency occupancy periods. Their methodology can incorporate population information about location, gender, age, and race to develop a mobility table based on US Census data. The mobility table contains the probability that a person with the demographic characteristics considered would not move. A mortality table is also used which determines the probability that a person with the demographic characteristics considered would die. Some of the results from this study are presented in Table 11.3.

Although the published methodology can be used to determine mobility for different income groups, the published tables are for the entire U.S. population. In addition, as is pointed out in the study, the Monte Carlo methodology employed in the study uses the same probability of moving for persons who have resided in their current residence for extended periods as for those who have recently moved in. The data collected by the U.S. Census does not indicate where the individuals queried move to, other than broad descriptions such as "in county", "out of county", "within metropolitan area", and so forth. This problem is common to all of the studies discussed. As a result, it is difficult to

define residence time within a zone of impact for those who do not move very far (e.g., within the same apartment complex, neighborhood, or town). The conclusions of this study are similar to the results that the U.S. EPA (1997) reached using the AHS study (Bureau of the Census, 1993) (Table 11.3).

The U.S. EPA (1997) has reviewed the studies presented above. In addition, the U.S. EPA (1997) reviewed the results of the 1991 AHS (Bureau of the Census, 1993). The U.S. Bureau of the Census (1993) conducted a survey using 55,000 interviews, which covered homeowners and renters. Black, white and Hispanic ethnic groups were represented in this study. The U.S. EPA used the information available in this study to determine a distribution of the percent of households who have lived at their current address for several ranges of years. The median and 90th percentiles of this distribution are 9.1 and 32.7 years, respectively. The methodology used to derive the distribution was not specified in the report (U.S. EPA, 1995). Based on the studies by Israeli and Nelson (1992), Johnson and Capel (1992), and their analysis of the U.S. Bureau of the Census (1993), U.S. EPA recommends a central tendency estimate of 9 years, and a high-end estimate of 30 years for residency time.

11.~~6~~5.2 California-Specific Data on Residency Time

Appendix L used data from The Integrated Public Use Microdata Series (IPUMS-USA) to evaluate residency time. IPUMS-USA consists of more than fifty samples of the American population drawn from fifteen federal censuses and from the American Community Surveys (ACS). ACS is a nationwide survey that collects and produces population and housing information every year from about three million selected housing unit addresses across every county in the nation (ACS). IPUMS-USA samples, which draw on every surviving census from 1850-2000 and the 2000-2009 ACS samples, collectively constitute the quantitative information on long-term changes in the American population. These records for the period since 1940 only identify geographic areas with equal or larger than 100,000 residents (250,000 in 1960 and 1970) (IPUMS-USA).The IPUMS-USA identifies the date moved into the residence and therefore a cumulative distribution of length of time that population has lived in the current residence can be constructed from these data. Figure L2 shows that 91% of the population has lived in their current residence for 29 years or less. This means that only 9% of the population has lived more than 29 years in his or her current residence.

Table 11.3 Summary of Studies of United States Residency Times (in Years)

Israeli and Nelson (1992)	1.4, 23.1 (50th and 95th %tile)
Johnson and Capel (1992)	2.0, 9.0, 33 (5th, 50th and 95th %tile)
U.S. EPA (1997); evaluation of BOC (1993) data	9.1, 32.7 (50th, 90th %tile)
CARB Analysis of IPUMS data (Appendix L)	29 (91st percentile)

11.6 Available Studies for Assessing Job Tenure and Exposure Duration for the Offsite Worker Exposure Scenario

11.6.1 Key National Studies on Job Tenure

The data with respect to job tenure in the United States are mainly cross sectional for determining a Tier 1 default. However, there are some longitudinal data. The purpose of the Census Bureau's Survey of Income and Program Participation (SIPP) is to collect information on source and amount of income, labor force participation, program participation and eligibility, and general demographic characteristics, to measure the effectiveness of existing federal, state, and local programs. The data were collected to estimate future costs and coverage for government programs, such as food stamps, to provide improved statistics on the distribution of income and measures of economic well-being; and to evaluate the effectiveness of federal, state, and local programs.

Like NHANES, the SIPP sample is a multistage-stratified sample of the U.S. civilian non-institutionalized population. Individuals selected for the survey, along with others who live with them, are interviewed once every 4 months over a 48-month period. To spread the work evenly over the 4-month reference period for the interviewers, the Census Bureau randomly divides each panel into four rotation groups. Each rotation group is interviewed in a separate month. Four rotation groups constitute one cycle, or wave, of interviewing, for the entire panel.

The first SIPP panel began interviews in 1983. During the period 1984-1993, a new panel of households was introduced each year in February. In 1990, the Committee on National Statistics (CNSTAT) at the National Research Council reviewed SIPP protocols and made recommendations, many of which were implemented in 1996 and continue to be followed today. In the current version, SIPP is a longitudinal survey that consists of 12 waves of 4 months (4 rotations) each, resulting in a 4-year non-overlapping, continuous cycle, with sample size ranging from approximately 14,000 to 36,700 interviewed households. Included in the SIPP database is information about employment, such as number of concurrent jobs, starting and ending dates of jobs, types of employment, employment income and unemployment compensation, and reasons for leaving a job.

OEHHA analyzed the most recent set of SIPP job data from Wave 1 of the 2008 SIPP survey to evaluate the distribution of employment tenure among employed people in a nationally representative sample. SIPP participants were asked when they started working for a current or most recent past employer, and when they stopped working for that same employer. We disregarded data pertaining to second jobs for individuals who had more than one job at a time. We calculated job duration using job start and end dates, and used an end date of December 31, 2008 for those who were still employed at the same job. We ran frequency distributions of years on the job and years on the job by age using the FREQUENCY and SURVEYFREQ procedures in SAS version 9.1.3 (Table 11.4).

Table 11.4 Employment Tenure by Years on the Job from the Survey of Income and Program Participation (SIPP), 1996-2008

Years on the Job	**Percent of Total**					
	1996-2008	**1996-2008 Summary**	**2008 Only**	**2008 Summary**	**2008 Cumulative Total 0 to 100%**	**2008 Cumulative Total 100 to 0%**
N	**150,017**	**150,017**	**45,363**	**45,363**	**-**	**-**
0	12.67		19.42			100
1	17.87		13.15			
2	10.34		9.87			
3	7.86		7.53			
4	6.06	54.79	5.41	55.38	55.38	44.62
5	5.09		4.58			
6	4.34		3.62			
7	3.48		3.72			
8	3.30		3.87			
9	2.47	18.67	2.59	18.39	73.77	26.23
10	2.82		3.20			
11	2.08		1.93			
12	1.84		1.75			
13	1.59		1.70			
14	1.52	9.84	1.33	9.91	83.68	16.32
15	1.59		1.40			
16	1.45		1.12			
17	1.22		0.94			
18	1.30		1.27			
19	1.05	6.61	1.05	5.78	89.46	10.54
20	1.23		1.34			
21	0.86		0.90			
22	0.82		0.91			
23	0.83		0.84			

Table 11.4 Employment Tenure by Years on the Job from the Survey of Income and Program Participation (SIPP), 1996-2008

Years on the Job	Percent of Total					
	1996-2008	**1996-2008 Summary**	**2008 Only**	**2008 Summary**	**2008 Cumulative Total 0 to 100%**	**2008 Cumulative Total 100 to 0%**
24	0.75	4.48	0.63	4.62	94.08	5.92
25	0.70		0.62			
26	0.64		0.47			
27	0.53		0.50			
28	0.57		0.72			
29	0.43	2.87	0.45	2.75	96.83	3.17
30	0.51		0.62			
31	0.37		0.38			
32	0.30		0.30			
33	0.23		0.26			
34	0.23	1.65	0.30	1.87	98.7	1.3
35	0.22		0.26			
36	0.17		0.17			
37	0.13		0.16			
38	0.11		0.17			
39	0.09	0.72	0.12	0.88	99.58	0.42
40	0.08		0.12			
41	0.07		0.06			
42	0.04		0.05			
43	0.04		0.06			
44	0.03	0.25	0.02	0.31	99.89	0.11
45	0.02		0.03			
46	0.01		0.01			
47	0.01		0.01			
48	0.02		0.03			
49	0.01	0.08	0.01	0.09	99.98	0.02
50	0.01		0.01			
51-70	0.044	0.044	0.02	0.02	100	

11.6.2 Supporting Studies

11.6.2.1 Current Population Survey

The Bureau of Labor Statistics (BLS) collects extensive information on the U.S. labor force through the ongoing Current Population Survey (CPS). The CPS is a monthly survey of about 60,000 households that provides data on the labor force status,

demographics, and other characteristics of the civilian noninstitutional population ≥16 years of age. One part of the survey includes questions about employee tenure, which is a measure of how long workers had been with their current employer at the time of the survey (BLS, 2008a). Information on employee tenure has been obtained from supplemental questions to the current CPS every two years since 1996. The percent distribution by tenure with current employer is shown in Table 11.5. The data refer to the sole or principal job of full- and part-time workers. All data exclude the incorporated and unincorporated self-employed.

Table 11.5 Distribution of Employed Wage and Salary Workers by Tenure with Current Employer and Age, Males and Females Combined, January 2008 From BLS CPS

Age Group (yrs)	**Number employed (in thousands)**	**Percent Distribution by Tenure with Current Employer**							
		≤12 mo	13 to 23 mo	2 yrs	3 to 4 yrs	5 to 9 yrs	10 to 14 yrs	15 to 19 yrs	≥20 yrs
≥16	129,276	22.9	7.4	5.6	16.9	20.2	10.6	6.2	10.3
16-19	5,200	73.8	11.5	7.5	7.0	0.3	- [a]	-	-
≥20	124,076	20.8	7.2	5.5	17.3	21.0	11.0	6.4	10.7
20 - 24	13,139	49.9	13.2	10.2	20.4	6.4	<0.05	-	-
25 - 34	29,097	28.2	10.4	8.5	23.4	23.5	5.4	0.6	<0.05
35 - 44	30,150	17.1	6.6	4.8	18.1	25.5	15.3	8.2	4.5
45 - 54	30,151	12.9	4.4	3.5	13.7	21.6	14.4	9.9	19.4
55 - 64	17,242	9.4	4.3	2.6	11.2	19.7	14.1	10.9	27.8
≥65	4,297	8.9	2.5	2.8	10.6	18.9	16.6	10.4	29.2

[a] Dash represents zero or rounds to zero.

The tenure question in the CPS was designed specifically as a gauge of employment security. Tenure durations beyond 20 years were not computed for Table 11.5, possibly due to the definition of a "lifetime" job lasting at least 20 years by Hall (1982). Thus, longer tenure employment statistical analysis was not considered necessary.

The BLS also presented longitudinal data for median employee tenure by age over the years 1996 to 2008 (Table 11.6). Other distributional percentiles for this tenure data were not presented in the report.

Table 11.6 Median (50th Percentile) Years of Tenure with Current Employer for Employed Wage and Salary Workers by Age 1996 to 2008, Males and Females Combined, from BLS

Age Group (yrs)	1996	1998	2000	2002	2004	2006	2008
≥16	3.8	3.6	3.5	3.7	4.0	4.0	4.1
16 - 17	0.7	0.6	0.6	0.7	0.7	0.6	0.7
18 - 19	0.7	0.7	0.7	0.8	0.8	0.7	0.8
20 - 24	1.2	1.1	1.1	1.2	1.3	1.3	1.3
≥25	5.0	4.7	4.7	4.7	4.9	4.9	5.1
25 - 34	2.8	2.7	2.6	2.7	2.9	2.9	2.7
35 - 44	5.3	5.0	4.8	4.6	4.9	4.9	4.9
45 - 54	8.3	8.1	8.2	7.6	7.7	7.3	7.6
55 - 64	10.2	10.1	10.0	9.9	9.6	9.3	9.9
≥65	8.4	7.8	9.4	8.6	9.0	8.8	10.2

A number of factors can affect employee tenure, including the age profile among workers, type of occupation, and changes in the number of hires and separations with time. The most apparent effect on employee tenure is the age of the worker. As expected, length of tenure to one's employer is strongly related to the age of the worker. For example, in Table 11.6 the median tenure for employees age 55 to 64 in 2008 was 9.9 years, almost four times the tenure (2.7 years) for workers age 25 to 34. Younger working age participants tend to be a more mobile work force. Younger participants also have not accumulated enough working years with any one employer to be considered long-term tenured workers. As workers age, both job stability increases and the number of years since the worker initially began working increases resulting in more workers with jobs that will last 20 years or more.

An earlier study by Farber (1995) used the raw data from the CPS to calculate a distribution of employment-based job duration. Table 11.7 presents the median (50th percentile) and 0.9 quantile (90th percentile) results based on the 1993 CPS findings for tenure with current employer. Although the quantile job tenure results were generated in 1993, the longitudinal median tenure findings in Table 11.6 suggest there has been little change in the numbers since the 1990s.

Table 11.7 Median (50th Percentile) and 0.9 Quantile Job Tenure (in Years) with Current Employer in 1993, Males and Females Combined

Job Tenure Quantiles	Age Category (Years)			
	25-34	35-44	45-54	55-64
Median	3.2	5.8	9.5	12.4
0.9	9.7	17.5	25.2	31.5

The main limitation using the CPS to estimate occupational duration at a single location is that the job tenure question asks for years spent with current employer (i.e., the job is

still in progress), rather than completed job duration where there is a start and end date. However, the survey covers the entire span of working years from age 16 to 70+ years. In particular, the oldest groups of participants represent those workers at or near retirement age with a full work history. In addition, Nardone et al. (1997) observed that similar job tenure percentiles were obtained when comparing young workers from both the CPS and NLSY79 surveys (see below).

Comparison of this survey with the SIPP shows that for the first 20 years of employment beginning at age 15 or 16 years, the tenure percentages are almost identical. The CPS shows that 10.3 percent of participants beginning at age 16 are still with their current employer after 20 years. The SIPP (Table 11.4) estimates 10.54 percent of participants are still with their current employer after 20 years.

11.6.2.2 National Survey of Youth 1979

The BLS also collects employment duration data from a separate survey called the National Survey of Youth 1979 (NLSY79). A unique feature of this survey is that it collects the beginning and ending dates of all jobs held by a respondent so that a longitudinal history can be constructed of each respondent's work experience. The NLSY79 is a nationally representative sample of 12,686 young men and women who were 14 to 22 years of age when first surveyed in 1979. The estimates in the current release of data for 2006-2007 contain the first 22 rounds of the survey since 1979 (BLS, 2008b).

The respondents in the NLSY79 are still relatively young, ages 41 to 50 in 2006-07. As the cohort continues to age, information that is more complete will become available. Thus, the current release covers only the period while the respondents were ages 18 to 42; older participants in the study are not included because sample sizes were still too small to provide statistically reliable estimates for age groups >42.

As part of the NLSY79, the duration of employment with a single employer for all jobs started from age 18 to 42 in 1978-2006 is estimated. A job is defined in the survey as an uninterrupted period of work with a particular employer. Jobs are therefore employer-based, not position-based. However, if a respondent indicates that he or she left a job but in a subsequent survey returned to the same job, it is counted as a new job.

Individuals were surveyed annually from 1979 to 1994 and biennially since 1994. In 2006-07, 7,654 individuals responded to the survey, for a retention rate of 77 percent. Only these individuals are included in the estimates in this release. All results are weighted using the 2006-07 survey weights that correct for the oversampling, interview nonresponse, and permanent attrition from the survey. When weighted, the estimates represent all persons born in the years 1957 to 1964 and living in the U.S. when the survey began in 1979 (Table 11.8). Not represented are U.S. immigrants who were born from 1957 to 1964 and moved to the United States after 1979.

Table 11.8 Duration of Employment Relationships with a Single Employer for All Jobs Started from Age 18 to Age 42 in 1978-2006 by Age at Start of Job

Age Group (yrs)	Cumulative Percent Distribution of Duration of Completed Employment Relationships					Percent of jobs ongoing in 2006
	<1 yr	<2 yrs	<5 yrs	<10 yrs	<15 yrs	
18 - 22	72.3	85.2	94.1	97.1	98.0	1.3
23 - 27	59.2	75.9	88.8	94.0	95.7	3.5
28 - 32	52.5	69.7	85.5	91.6	93.6	6.2
33 - 37	42.8	60.7	80.6	88.2	88.9	11.1
38 - 42	30.5	46.6	65.1	ND	ND	30.2

ND - No data. Estimates are not presented for these categories because most sample members were not yet old enough at the time of the 2006-07 survey to have completed jobs of these durations.

Unlike the CPS results, the job duration data in the NLSY79 report are based on starting and ending dates for jobs with a single employer. A limitation of the data is that the survey is still ongoing. Hence, some of the numbers in Table 11.8 will change as the survey is periodically updated, particularly for the most recent findings. Presumably, additional information will also be available for long-term employment in future surveys (i.e., duration of completed employment 15 to <20 yrs).

11.6.2.3 Comparison of the CPS and the NLSY79

Job durations the CPS report were compared by Nardone *et al.* (1997) with a similar cohort of individuals from the NLSY79 data as a yardstick to examine the quality of the CPS data. Specifically, the most recent job tenure data from the NLSY79 28- to 36-year old workers collected in 1993 were compared to the CPS findings for the same age group. Despite the differences in data collection methods between the CPS and NLSY79, the differences in the job tenure distributions were quite small (Table 11.9). Little difference is found at the 90th percentile, with CPS job tenure registering 11.22 years and that of the NLSY79 11.13 years. Overall, Nardone et al. (1997) concluded that the CPS data appear to provide an adequate approximation of the tenure distribution among young workers.

Table 11.9 Distribution of Years of Tenure Among 28- to 35-year old Workers, Current Population Survey (CPS) and National Longitudinal Survey of Youth 1979 (NLSY79), Males and Females Combined

Job Tenure Quantiles	Percentile				
	10th	25th	50th	75th	90th
CPS	0.04	1.04	3.34	7.00	11.22
NLSY79	0.37	1.13	3.46	7.03	11.13

11.7 Individual Resident Cancer Risk vs. Residential Population Risk

A threshold dose for cancer risk for almost all carcinogens cannot be established. Therefore, risk managers must establish a cancer risk that is considered acceptable or de minimus through the political process. Most risk assessments estimate cancer risk at the worker point of maximum exposure (Maximum Exposed Individual Worker or MEIW) and the residential point of maximum exposure (MEIR). This ensures that individual risk is measured at the point with the estimated highest air concentrations of cancer-causing chemicals. ~~This~~ The acceptable risk level for individual cancer risk varies in different Federal and State programs from 1 X 10^{-6} to 1 X 10^{-4}. In the Hot Spots program, a 1 X 10^{-5} level for notification is a common standard for the Air Districts. The District may have different levels for permitting, or requiring additional pollution control devices for existing facilities. ~~The individual cancer risk is measured at the worker point of maximum exposure (worker Maximum Exposed Individual or MEI) and the residential point of maximum exposure (residential MEI). This ensures that individual risk is measured at the point with the estimated highest air concentrations of cancer-causing chemicals. Since individual risk is proportional to exposure duration, the length of time that the residential or worker MEI resides at his or her job, or lives at his or her residence is a critical parameter.~~

The previous OEHHA recommendation of estimating cancer risk for a 70-year residency as a default is health protective for individual risk and provides a degree of population risk public health protection as well. Basing risk management on the cancer risk estimated for a 70 year exposure duration helps reduce the chances a person will experience a cancer risk greater than the acceptable limit (e.g., 10^{-5}) if he or she moves within the isopleths of another similar-risk facility. However, a 70-year residency default also confuses the two concepts of individual risk and population risk. The cancer potency factors are based on the risk to a population, either the population of workers in an occupational study or a population of animals. Yet it is applied to a person or a few people living at the estimated point of maximum impact (the MEI). On the other hand, whether or not a single person is residing at the MEI location over 70 years, there is an assumption in considering population risk that someone will always be living at the MEI location. Thus, in terms of population risk it is irrelevant that the risk at that location is spread over different individuals over time (see discussion below of population versus maximally exposed individual risk).

The individual cancer risk approach has some inherent limitations in terms of protecting public health. A small facility with a single stack can impact a few individuals with an individual cancer risk that is unacceptable, whereas a large facility may have an individual cancer risk that is below the acceptable limit for individual risk but exposes many more people. This large facility can cause more potential cancer cases than the smaller facility and thus have a greater public health impact.

For large facilities with multiple sources such as refineries, ports or rail yards, the population impacts are the primary public health concern. A population risk metric is a better measure of the public health impact and efficacy of proposed control measures.

For example, dispersal of repair operations with high diesel emissions in a rail yard will lower individual risk but will not impact population risk. Such a dispersal of operations would not affect the number of cancer cases that would be ~~expected~~predicted, but would spread the risk over a larger number of people. Individual risk is a poor metric for progress in public health protection in this example.

To evaluate population risk, regulatory agencies have used the cancer burden as a method to account for the number of excess cancer cases that ~~would~~ could occur in a population. The population burden can be calculated by multiplying the cancer risk at a census block centroid times the number of people who live in the census block, and adding up the cancer cases across the zone of impact. A census block is defined as the smallest entity for which the Census Bureau collects and tabulates decennial census information; it is bounded on all sides by visible and nonvisible features shown on Census Bureau maps. The centroid is defined as the central location within a specified geographic area (U.S. Department of Commerce, 1994).

The cancer burden is calculated on the basis of lifetime (70 year) risks. It is independent of how many people move in or out of the vicinity of an individual facility. The number of cancer cases is considered independent of the number of people exposed, within some lower limits of exposed population size, and the length of exposure (within reason). If 10,000 people are exposed to a carcinogen at a concentration with a $1X10^{-5}$ cancer risk for a lifetime the cancer burden is 0.1, and if 100,000 people are exposed to a $1 X 10^{-5}$ risk the cancer burden is 1.

There are different methods that can be used as measure of population burden. The number of individuals residing within a $1 X 10^{-6}$, $1 X 10^{-5}$, and/or $1 X 10^{-4}$ isopleth is another potential measure of population burden (OEHHA, 2003).

11.8 Factors That Can Impact Population Risk – Cumulative Impacts

Although the Hot Spots program is designed to address the impacts of single facilities and not aggregate or cumulative impacts, there are a number of known factors that influence the susceptibility of the exposed population and thus may influence population risk. Socioeconomic status influences access to health care, nutrition, and outcome after cancer diagnosis. Community unemployment can affect exposure and residency time near a facility. Factors that affect the vulnerability of the population are discussed in the report *Cumulative Impacts Building a Scientific Foundation* (OEHHA, 2010). Information on many of these factors is relatively easy to obtain on a census tract level. The OEHHA recommends that these types of factors be considered by the risk manager, along with the quantitative measures of population risk. OEHHA is in the process of developing guidance on quantification of the impact of these factors.

11.9 Cancer Risk Evaluation of Short Term Projects

The local air pollution control districts sometimes use the risk assessment guidelines for the Hot Spots program in permitting decisions. Frequently, the issue of how to address cancer risks from short term projects arises.

Cancer potency factors are based on animal lifetime studies or worker studies where there is long-term exposure to the carcinogenic agent. There is considerable uncertainty in trying to evaluate the cancer risk from projects that will only last a small fraction of a lifetime. There are some studies indicating that dose rate changes the potency of a given dose of a carcinogenic chemical. In others words, a dose delivered over a short time period ~~has~~ may have a different potency than the same dose delivered over a lifetime.

The OEHHA's evaluation of the impact of early-in-life exposure has likely reduced some of the uncertainty in evaluating the cancer risk to the general population for shorter-term exposures, as it helps account for susceptibility to carcinogens by age at exposure (OEHHA, 2009). Thus, we have recommended for short term exposures that the risk assessment start at the third trimester for cancer risk calculation.

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