Hg OBJECTIVES
Deadline: 2/28/07 5pm

NRDC
THE EARTH'S BEST DEFENSE

NATURAL RESOURCES DEFENSE COUNCIL

February 27, 2007

By Facsimile (916.341.5620), Email (commentletters@waterboards.ca.gov), and U.S. Mail

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Re: Comment Letter – Methylmercury Objectives

We write on behalf of the Natural Resource Defense Council and its more than 1.2 million members and activists (including some 125,000 members who live in California), as well as Baykeeper and Clean Water Action, to comment on the State Board's "Proposed Methylmercury Objectives for Inland Surface Waters, Enclosed Bays, and Estuaries in California." We appreciate this opportunity to participate in the State Board's deliberations.

The proposed fish tissue objective (FTO) is insufficiently protective of the health of California fish consumers and particularly inadequate to protect women of reproductive age, children, and subsistence anglers. The State Board should adopt a fish tissue objective of no more than 0.05 mg/kg, applying the more protective body weight and fish consumption assumptions promulgated for risk assessments by the CalEPA Office of Environmental Health Hazard Assessment (OEHHA).[1] In conducting its California Environmental Quality Act analysis, we ask the State Board to consider a fish tissue objective of 0.05 mg/kg and to utilize the more protective and accurate assumptions discussed in these comments.

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[1] *See* Cal. Envtl. Prot. Agency, Office of Envtl. Health Hazard Assessment, *Air Toxics Hot Spots Program Risk Assessment Guidelines: Part IV Technical Support Document for Exposure Assessment and Stochastic Analysis* (Sept. 2000) (hereinafter "OEHHA, *Risk Assessment Guidelines*"), available at http://www.oehha.ca.gov/air/hot_spots/finalStoc.html#download.

Pregnant Women and Children are the Populations at Risk

Methylmercury acts as a neurotoxin in humans. Exposure to mercury can be particularly hazardous for pregnant women and small children. Mercury readily crosses the placenta. During the first several years of life, a child's brain is still developing. Prenatal and infant mercury exposure at high concentrations can cause mental retardation, cerebral palsy, deafness and blindness. Even in low doses, mercury may affect a child's development, delaying walking and talking, shortening attention span and causing learning disabilities. The EPA and FDA have reviewed the data on methylmercury exposure and have focused their fish advisories on women of reproductive age, and on children.[2] These two populations – and, especially, subsistence consumers of fish within these two subpopulations – should be the focus of the State Board's effort to derive a health-protective fish tissue objective.

Body Weight Assumption Should Be Lowered

Several years ago, OEHHA developed guidance documents for the preparation of risk assessments. One of these documents (attached as Appendix A) exhaustively reviews the available data on body weight distributions in the general population of the United States and derives default body weights for use in different risk assessment scenarios. For the adult worker scenario, the default is 70 kg. However, for the general population, OEHHA recommended using a default body weight of 63 kg. OEHHA further suggested adjusting that default downward if the population of greatest concern were female (as, for adults, it is here), since the 63 kg number represents an average of male and female body weights. For example, OEHHA presented the recommendations of the International Commission on Radiological Protection (ICRP), which uses a default female body weight of 56.7 kg.[3] For children ages 0-9, OEHHA recommended a default body weight of 18 kg. Consistent with these OEHHA findings and recommendations, we ask that the State Board adopt a body weight default in the range of 56.7-63 kg for the adult female for purposes of developing a fish tissue objective. We also recommend that the State Board derive a calculation for children consuming fish from California water bodies.

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[2] *See* U.S. Dept. of Health & Human Serv. & U.S. Envtl. Prot. Agency, "What You Need to Know About Mercury in Fish and Shellfish: 2004 EPA and FDA Advice For: Women Who Might Become Pregnant, Women Who are Pregnant, Nursing Mothers, Young Children," EPA Doc. No. EPA-823-R-04-005 (March 2004). http://www.cfsan.fda.gov/~dms/admehg3.html.

[3] OEHHA, *Risk Assessment Guidelines*, *supra* n.1, at 10-6.

Fish Consumption Rate Should Be Raised

The U.S. EPA fish consumption default rates should not be used to develop a fish tissue objective for California. The EPA number does not account for populations that have high rates of fish consumption such as Native Americans, Asians, Pacific Islanders, or others who may fish for subsistence – even though these populations have a significantly higher prevalence of elevated blood mercury than all other racial/ethnic groups.[4] California contains especially large numbers of people in these (and other) communities that consume fish at far greater rates than the U.S. average.

Although the fish consumption rate derived by the San Francisco Estuary Institute (SFEI) is a more reasonable estimate, it suffers from multiple problems: (1) It is based on the 95th percentile, whereas the State Board should – as a matter of policy – protect a greater proportion of the population. We would urge the Board to select the 98th percentile if it chooses to use the SFEI numbers. The 98th percentile is still a statistically stable number and is therefore likely to be reliable, but it protects a significantly greater proportion of the population; (2) The SFEI number is "adjusted for avidity bias", which will have adjusted the measured rates downward. This adjustment may not be justified because it will systematically result in an underestimate of the consumption rates of the more "avid" consumers – precisely those that the State Board should be striving to protect. We urge the State Board to reconsider the adjustment if it chooses to use the SFEI number.

OEHHA's exposure assessment guidance document, referenced above, contains a detailed analysis of fish consumption rates in California. OEHHA reviewed all available data and concluded that the following default values should be used for California risk assessments involving "fisher caught fish":

OEHHA Default Values for Fisher Caught Fish Consumption (g/day)[5]

	9-Year Exposure Scenario (children)[a]	30- and 70-Year Exposure Scenario
Average	8.7	30.5
High End	24.3	85.2

The current State Board draft calculation uses a number that is essentially the average consumption rate from the 30- and 70-year scenario. Choosing an

[4] *See* Jane M. Hightower, *et al.*, "Blood Mercury Reporting in NHANES: Identifying Asian, Pacific Islander, Native American, and Multiracial Groups," 114 *Envtl. Health Perspectives* 173, 173 (Feb. 2006).

[5] OEHHA, *Risk Assessment Guidelines*, *supra* n.1, at 9-14.

average will fail to protect a large proportion of the fish-eating population. NRDC strongly urges that the State Board choose the high-end fish consumption rate of 85.2 g/day as recommended by OEHHA for the adult scenario. In addition, we ask that the State Board also use the default consumption rate for children in combination with the child body weight discussed above, to calculate a fish tissue objective that will be protective of children.

Revised Fish Tissue Objectives

Using the OEHHA approach to deriving a fish tissue objective, NRDC presents the following calculations as more reasonable, defensible, and health-protective approaches to developing a final fish tissue objective for California:

$$\mathrm{FTO} = \frac{\mathrm{BW} * (\mathrm{RfD} - \mathrm{RSC})}{\mathrm{CR}} \qquad \mathrm{CR}=\text{consumption rate in kg/day}$$

Adult Scenario:

$$0.054 = \frac{63\ \mathrm{kg} * (0.0001 - 2.7 \times 10^{-5})}{0.0852}$$

or, using a lower body weight assumption cited by OEHHA

$$0.049 = \frac{56.7\ \mathrm{kg} * (0.0001 - 2.7 \times 10^{-5})}{0.0852}$$

Child Scenario:

$$0.054 = \frac{18\ \mathrm{kg} * (0.0001 - 2.7 \times 10^{-5})}{0.0243}$$

In conclusion, if the State Board were to follow the exposure assessment guidelines promulgated by OEHHA, it would calculate a fish tissue objective in the range of 0.05 mg/kg. Such an objective would be far more likely to protect the health of pregnant women, women of reproductive age, and children that eat fish for subsistence from California waterways than the presently proposed objective, which is unlikely to achieve this goal. We urge the State Board to analyze a 0.05 mg/kg fish tissue objective alternative under CEQA and to conduct its CEQA analysis of each alternative using the more protective and more accurate body weight and fish consumption assumptions articulated here.

Thank you for considering our comments.

Sincerely,

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Air Toxics Hot Spots Program Risk Assessment Guidelines

Part IV

Technical Support Document for Exposure Assessment and Stochastic Analysis

September 2000

Secretary for Environmental Protection
California Environmental Protection Agency
Winston H. Hickox

Director
Office of Environmental Health Hazard Assessment
Joan E. Denton, Ph.D.

Final Draft

September 2000

Air Toxics Hot Spots Program
Risk Assessment Guidelines
Part IV

Technical Support Document

Exposure Assessment and Stochastic Analysis

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These individuals participated as an ad hoc advisory group to provide input to the document and in particular to the stochastic modeling effort. The advisory group met 10 times over a period of one year. The advisory group members acted as science advisors and may or may not agree with all recommendations in the document. Representatives from the local air districts were asked to participate as consultants from the California Air Pollution Control Officers Association. Representatives of environmental and regulated communities, academia, and other California Environmental Protection Agency boards and departments provided additional input into this new and expanding area of risk assessment science. The members of the advisory group did not receive any compensation from The Office of Environmental Health Hazard Assessment for their time or expenses. We are grateful for their hard work and the useful suggestions and insights they provided.

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- We also appreciate the helpful comments and suggestions from our colleagues within OEHHA, and from the public.

- In addition, this document was peer reviewed by the State's Scientific Review Panel on Toxic Air Contaminants (SRP). We would like to acknowledge the Panel for their time and effort spent reviewing the document. Members of the SRP are:

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Air Toxics "Hot Spots" Program Risk Assessment Guidelines Part IV

Technical Support Document
for
Exposure Assessment and Stochastic Analysis

September 2000

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Section 3: Daily Breathing Rates

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Section 5: Breast Milk Consumption Rate

Executive Summary

ES.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 and ultimately to the state Air Resources Board. Following prioritization of facilities by the Districts based on quantity and toxicity of emissions, facilities may be required to conduct a health risk assessment. Health risk assessment involves a comprehensive analysis of the dispersion of emitted chemicals in the air 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). The statute specifically requires OEHHA to develop a "likelihood of risks" approach to health risk assessment; OEHHA has, therefore, developed a stochastic, or probabilistic, approach to exposure assessment to fulfill this requirement.

The Air Toxics Hot Spots Program Part IV: Technical Support Document, Exposure Assessment and Stochastic Analysis (Part IV) provides a review of the scientific literature on the exposure variates needed in order to perform risk assessment for the Air Toxics Hot Spots program. The airborne toxicants addressed are listed in the statute and include Toxic Air Contaminants. Most of the chemicals listed are volatile and thus only present a significant risk when emitted into the air if inhaled. However, a few chemicals that are listed, such as heavy metals and semivolatile organic compounds, can also be deposited onto vegetation, water and soil. Thus, Part IV also addresses other potential exposure pathways including ingestion of contaminated soil, home grown produce, meats, cow's milk, mothers milk, noncommercial fish, surface drinking water and skin contact with soil. Specific recommendations are made for the most appropriate parameters and distributions. 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. In addition, this document updates the point estimate approach currently used in the Air Toxics Hot Spots program.

A companion document, Air Toxics "Hot Spots" Risk Assessment Guidance Manual, is under development and is designed to be concise compendium of the alogrithms, parameters and tables of health values (cancer potency factors, acute and chronic reference exposure levels) needed to perform an AB-2588 risk assessment.

ES.2 OEHHA's Approach to Exposure Assessment

The traditional approach to exposure and risk assessment has been to assign a single value for each exposure parameter, such as breathing rate, generally chosen as a high-end value so that risk will not be underestimated. The "high-end" value has not in the past been well defined such that it is unclear where the value fell on a distribution. An improvement over the single point estimate approach is to select two values, one representing an average and another representing a defined high-end value. OEHHA provides information in this document on average and defined high-end values for key exposure variates. The average and "high-end" values of point estimates in this document are defined in terms of the probability distribution of values for that variate. We chose the means to represent average values for point estimates and the 95th percentiles to represent high-end values for point estimates from the distributions identified in this document. Thus, within the limitations of the data, average and high end are well-defined points on the distribution

OEHHA was directed under SB-1731 to develop a "likelihood of risk" approach to risk assessment. To satisfy this requirement, we developed a stochastic approach to risk assessment which utilizes distributions for exposure variates such as breathing rate and water consumption rate rather than a single point estimate. The variability in exposure can be propagated through the risk assessment model using the distributions as input and a Monte Carlo or similar method. The result of such an analysis is a range of risks that at least partially characterizes variability in exposure. Such information allows the risk manager an estimate of the percentage of the population at various risk levels.

We also recommend a tiered approach to risk assessment. Tier 1 is a standard point estimate approach using the recommended point estimates presented in this document. If site-specific information is available to modify some point estimates and is more appropriate to use than the recommended point estimates in this document, then Tier 2 allows use of that site-specific information. In Tier 3, a stochastic approach to exposure assessment is taken using the distributions presented in this document. Tier 4 is also a stochastic approach but allows for utilization of site-specific distributions if they are justifiable and more appropriate for the site under evaluation than those recommended in this document.

ES.2.1 Stochastic Exposure Assessment

Distributions of key exposure variates were taken from the literature, if adequate, or developed from raw data of original studies. Intake variates such as vegetable consumption are relatively data rich for which reasonable probability distributions can be constructed. However, the data necessary to characterize the variability in risk assessment variates are not always available. For example, for the fate and transport parameters (i.e., fish bioconcentration factors), there are only a few measurements available which precludes the adequate characterization of a probability distribution. We only developed distributions for those key exposure variates that were adequately characterized by data.

Note that the stochastic approach employed in the Air Toxics "Hot Spots" program does not address either exposure model uncertainty or true uncertainty about an exposure variate. In addition, this document does not characterize uncertainty in dose-response modeling. Although stochastic methods like the one described in this document are frequently referred to in the risk assessment literature as "uncertainty" analyses, in reality, they may deal only with the measured variability in those variates treated stochastically, and not with true uncertainty. The results of the stochastic risk assessment using the information in this document are intended to quantify a good portion of the variability in human exposure in the population.

OEHHA attempted to use studies representative of the population of California in so far as possible. OEHHA identified the best distribution in the literature for water consumption rates. We developed a distribution for fisher caught non-commercial fish consumption from raw data from a study done in Santa Monica Bay in California. We developed a breathing rate distribution from the data of two activity studies and a breathing rate study sponsored by the California Air Resources Board. We developed a distribution of breast milk consumption rates for infants by combining raw data from two different studies. We developed distributions of the consumption rates of chicken, beef, pork, dairy products, leafy, exposed, protected, and root vegetables from information in the USDA Continuing Survey of Food Intake. Where data permitted we developed children's consumption distributions separately. Our distributions are expressed as intake per unit body weight utilizing in all but one case the body weights of the subjects reported in the original studies. As more data become available, OEHHA will periodically update Part IV.

ES.2.2 Point Estimate Approach to Exposure Assessment

OEHHA updated the parameters used in the point estimate approach. We refined our approach by using an estimate of average and high-end consumption rates, defined as the mean and 95th percentiles of the distribution, respectively, rather than a single point estimate. In this document, we introduce evaluation of 9, 30 and 70 year exposure durations instead of just a single 70-year exposure duration. The parameters used for the 9-year exposure scenario are for the first 9 years of life and are thus protective of children. Children have higher intake rates on a per kg body weight basis and thus receive a higher dose from contaminated media.

ES.3 Contents of This Document

ES.3.1 Air Dispersion Modeling

The concentration of pollutants in the ambient air is a key determinant of risk and is needed to conduct a risk assessment. Chapter 2 provides a description of available air dispersion models useful for the risk assessment of airborne contaminants emitted by stationary sources. Appropriate models are all USEPA approved. A description of appropriate air dispersion modeling report preparation is provided in Section 2.15.

ES.3.2 Breathing Rate

Chapter 3 provides information we used to develop breathing rate distributions. To characterize distribution of breathing rates in L/kg-day, we evaluated data from Adams (1993) on ventilation rates in a cross-section of the population measured while performing specific tasks. Mean breathing rates for specific tasks in the Adams study were then assigned to similar tasks recorded in two large activity patterns surveys (Wiley et al., 1991 a and b; Jenkins et al. 1992; see References Section 3.7). Daily breathing rates were then calculated for each individual in the activity patterns surveys by summing minutes at a specific activity times the ventilation rate for that activity across all activities over a 24 hour period. These breathing rates were then used to develop a distribution of breathing rates for children and for adults. A simulated breathing rate distribution for a lifetime (from age 0 to 70 years) was derived from the children and adult distributions. Recommendations for point estimates and distributions of breathing rate useful for chronic exposure assessment are provided in Section 3.6.

ES.3.3 Soil Ingestion Rates

Airborne chemicals may deposit onto soil and pose a risk through incidental or intentional ingestion of contaminated surface soil. Chapter 4 focuses on the soil ingestion pathway of exposure, and in particular on the default point estimates of soil ingestion rates. This pathway is not a major contributor to the risk for most chemicals in the Air Toxics “Hot Spots” program. However, there are some compounds (e.g., polychlorinated dibenzo-p-dioxins and furans, polycyclic aromatic hydrocarbons, some metals) for which soil ingestion may contribute a significant portion of the total dose and cancer risk estimate. It is not possible given the existing studies to develop reliable soil ingestion rate distributions appropriate to use for site-specific risk assessments. At this time, OEHHA is not recommending a distribution for use in the Air Toxics “Hot Spots” program pending resolution of the various problems associated with estimating soil ingestion rates and characterizing an appropriate distribution. Recommendations of point estimates useful in a risk assessment involving potential exposure via soil ingestion can be found in Section 4.7.

ES.3.4 Breast milk consumption

Chapter 5 describes information on breast milk consumption and the development of a distribution for breast milk consumption rates. Breast milk consumption is an indirect but important exposure pathway for some environmental contaminants. For example, some airborne toxicants (e.g., semi-volatile organic chemicals) deposited in the environment bio-magnify and become concentrated in human adipose tissue and breast milk lipid. Highly lipophilic, poorly metabolized chemicals such as TCDD, DDT and PCBs are sequestered in adipose tissue and only very slowly eliminated except during lactation. These toxicants in breast milk lipid appear to be in equilibrium with adipose tissue levels, and over time the breast-fed infant may receive a significant portion of the total maternal load. OEHHA developed distributions of breast milk intake rates from data published in two studies (Dewey et al., 1991; Hofvander et al., 1982; see References Section 5.7). Recommendations for point estimate values and distributions for use in exposure assessment where breast milk is a potential exposure pathway are presented in Section 5.6.

ES.3.5 Dermal Exposure

Uptake of chemicals through the skin could be significant for some of the Hot Spots-listed contaminants. However, it should be noted that dermal absorption of chemicals that are originally airborne is a relatively minor pathway of exposure compared to inhalation and ingestion exposure pathways. Uptake of chemicals which have settled onto surfaces as particles onto a surface (leaves, soil, furniture, etc.) is the important relevant pathway for initially airborne substances. This route applies to semivolatile organic chemicals like dioxins and PCBs, and some metals like lead. Competition between evaporation from the skin and dermal absorption results in a distribution of the chemicals between air, dust particle, and skin phases which depends on volatility, relative solubilities in the phases, temperature, and other factors. We are recommending a simple point estimate approach to assessing dermal exposure. Values of expose surface area, soil loading, and exposure frequency useful for assessing dermal exposure are provided in Section 6.5. In addition, dermal absorption factors are provided for specific chemicals in Appendix F.

ES.3.6 Food Intake Rates

Some of the toxic substances emitted by California facilities such as semivolatile organics and metals can be deposited as particles onto soil, surface water and food crops. Home raised chickens, cows and pigs may be exposed through consumption of contaminated feed, pasture, soil, water and breathing of contaminated air. Persons consuming garden produce or home-raised animal products may be exposed to toxic substances that were initially airborne but made there way into the food chain. Probability distributions and default consumption rates for homegrown vegetables and fruits, chicken, beef, pork, cow’s milk and eggs are discussed in Chapter 7. Homegrown rather than commercially produced produce, meat and milk are evaluated in the AB-2588 program because risk to the population adjacent to a facility is influenced more by home-grown or raised foods than commercially-bought foods. While a facility could contaminate commercially grown produce, meat and milk, typically commercially grown products come from diverse sources. Thus the risk to an individual from consuming commercial products contaminated from a single facility is likely to be quite small.

OEHHA has used the U.S. Department of Agriculture’s Continuing Survey of Food Intakes of Individuals (CSFII) 1989-91 survey data for the Pacific region to generate per capita consumption distributions for produce, meat (beef, chicken, and pork), dairy products and eggs. Produce was categorized into exposed, leafy, protected, and root for the purposes of determining concentrations in the produce. The availability of body weight data for each subject in the survey enabled consumption rates to be expressed in gram/kg body weight/day. Recommendations for point estimates and distributions are found in Section 7.9.

ES.3.7 Water Intake Rates

Deposition of airborne contaminants can result in exposure through drinking water. Airborne substances can deposit directly on surface water bodies used for drinking water and other domestic activities. (Material carried in by surface run-off is not considered at this time.) Chapter 8 assesses available information on individual water consumption rates and distributions for use in stochastic types of exposure assessment. OEHHA adopted distributions published in the literature (Ershow and Cantor, 1989; Ershow et al., 1991; see References Section 8.5) of water intake rates based on data from the USDA 1977-78 Nationwide Food Consumption Survey. We simulated a distribution for 0-9 year exposures using information in the literature. Recommendations for point estimates and distributions are provided in Section 8.4.

ES.3.8 Fish Consumption Rates

The “Hot Spots” (AB-2588) risk assessment process addresses contamination of bodies of water, mostly fresh water, near facilities emitting air pollutants. Chapter 9 describes available information on fish consumption rates and describes the development of a distribution from the Santa Monica Bay Seafood Consumption Study (1994; see References Section 9.7). The consumption of fish from contaminated bodies of water can be a significant exposure pathway, particularly for lipophilic toxicants such as dioxins. Commercial store-bought fish generally come from a number of sources. Thus, except in the rare event that fish in these bodies of water are commercially caught and eaten by the local population, the health risks of concern are due to noncommercial fishing. Therefore, the noncommercial fish consumption rate is a critical variate in the assessment of potential health risks to individuals consuming fish from waters impacted by facility emissions. Recommendations of values for point estimates and distributions of fish consumption rates are provided in section 9.5.

ES.3.9 Body Weight

Body weight (BW) is an important variate in risk assessment that is used in calculating dose (mg/kg BW/day). Many of the studies that OEHHA used to generate the distributions and point estimates collected body weight data on the subjects in the study. The consumption rate for each subject was divided by the body weight of that subject, and distributions of consumption per unit body weight per day were generated. However, the study used to determine fish consumption rate, did not collect body weight information on the subjects. Chapter 10 provides a review of the body weight literature. The published literature on body weight is mainly based on data gathered in the first National Health and Nutrition Examination Survey conducted between 1970 and 1974, and more recently in the second National Health and Nutrition Examination Survey (NHANES II). Appropriate body weight defaults were selected for our purposes. Recommendations are provided in Section 10.4.

ES.3.10 Duration of Exposure

Currently an assumption of lifetime exposure duration (70 years) for the calculation of cancer risk is incorporated into the cancer unit risk factor and oral cancer potency factors. Thus, when risk is calculated by multiplying modeled or measured concentrations in air by the unit risk factor, the risk is generally considered a “lifetime” risk. A cancer risk of 5×10^{-5} means that in a population exposed for 70 years, 50 people per million exposed would theoretically develop cancer over that 70 year period.

The point estimate risk assessment approach (Tier 1 and 2) can be used with more than one estimate of exposure duration to give multiple point estimates of cancer risk resulting from various chronic exposure durations. For stochastic risk assessment (Tier 3 and 4), the assessor could calculate separate cancer risk distributions for each fixed duration of exposure. In Chapter 11, OEHHA presents information for point estimates of exposure duration of 9, 30, and 70 years. Recommendations are provided in Section 11.5.

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 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 emitted chemicals in the air 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.

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; OEHHA has, therefore, developed a stochastic, or probabilistic, approach to exposure assessment to fulfill this requirement. 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.

Information on both dose-response relationship and exposure is required in order to quantify estimates of health risks. OEHHA has developed a series of documents describing the information supporting the dose-response assessment for "Hot Spots" chemicals and the exposure assessment methodologies. Part I, "Technical Support Document for the Determination of Acute Toxicity Exposure Levels for Airborne Toxicants" (March 1999) describes acute Reference Exposure Levels for approximately 50 chemicals and the methods used to determine those levels. Part II, "Technical Support Document for Determining Cancer Potency Factors" (April 1999), describes the methods and results of determining cancer potency factors for approximately 120 carcinogens. Part III, "Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels for Airborne Toxicants" (February, 2000), describes the methods of determining chronic Reference Exposure Levels (REL) and 38 chronic RELs for use in estimating noncancer health impacts from chronic exposure. Additional chronic RELs are currently undergoing peer review. The purpose of this document Part IV, "Technical Support Document for Exposure Assessment and Stochastic Analysis" is to describe 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. 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). In addition, OEHHA formed an External Advisory Group (EAG) to help evaluate the information used in the stochastic exposure analysis. This group was composed of representatives from industry, environmental organizations, universities, the CAPCOA Toxics Committee, ARB, the Department of Pesticide Regulation, the Department of Toxics Substances Control, and the U.S. Environmental Protection Agency (EPA). The purpose of the EAG was to get early input from stakeholders into the preparation of the stochastic methodology. Meetings of the EAG were held every 4 to 6 weeks to discuss available data on key exposure variates and the characterization of the distributions of key exposure variates.

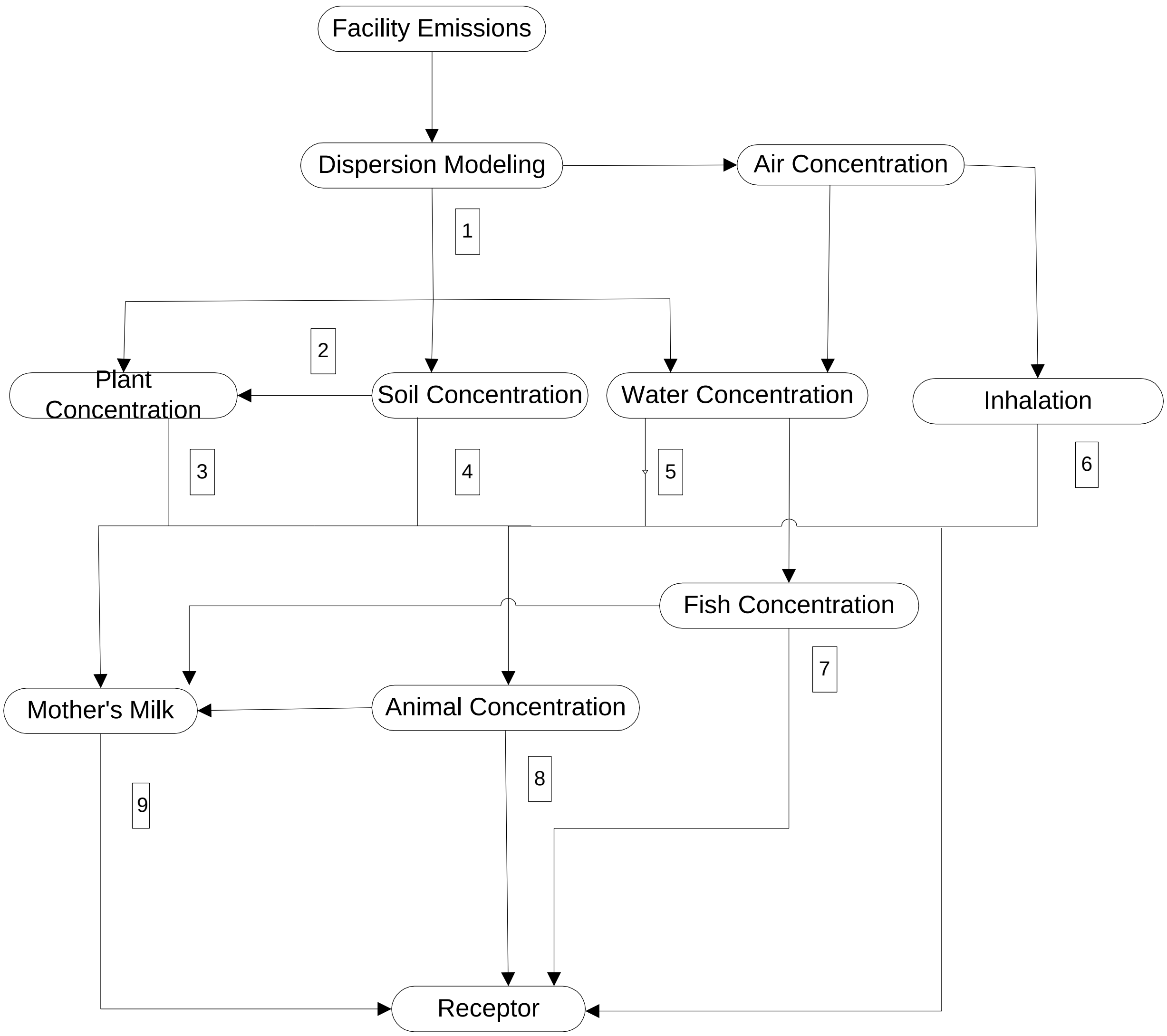
Finally, a companion document is being developed, “Air Toxics ‘Hot Spots’ Risk Assessment Guidance Manual”, which contains the essential information to conduct a health risk assessment based on the four technical support documents described above.

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 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 (the latter is not considered under these guidelines). 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.

Inhalation exposure is assessed for all “Hot Spots”-listed chemicals which have either Cancer Potency Factors and/or Reference Exposure Levels (see Technical Support Documents, Parts I, II, and III for information on these values (OEHHA, 1999a, 1999b, 2000)). The noninhalation exposures are assessed only for semivolatile organics and metals listed in Appendix E, Table E.2. Appendix E contains a description of the process used to decide which

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.
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.

chemicals should be evaluated by multipathway exposure assessment. Only the exposure pathways which exist at a particular site need to be assessed. 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 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 runnoff 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

Traditionally, site-specific risk assessments have been conducted using a point estimate (sometimes referred to as a deterministic) approach in the exposure and risk model. In the point estimate approach, a single value is assigned to each variate in the model (e.g., breathing rate is assumed to be 20 m^3/day, body weight to be 70 kg). 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 near the high-end of the range of estimated risks and are therefore protective of public health.

OEHHA is providing guidance in this document on the point estimate approach including both algorithms and default values where appropriate. OEHHA started with the current methods used in the Air Toxics “Hot Spots” program as described in the CAPCOA Air Toxics “Hot Spots” Program Revised 1992 Risk Assessment Guidelines, October 1993 (CAPCOA, 1993). These algorithms are consistent with the U.S. EPA Risk Assessment Guidance for Superfund and are widely used. The algorithms and point estimate values were reevaluated for their utility, and whether they represent the best scientific approach. The evaluation showed that the existing algorithms were appropriate for the point estimate approach. A number of the point estimate values for exposure factors or variates were updated based on literature reviews. Some values (e.g., soil ingestion rates, dermal exposure factors) are adopted from U.S. EPA documents (U.S. EPA 1991, 1997). The mean of exposure variate values from several equally regarded studies was used when appropriate. When OEHHA developed or adopted a distribution for an exposure variate, the information from the distributions was used to determine central tendency and high end point estimates. OEHHA has used the arithmetic mean to reflect central tendency and the 95% upper confidence limit to represent a high-end estimate in this document.

U.S. EPA (1995) promotes the use of risk descriptors for "(1) individual risk that include central tendency and high-end portions of the risk distribution, (2) population risk and (3) important subgroups of the population, such as highly exposed or highly susceptible groups" (U.S. EPA, 1995, attachment p. 12). The U.S. EPA (1992) Guidelines for Exposure Assessment state "conceptually, high-end risk means risks above the 90th percentile of the population distribution but not higher than the individual in the population who has the highest risk." Similarly, high end of exposure is presented as ranging from the 90th to the 99.9th percentile (U.S. EPA, 1992, p. 22923). U.S. EPA (1995) risk characterization guidance states that it will be difficult to estimate exposures or doses and associated risk at the high end with much confidence if very little data are available on the range of a variate. U.S. EPA further state "One method that has been used in such cases is to start with a bounding estimate and "back off" the limits used until the combination of parameter values is, in the judgment of the assessor, within the distribution of expected exposures, and still lies within the upper 10% of persons exposed. Obviously, this method results in a large uncertainty and requires explanation." (U.S. EPA, 1995, p. 15). OEHHA has not established any bounding estimates in this document or used this method to create a high-end estimate. "Central tendency" is meant to reflect typical or average estimates of exposure. U.S. EPA (1995) bases central tendency on either the arithmetic mean or median exposure estimate.

Frequently, there are little data for identifying point estimate values for exposure variates. This makes evaluation of the information and choice of a scientifically defensible value difficult. When the data are limited, a mean value derived from scientifically valid studies is the most defensible, as it is the best estimate of the central tendency and is less uncertain than an upper or lower end estimate. OEHHA has chosen a central tendency estimate (mean or approximation of the mean) when little data are available to evaluate a specific variate. If there are enough data to generate a mean and high-end estimate, then OEHHA has provided both the mean and a high-end estimate for those variates.

A tiered approach to risk assessment including point estimate methods, which allows for both consistency and flexibility, is described in Section 1.4. OEHHA's proposed algorithms and default point estimates for each major exposure pathway are described in Chapters 3 through 11. Information supporting the choice is briefly summarized in each section.

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, quantitative risk assessment is associated with much uncertainty. A single point estimate approach provides only limited information on the variability in the dose or risk estimates. Information about the potential range of risks in the population is presented as average or high-end point estimates of risk.

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

Quantitative risk estimates are uncertain. In common use, the term "uncertainty" in a risk estimate can be viewed as composed of variability as well as true uncertainty in exposure and dose-response. 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.

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 attempts to quantify some of the "uncertainty" in the risk estimates by using measured variability in data describing key exposure variates to characterize the distribution of that variate. Under the stochastic approach, a distribution of values is used as input for one or more variates in the model. Using statistical methods, such as Monte Carlo simulation, to propagate the variance of exposure variates through the model, the risk estimates are expressed as a range rather than as a single point estimate.

Note that the stochastic approach employed in the Air Toxics "Hot Spots" program does not address either exposure model uncertainty or true uncertainty about a variate that is not reflected in the measured variance of the exposure variate. This lack of information (true uncertainty) may occur because a variable is not currently measurable with available scientific methods, the accuracy in measuring the variable is unknown, or there is otherwise a lack of knowledge about the variable. Although stochastic methods like the one described in this document are frequently referred to in the risk assessment literature as "uncertainty" analyses, in reality, they may deal only with the measured variability in those variates treated stochastically, and not with true uncertainty.

The primary benefits of stochastic analysis are the quantitative or semi-quantitative treatment of variability in risk estimates and the increase in information on which to base decisions. In contrast, a point estimate approach generally treats variability and uncertainty in the risk estimate qualitatively, if at all. The disadvantages of the stochastic approach include the resource-intensive nature of such an analysis, difficulty in treating true uncertainty, that is, lack of knowledge about factors which impact the risk estimate, and difficulty in communicating the results to risk managers and the public. In order to use a stochastic approach fully, much work needs to go into the characterization of probability distributions for key exposure variates, and one may still be unable to treat the major sources of uncertainty due to a lack of data. Since stochastic analysis is resource-intensive, this approach is more appropriate when addressing important problems that merit the necessary effort.

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.

In deciding which variates were important and amenable to stochastic analysis, OEHHA considered several criteria. First, the importance of a given pathway in the multipathway analysis of risk was taken into consideration. All chemicals in a “Hot Spots” risk assessment are evaluated via the inhalation pathway. Therefore, OEHHA chose to evaluate data on minute ventilation and activity patterns to develop distributions for daily breathing rates for adults and children. Second, for each indirect noninhalation pathway, OEHHA evaluated data describing the key intake variate in order to characterize distributions for those important inputs. For example, the distribution of breast milk consumption in the first year of life was characterized using raw data on consumption from published studies. Two important considerations in developing the distributions in this document were the importance of the exposure pathway relative to inhalation exposure and the quality of data available to characterize the value of key variates. We chose not to develop distributions applicable to the soil ingestion pathway because data available to characterize soil ingestion rates are problematic. We also chose not to develop distributions for the variates involved in the dermal pathway because this pathway is less important overall and data available for some variables are extremely limited.

The exposure distributions developed were designed to cover from age 0-9 years and age 0-70 years. The exception to this is the breast milk consumption distribution that is only for the first year of life. Nine and 70-year distribution are simulated where necessary, using Monte Carlo methods. These distributions can be used for evaluating the 9- and 70-year exposure durations which are recommended in this document. In the interest of simplicity, we are recommending that 0-70 year distributions be used for evaluating the 30-year exposure duration. The 0-9 year distributions are based on the first 9 years of life in which exposure on a per kg body weight basis and thus dose is greater than for adults. Thus the 9-year distributions are appropriate for children but will overstate the risk for 9 years of an adult exposure.

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.

In analyzing distributions, OEHHA gathered information on existing point estimates and distributions for key exposure variates in use by Cal/EPA or U.S. EPA, and suggested in the literature or in available documents (e.g., the American Industrial Health Council’s Exposure Factors Sourcebook). The underlying bases for the distributions were evaluated for applicability to the Air Toxics “Hot Spots” program. In some instances available distributions were found to be useful in their current form. Some distributions were modified by adding more recent information. In other instances, OEHHA chose to characterize a distribution from available raw data. In general, the statistical package SAS® was used in the Proc Univariate mode to analyze distributions from raw data. More detail is provided in each individual section on the characterization of the distributions.

There are undoubtedly exposure variates for which distributions could be characterized based on available data. However, due to resource and time constraints, OEHHA evaluated those exposure intake variables that are likely to have greater impacts on quantitative estimates of risk and for which there are useful data to characterize a distribution (see Chapters 3 through 11). We hope to develop additional distributions in the future.

1.4 Tiered Approach to Risk Assessment

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 lower costs to facilities conducting risk assessments, 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.

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 Part IV, is given in the companion document "Office of Environmental Health Hazard Assessment Air Toxics "Hot Spots" Risk Assessment Guidelines" (to be released following completion of Parts I-IV). Site-specific values such as 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, which 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. This 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.

In some instances, a facility's emissions may not pose a cancer risk, but instead the driver is a noncarcinogen. OEHHA is recommending the hazard index (HI) approach to assess the potential for noncancer health impacts. 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. The HI approach calculations and the estimate of the Reference Exposure Level do not necessarily directly involve inhalation rate. Therefore, the determination of mean and high-end estimate is not as easily applied.

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). 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.

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 need to be presented clearly in the risk assessment, and the risk assessment need to include a justification for the exposure scenarios developed.

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 uncertainty in the risk 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 of this document.

OEHHA is recommending that a stochastic analysis be performed for cancer risk assessment only. OEHHA is considering various issues that still need to be resolved in order to develop a useful noncancer stochastic risk assessment approach. This issue may be addressed in future updates of the document. OEHHA is recommending a point estimate approach only for assessing the impact of AB-2588 facilities on workers employed at nearby work sites. 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. OEHHA and the Air Resources Board are working towards a software product that will be available to the public and will be able to perform the point estimate and stochastic risk assessments.

1.4.4 Tier 4

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. 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 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.

1.6 Children's Exposures

In the 1996 Public Review Draft of this document (OEHHA, 1996), Chapter 5 Breast Milk Consumption Rate, the issue of weighting early in life exposures proportionally greater than later in life exposure is discussed. There is evidence for some chemicals that an early-in-life exposure to the same dose is more potent in causing cancer than later in life exposure (Drew et al., 1983, Peto et al., 1992). Although exposure to toxicants via the breast milk pathway is a very early in life exposure, early-in-life exposure also occurs via other pathways, for example, soil ingestion and food ingestion. We are mandated under SB-25 to evaluate if current OEHHA cancer potency factors, unit risk factors, and Reference Exposure Values are protective of children's health. As part of the SB-25 mandate, OEHHA will be evaluating the important issue of weighting early-in-life exposure and its significance in protecting public health. In addition, we are striving towards more complete evaluation of exposures to infants, young children, and adolescents. This requires more and better data than we have utilized as the basis for the distributions presented in this document for the 0 to 9 year exposure scenarios. This document will be updated as new data become available.

1.6 References

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2. Air Dispersion Modeling

2.1 Air Dispersion Modeling in Risk Assessment: Overview

The concentration of pollutants in the ambient air is integral to characterizing the airborne exposure pathway and the overall risk assessment process. Pollutant concentrations are required in risk assessment calculations to estimate the cancer risk or hazard indices associated with the emissions of any given facility. Although monitoring of a pollutant provides excellent characterization of its concentrations, it is time consuming, costly and is typically limited to a few receptor locations. Air dispersion modeling has the advantage of being relatively inexpensive and is less time consuming provided that all the model inputs are available. In addition, air dispersion modeling provides greater flexibility in terms of receptor locations, assessment of individual and cumulative source contributions, and characterization of concentration over greater spatial extents. The air dispersion models used in Hot Spots program do not consider chemical reactions. Atmospheric reactions (including photolysis) will decrease atmospheric concentrations for chemicals that react (or photolyze). The air modeling will thus tend to overestimate concentrations for these chemicals. The air pollution control districts evaluate and approve modeling of the emissions from facilities. Application of professional judgment is required throughout the modeling process and the local air district is the final authority on modeling protocols. The guidance that follows is only intended to assist in understanding the process.

Air dispersion modeling requires the execution of the following steps (see Fig 1):

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

(2) classify the emissions according to source type and source quantity (Section 2.3)

(3) classify the analysis according to terrain (Section 2.4)

(4) determine level of detail for the analysis: refined or screening analysis (Section 2.5)

(5) identify the population exposure(Section 2.6)

(6) determine the receptor locations where impacts need to be analyzed (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 modeling protocol and submit to the local Air District (hereafter referred to as "the District") (Section 2.14)

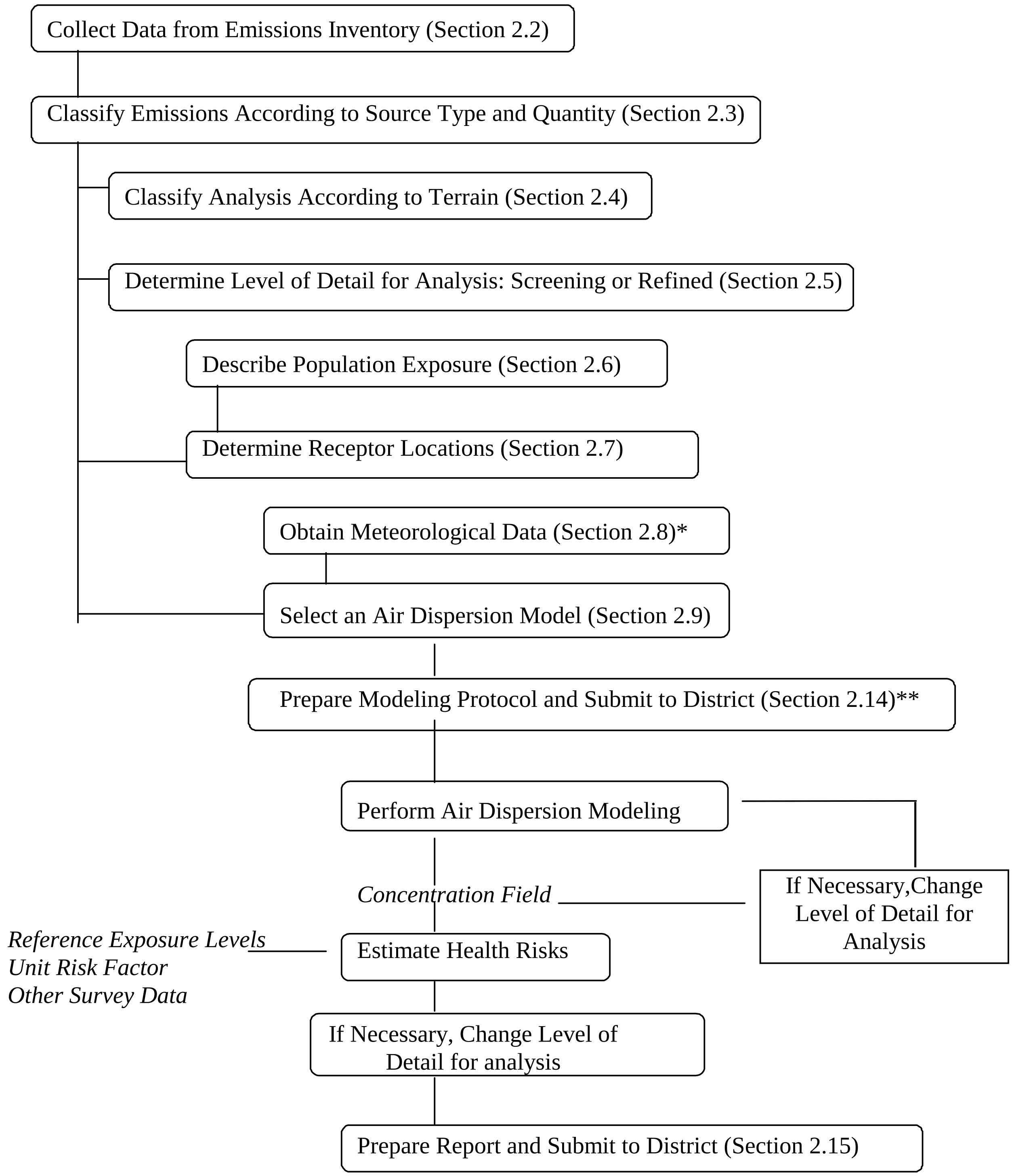
(10) perform an air dispersion analysis

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

(12) perform risk assessment

(13) if necessary, change from screening to refined model 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 an air dispersion modeling analysis will be a receptor field of concentrations of the pollutant in ambient air. These concentrations in air need to be coupled with reference exposure levels and unit risk factors to estimate the hazard indices and potential carcinogenic risks. It should be noted that in the Air Toxics "Hot Spots" program, facilities model the dispersion of the chemical emitted, and do not model any atmospheric transformations or dispersion of products from such reactions.

2.2 Emission Inventories

The emission information contained in the Emission Inventory Reports ("Inventory Reports") developed under the Air Toxics "Hot Spots" Information and Assessment Act (AB2588), provides data to be used in the risk assessment and in the air dispersion modeling process. The Inventory Reports contain information regarding 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.

Use of updated emission information to account for process changes, emission factor changes, material/fuel changes, or shutdown must be approved by the District prior to the submittal of the risk assessment. 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 information which is 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. Under the regulations, the list is divided into three groups for reporting purposes[2]. For the first group (listed in Appendix A-I of the Inventory Guidelines Report), all emissions must be quantified. For substances in the second group (listed in Appendix A-II of the Inventory Guidelines Report), emissions do not need to be quantified, however, facilities must report whether the substance is used, produced, or otherwise

[1] Title 17, California Code of Regulations, Sections 93300-93300.5
[2] The most recent amendments became effective July 1, 1997.

present on-site. For the third group (listed in Appendix A-III of the Emissions Inventory Guidelines Report), 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 required to be quantified in the facility's emission inventory report. Specifically, risk assessments should include both annual average emissions and maximum 1-hour emissions for each pollutant. Emissions for each substance must be reported for individual emitting processes associated with unique 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 risk assessment 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 risk assessment 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 risk assessment 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 presenting emission estimates included in the previously submitted emission inventory report as well as those for the risk assessment should be presented. The District should be consulted concerning the specific format for presenting the emission information. A revised emission inventory report must be submitted to the District prior to submitting the risk assessment and forwarded by the District to the CARB, if revised emission data are used.

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 Release Parameters

It is necessary to report how substances are released into the atmosphere. Release parameters (e.g., stack height and inside diameter, stack gas exit velocity, release temperature and emission source location in UTM coordinates) are needed to use air dispersion models. 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 portion 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., degrees K vs. degrees F).

2.2.1.4 Operation Schedule

The risk assessment should include a discussion of the facility operation schedule and daily emission patterns. Special weekly or seasonal emission patterns may vary and should be discussed. This is especially important in a refined risk assessment. Diurnal emission patterns should match the diurnal dispersion characteristics of the ambient air. In addition, for the purposes of exposure adjustment, the emission schedule and exposure schedule should corroborate any exposure adjustment factors. (For example, no exposure adjustment factor should be made when the worker and the emissions are on a coincident schedule.) Some fugitive emission patterns may be continuous. A table should be included with emission schedule on an hourly and yearly basis.

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

The facility's emissions need to be characterized according to the source type and quantity in order to select an appropriate air dispersion model.

2.3.1 Classification According to Source Type

Air dispersion models can be classified according to the type of source that they are designed to simulate, including: point, line, area and volume sources. Several models have the capability to simulate more than one type of source.

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 practical terms, line sources are 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.

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 at the same elevation 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. Sources of fugitive emissions with a significant vertical extent should be modeled as volume sources.

In general, the computer algorithms used to model area sources impose certain restrictions on the proximity of the receptors to the source. Refer to each model's section for specific restrictions.

2.3.1.4 Volume Sources

Non-point sources with emissions containing 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 Classification According to Quantity of Sources

Selection of an air dispersion model also requires the classification of the source in terms of quantity. Some dispersion models are capable of simulating only one source at a time, and are therefore referred to as single-source models (e.g., SCREEN3).

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 the distance of the receptor to the nearest stack).

- running the model for each individual source and superimposing results

  Superposition 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 Characterization

Two types of terrain characterizations are required to select the appropriate model. One classification is made according to land type and another one according to terrain topography.

2.4.1 Classification According to Land Type

Most air dispersion models 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, e.g., on the coast, the District should be consulted concerning the classification. 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.

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).

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 Classification According to Terrain 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 various 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. Topography can be classified as follows:

2.4.2.1 Simple Terrain (alsoReferred 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.

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.

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 in which 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 chronic and acute Health Hazard Indices) on a separate map would 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.

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

- Use a screening dispersion model (e.g., SCREEN3) 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 this document.

- 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}. This exercise should be repeated for the noncancer health impacts.

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, 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. 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 at which 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, census tracts which the facility could significantly impact should be identified (see Section 2.6.3.1). A census tract should 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.

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 for which 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. Maps showing census tract boundaries and numbers can be obtained from "The Thomas Guide® - Census Tract Edition". Statistics for each census tract can be obtained from the U.S. Census Bureau. 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 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 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). If only a portion of the census tract lies within the zone of impact, the population used in the burden calculation should include the proportion of the population in that isopleth zone. 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 may be computerized and minimizes manual mapping of centroids and census tracts.

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.

It is necessary to limit the size of the detailed analysis area because inclusion of all subcensus tracts would greatly increase the resource requirements of the analysis. For example, an urban area of 100,000 persons would involve approximately 25 census tracts, approximately 100 to 150 block groups, and approximately 1,000 to 1,400 blocks. Furthermore, a high degree of resolution at large distances from a source would not significantly affect the analysis because the concentration gradient at these distances is generally small. Thus, the detailed analysis of census tracts within several kilometers of a facility should be sufficient. The District should be consulted to determine the area that requires detailed analysis.

The District should also be consulted to determine the degree of resolution required. In some cases, resolution of residential populations to the BG/ED level may be sufficient. However, resolution to the block level may also be required for those BG/EDs closest to the facility or those having maximum concentration impacts. The identified employment subareas should be resolved to a similar degree of resolution as the residential population. For each subarea analyzed, the number of residents and/or workers exposed should be estimated.

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 sensitive individuals are protected by general assumptions made in the cancer risk assessment, their identification may be useful to assure the public that such individuals are being considered in the analysis. For noncancer effects, the identification of such individuals may be crucial in evaluating the potential impact of the toxic effect.

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 carcinogenic and noncarcinogenic effects. It is possible that the estimated PMI, MEIR and MEIW risk for carcinogenic, chronic noncarcinogenic, and acute noncarcinogenic health effects occur at different locations. The results from a screening model (if available) can be used to identify the area(s) where the maximum concentrations are likely to occur. Receptor points should also be located at the population centroids (see Section 2.7.2) and sensitive receptor locations (see Section 2.6.4). The exact configuration of the receptor array used in an analysis will depend on the topography, population distribution patterns, and other site-specific factors. All receptor locations should be identified in the risk assessment using UTM (Universal Transverse Mercator) coordinates and receptor number. The receptor numbers in the summary tables should match receptor numbers in the computer output. In addition to UTM coordinates, the street address(es), where possible and as required by the local district, should be provided for the PMI, MEIR and MEIW for carcinogenic and noncarcinogenic health effects.

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 to represent the breathing zone, or direct inhalation, 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 multipathway analysis which requires the deposition at ground level. 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 should be with District.

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. Where population is not uniformly distributed, a population-weighted centroid is needed. Another alternative could be to use 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.

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 census tracts maps and street maps to determine the centroid location. At the block level, a geographic centroid is sufficient.

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, 1995c) 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 period of record recommended for use in the air dispersion model is five years. If it is desired to use a single year to represent long-term averages (i.e., chronic exposure), then the worst-case year should be used. The worst-case year should be the year that yields the greatest maximum chronic off-site risk. If the only adverse health effects associated with all emitted pollutants from a given facility are acute, the worst-case year should be the year that yields the greatest maximum acute off-site risk. However, the District may determine that one year of representative meteorological data is sufficient to adequately characterize the facility's impact.

Otherwise, to determine annual average concentrations for analysis of chronic health effects, the data can be averaged if a minimum of three years of meteorological data are available. For calculation of the one-hour maximum concentrations needed to evaluate acute effects, the worst-case year should be used in conjunction with the maximum hourly emission rate. For example, the annual average concentration and one-hour maximum concentration at a single receptor for five years of meteorological data are calculated below:

Year	Annual Average (μg/m^3)	Maximum One-Hour (μg/m^3)
1	7	100
2	5	80
3	9	90
4	8	110
5	6	90
5-year average	7	

In the above example, the long-term average concentration over five years is 7.0 μg/m^3. Therefore, 7 μg/m^3 should be used to evaluate carcinogenic and chronic effects (i.e., annual average concentration). The one-hour maximum concentration is the highest one-hour concentration in the five-year period. Therefore, 110 μg/m^3 is the peak one-hour concentration that should be used to evaluate acute effects.

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.

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.

2.8.1 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) and PCRAMMET. 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.

The input format for the U.S. EPA long-term models should be of the stability wind rose (STAR) variety generated for the National Weather Service (NWS) stations by the National

Climatic Data Center. U.S. EPA recommended software for processing STAR data includes the PCSTAR program and MPRM. Individual model user's guides should be referred to for additional details on input data formats.

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.

2.8.2 Treatment of Calms

Calms are normally considered to be wind speeds below the starting threshold of the anemometer or vane (whichever is greater). 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. 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.

2.8.3 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. In order for the regulatory models to function properly, there must be a data value in each input field. 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 a field of nines. This value will act as a missing flag in any further use of the data set.

At the present time, the short-term regulatory models contain no mechanism for handling missing data in the sequential input file. Therefore, in order to run these models a complete data set, including substitutions, is required. 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.

2.8.4 Representativeness of Meteorological Data

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

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 with the meteorological data sets used 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.

2.8.4.1 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.

2.8.4.2 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. In general, the climatic period of five years is adequate to represent these yearly variations.

2.8.4.3 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.

2.8.5 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 2.8.3, 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).

2.8.5.1 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 format for U.S. EPA long-term models is the STAR format utilized by the National Climatic Data Center. Both 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.

If data are missing from the primary source, they should be handled as follows, in order of preference: (l) 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 field of nines, according to the discussions in Section 2.8.3. However, in order to run existing short-term regulatory models, a complete data set, including substitutions, is required.

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

2.8.6 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 is in the process of adding three new models to the preferred list of models: ISC-PRIME, AERMOD, and CalPuff. 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. New models placed on U.S. EPA's preferred list of models (i.e., ISC-PRIME, AERMOD, and CalPuff) can be considered at that time. 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 shown in Table 2.2. Currently, SCREEN3 and ISCST3 are the two models used for most risk assessments. This could change when the U.S. EPA places ISC-PRIME, AERMOD, and CalPuff on the preferred list. Some of the names of the air dispersion models reflect the version number at the time of the writing of this document. The most current version of the models should be used for the risk assessment analysis. More than one model may be necessary in some situations, for example, when modeling scenarios have receptors in simple and complex terrain. Some facilities may also require models capable of handling special circumstances such as building downwash, dispersion near coastal areas, etc. 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).

TABLE 2.2 Recommended Air Dispersion Models

	AVERAGING PERIOD	TERRAIN TYPE	SINGLE SOURCE		MULTIPLE SOURCE	
			RURAL	URBAN	RURAL	URBAN
REFINED MODELS	SHORT TERM (1-24 hour avg)	SIMPLE	ISCST3	RAM ISCST3	ISCST3	RAM ISCST3
		COMPLEX	CTDMPLUS	CTDMPLUS	CTDMPLUS	CTDMPLUS
	LONG TERM (Monthly-Annual)	SIMPLE	ISCST3 ISCLT3	RAM ISCST3, ISCLT3	ISCST3 ISCLT3	CDM20 / RAM ISCST3 ISCLT3
		COMPLEX	CTDMPLUS	CTDMPLUS	CTDMPLUS	CTDMPLUS
SCREENING MODELS	SHORT TERM (1-24 hour avg)	SIMPLE	SCREEN3	SCREEN3	SCREEN3	SCREEN3
		COMPLEX	ISCST3 RTDM, CTSCREEN VALLEY SCRN	SHORTZ CTSCREEN VALLEY SCRN	ISCST3 CTSCREEN* VALLEY SCRN	SHORTZ CTSCREEN* VALLEY SCRN
	LONG TERM (Monthly-Annual)	SIMPLE	SCREEN3	SCREEN3	SCREEN3	SCREEN3
		COMPLEX	ISCST3 RTDM	LONGZ	ISCST3	LONGZ
	Other models (e.g., ISC-PRIME, AERMOD, CalPuff) may be added to this list at a future date.					

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 shown in Table 2.2. For more information on the applicability of alternative models refer to the following documents:

- U.S. EPA (1986). "Guideline on Air Quality Models (Revised)" 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 meteorological data are available and may be used as a preliminary estimate to determine if a more detailed assessment is warranted. Specific information about the screening models presented in Table 2.2 is provided in the following subsections. For more information regarding general aspects of model selection see Section 2.9.

Some screening models provide only 1-hour average concentration estimates. Maximum 1-hour concentration averages can be converted to other averaging periods in consultation and with approval of the responsible air district. Because of variations in local meteorology, the exact factor selected may vary from one district to another. Table 2.3 provides guidance on the range and typical values applied. The conversion factors are designed to bias predicted longer term averaging periods towards overestimation.

Table 2.3. Recommended Factors to Convert Maximum 1-hour Avg. Concentrations to Other Averaging Periods (U.S. EPA, 1995a; ARB, 1994).

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

2.10.1 SCREEN3

The SCREEN3 model is among the most widely used model primarily because it has been periodically updated to reflect changes in air dispersion modeling practices and theories. The SCREEN3 model represents a good balance between ease of use and the capabilities and flexibility of the algorithms. In addition, the calculations performed by the model are very well documented (U.S. EPA, 1995a). The SCREEN3 User's Guide (U.S. EPA, 1995d) also presents technical information and provides references to other support documents.

The most important difference between the SCREEN3 model and refined models such as ISCST3 is the meteorological data used to estimate pollutant concentrations. The SCREEN3 model can assume worst-case meteorology, which greatly simplifies the resources and time normally associated with obtaining meteorological data. Consequently, more conservative (higher concentration) estimates are normally obtained. Alternatively, a single stability class and wind speed may also be entered.

Number of Sources and Type

SCREEN3 was designed to simulate only a single source at a time. However, more than one source may be modeled by consolidating the emissions into one emission point or by individually running each point source and adding the results. SCREEN3 can be used to model point sources, flare releases, and simple area and volume sources. Input parameters required for various source-types are shown in Tables 2.4 (point), 2.5 (flare release), 2.6 (area) and 2.7 (volume).

Table 2.4. Required Input Parameters to Model a Point Source Using SCREEN3.

Emission Rate (g/s)	
Stack Height (m)	
Stack Inside Diameter (m)	
Stack Gas Exit Velocity (m/s) or Volumetric Flow Rate (ACFM, m^3/s)	
Stack Gas Temperature (K)	
Ambient Temperature (K)	
Receptor Height Above Ground (m)	
Receptor Distance from the Source (m)	[discrete distance or automated array]
Land Type	[urban or rural]
Meteorology: none	[option "1" (full meteorology) is normally selected]
In Addition, for building downwash calculations	
Building Height (m)	
Minimum Horizontal Dimension (m)	
Maximum Horizontal Dimension (m)	

Table 2.5. Required Input Parameters to Model a Flare Using SCREEN3.

Emission Rate (g/s)	
Flare Stack Height (m)	
Total Heat Release (cal/s)	
Receptor Height Above Ground (m)	
Receptor Distance from the Source (m)	
Land Type	[urban or rural]
Meteorology: none	[option "1" (full meteorology) is normally selected]
In Addition, for building downwash calculations	
Building Height (m)	
Minimum Horizontal Dimension (m)	
Maximum Horizontal Dimension (m)	

Table 2.6. Required Input Parameters to Model an Area Source Using SCREEN3.

Emission Rate (g/s-m^2)	
Source Release Height (m)	
Length of Larger Side of the Rectangular Area (m)	
Length of Smaller Side of the Rectangular Area (m)	
Receptor Height Above Ground (m)	
Receptor Distance from the Source (m)	
Land Type	[urban or rural]
Meteorology: none	[option "1" (full meteorology) is normally selected] [wind direction optional]

Table 2.7. Required Input Parameters to Model a Volume Source Using SCREEN3.

Emission Rate (g/s)	
Source Release Height (m)	
Initial Lateral Dimension of Volume (m)	
Initial Vertical Dimension of Volume (m)	
Receptor Height Above Ground (m)	
Receptor Distance from the Source (m)	
Land Type	[urban or rural]
Meteorology: none	[option “1” (full meteorology) is normally selected]

Regulatory Options

SCREEN3 algorithms contain all regulatory options internally coded including: stack-tip downwash and buoyancy-induced dispersion. These regulatory options are the default settings of the parameters so the user does not need to set any switches during a run.

Special Cases

SCREEN3 has the capability to model several special cases by setting switches in the input file or by responding to on-screen questions (if run interactively). The special cases include:

- simple elevated terrain
- plume impaction in complex terrain using VALLEY model 24-hr screening procedure
- building downwash (only for flat and simple elevated terrain)
- cavity region concentrations
- inversion break-up fumigation (only for rural inland sites with stack heights greater than or equal to 10 m and flat terrain)
- shoreline fumigation (for sources within 3,000 m from a large body of water)
- plume rise for flare releases

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 2.8). 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 2.9. 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 2.8. Time-scaling factors internally coded in CTSCREEN

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

Table 2.9. 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

2.10.4 SHORTZ

SHORTZ utilizes a special form of the steady-state Gaussian plume formulation for urban areas in flat or complex terrain to calculate ground-level ambient air concentrations. It can calculate 1-hour, 2-hour, 3-hour, etc., average concentrations due to emissions from stacks, buildings, and areas sources from up to 300 arbitrarily placed sources. Only a mainframe version of SHORTZ is available and its use has greatly diminished in favor of other PC-compatible models. For more information on SHORTZ consult the user's guide (Bjorklund and Bowers, 1982).

Special Cases

- Deposition
  Same algorithms as those included in ISC models with a reflection coefficient equal to zero.

2.10.5 LONGZ

LONGZ contains the same algorithms found in the SHORTZ model (see Section 2.10.4) but it is designed to handle meteorology in a manner more suitable to long-term concentration estimates. LONGZ requires meteorological data in the form of STAR summaries. For more information on LONGZ consult the user's guide (Bjorklund and Bowers, 1982).

2.10.6 RTDM

The RTDM screening technique can provide a more refined concentration estimate if on-site wind speed and direction, characteristic of plume dilution and transport, are used as input to the model. In complex terrain, these winds can seldom be estimated accurately from the standard surface (10 m level) measurements. Therefore, in order to increase confidence in model estimates, U.S. EPA recommends that wind data input to RTDM should be based on fixed measurements at stack top height. For stacks greater than 100 m, the measurement height may be limited to 100 m in height relative to stack base. However, for very tall stacks (e.g., greater than 200 m), the District should be consulted to determine an appropriate measurement height. This recommendation is broadened to include wind data representative of plume transport height where such data are derived from measurements taken with remote sensing devices such as SODAR. The data from both fixed and remote measurements should meet quality assurance and recovery rate requirements. The user should also be aware that RTDM in the screening mode accepts the input of measured wind speeds at only one height. The default values for the wind speed profile exponents shown in Table 2.10 are used in the model to determine the wind speed at other heights. RTDM uses wind speed at stack top to calculate the plume rise and the critical dividing streamline height, and the wind speed at plume transport level to calculate dilution. RTDM treats wind direction as constant with height.

RTDM makes use of the "critical dividing streamline" concept and thus treats plume interactions with terrain quite differently from other models such as SHORTZ and COMPLEX I. The plume height relative to the critical dividing streamline determines whether the plume impacts the terrain, or is lifted up and over the terrain. The receptor spacing to identify maximum impact concentrations is quite critical depending on the location of the plume in the vertical. Analysis of the expected plume height relative to the height of the critical dividing streamline should be performed for differing meteorological conditions in order to help develop an appropriate array of receptors. Then it is advisable to model the area twice according to the suggestions in Section 2.6.

Table 2.10. Preferred Options for the RTDM Computer Code When Used in a Screening Mode (U.S. EPA, 1986).

Parameter	Variable	Value	Remarks
PR001-003	SCALE		Scale factors assuming horizontal distance is in kilometers, vertical distance is in feet, and wind speed is in meters per second
PR004	ZWIND1	Wind measurement height	See Section 5.2.1.4
	ZWIND2	Not used	Height of second anemometer
	IDILUT	1	Dilution wind speed scaled to plume height
	ZA	0 (default) stack base	Anemometer-terrain height above
PR005	EXPON	0.09, 0.11, 0.12, 0.14, 0.2, 0.3 (default)	Wind profile exponents
PR006	ICOEF	3 (default)	Briggs Rural/ASME (1979) dispersion parameters
PR009	IPPP	0 (default)	Partial plume penetration; not used
PR010	IBUOY	1 (default)	Buoyancy-enhanced dispersion is used
	ALPHA	3.162 (default) coefficient	Buoyancy-enhanced dispersion
PR011	IDMX	1 (default)	Unlimited mixing height for stable conditions
PR012	ITRANS	1 (default)	Transitional plume rise is used
PR013	TERCOR	6*0.5 (default)	Plume patch correction factors
PR014	RVPTG	0.02, 0.035 (default)	Vertical potential temperature gradient values for stabilities E and F
PR015	ITIPD	1	Stack-tip downwash is used
PR020	ISHEAR	0 (default)	Wind shear; not used
PR022	IREFL	1 (default)	Partial surface reflection is used
PR023	IHORIZ	2 (default)	Sector averaging
	SECTOR	6*22.5 (default)	Using 22.5° sectors
PR016 to 019; 021; and 024	IY, IZ, IRVPTG, IHVPTG;IEPS; IEMIS	0	Hourly values of turbulence, vertical potential temperature gradient, wind speed profile exponents, and stack emissions are not used

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. Specific information about the refined models presented in Table 2.2 is provided in the following subsections. For more information regarding general aspects of model selection see Section 2.9.

2.11.1 ISCST3

The ISCST3 model (U.S. EPA, 1995b) is a steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. The ISCST3 model can be used for multiple sources in urban or rural terrain. The model includes the algorithms of the complex terrain model COMPLEX I. The user can specify if calculations are to be made for simple terrain, complex terrain or both. However since COMPLEX 1 is a screening model, the ISCST3 model is only a screening tool for receptors in complex terrain. The ISCST3 model can calculate concentration averages for 1-hour or for the entire meteorological data period (e.g., annual). A summary of basic input parameters needed to model a point source are shown in Table 2.11. Guidance on additional input requirements, e.g., for area and volume sources, may be found in the ISC Users Guide.

Table 2.11. Basic Input Parameters Required to Model a Point Source Using ISCST3.

Land Use	Urban or Rural
Averaging Period	
Emission Rate (g/s)	
Stack Height (m)	
Stack Gas Exit Temperature (K)	
Stack Gas Exit Velocity (m/s)	
Stack Diameter (m)	
Receptor Locations (x,y) coordinates (m)	discrete points; polar array; Cartesian array;
Meteorology	may be supplied by preprocessor PCRAMMET
Anemometer Height (m)	

2.11.1.1 Regulatory Options

Regulatory application of the ISCST3 model 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 regulatory options, automatically selected when the DFAULT keyword is used, are:

- Stack-tip downwash (except for Schulman-Scire downwash)
- Buoyancy-induced dispersion (except for Schulman-Scire downwash)
- Final plume rise (except for building downwash)
- Treatment of calms
- Default values for wind profile exponents
- Default values for vertical potential temperature gradients
- Use upper-bound concentration estimates for sources influenced by building downwash from super-squat buildings

2.11.1.2 Special Cases

a. Building Downwash

The ISC models automatically determine 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 algorithms in ISCST3 do not account for the area that is 1 m upwind from the receptor and, therefore, caution should be exercised when modeling very small areas with receptors placed within them or within 1 m from the downwind boundary.

c. Volume Sources

The volume source algorithms in ISCST3 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 ISC3 User's Guide (U.S. EPA, 1995b).

d. Intermediate Terrain

When simple and complex terrain algorithms are selected by the user, ISCST3 will select the higher impact from the two algorithms on an hour-by-hour, source-by-source and receptor-by-receptor basis for all receptors located in intermediate terrain (U.S. EPA, 1995b).

e. Deposition

The ISC models contain algorithms to model settling and deposition and require additional information to do so including particle size distribution. For more information consult the ISC3 User's Guide (U.S. EPA, 1995b).

2.11.2 RAM

RAM (Turner & Novak, 1978; Catalano et al., 1987) is a steady-state Gaussian model used to calculate short-term (i.e., 1-hour to 1-day) pollutant concentrations from single or multiple sources in flat or gently rolling terrain. RAM has the capability to model emissions from point and area sources in urban or rural areas. A total of 250 point sources and 100 area sources may be modeled in one single run. RAM provides several options to control the amount of information that is output by the program. A summary of input parameters is given in Table 2.12.

Table 2.12. Input Parameters Required to Run RAM.

For Point Sources:
Source coordinates; x and y (user units)
Emission rate (g/s)
Source Height (m)
Stack Diameter (m)
Stack Gas Exit Velocity (m/s)
Stack Gas Exit Temperature (K)
Receptors (x.y) coordinates (user units) [program can generate an array in polar coordinates or honeycomb configuration]
Meteorology: hourly data [may be provided with preprocessor RAMMET]
For Area Sources:
South-West corner coordinates of Area; x and y (user units)
Source Side Length (user units)
Total Area Emission Rate (g/s)
Effective Area Source height (m)
Receptors (x.y) coordinates (user units) [program can generate an array in polar coordinates or honeycomb configuration]
Meteorology: hourly data [may be provided with preprocessor RAMMET]

2.11.2.1 Regulatory Application

Regulatory application of the RAM model requires the specification of certain program options (i.e., parameters). All of the regulatory parameters can be set using the DEFAULT option (i.e., setting IOPT(38)=1). The DEFAULT switch automatically selects the following:

- final plume rise and momentum plume rise
- buoyancy-induced dispersion
- stack-tip downwash
- treatment of "calms"
- default wind profile exponents

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, each source must be evaluated to determine whether building downwash is a factor in the calculation of maximum ground-level concentrations. Furthermore, building downwash contributions are not automatically calculated in the cavity region of a building by most models and an underestimate of the health risk can occur in the immediate wake region of a structure. In such cases, consideration should be given to use of the 'wake cavity' feature of a model such as SCREEN3 to estimate concentrations in the cavity.

For regulatory application, a building is close enough to be considered for aerodynamic downwash if the distance from the source to the building is less than, or equal to, five times the lesser of the building height or its projected width (U.S. EPA, 1985b).

For direction-specific wind, a building is considered close enough for downwash to occur if the source is within a rectangle composed of two lines perpendicular to the wind direction, one at 5L downwind of the building and the other at 2L upwind from the building, and by two lines parallel to the wind direction at ½L away from each side of the building as shown below (where L is the lesser of the building height or its projected width). See Figure 2.

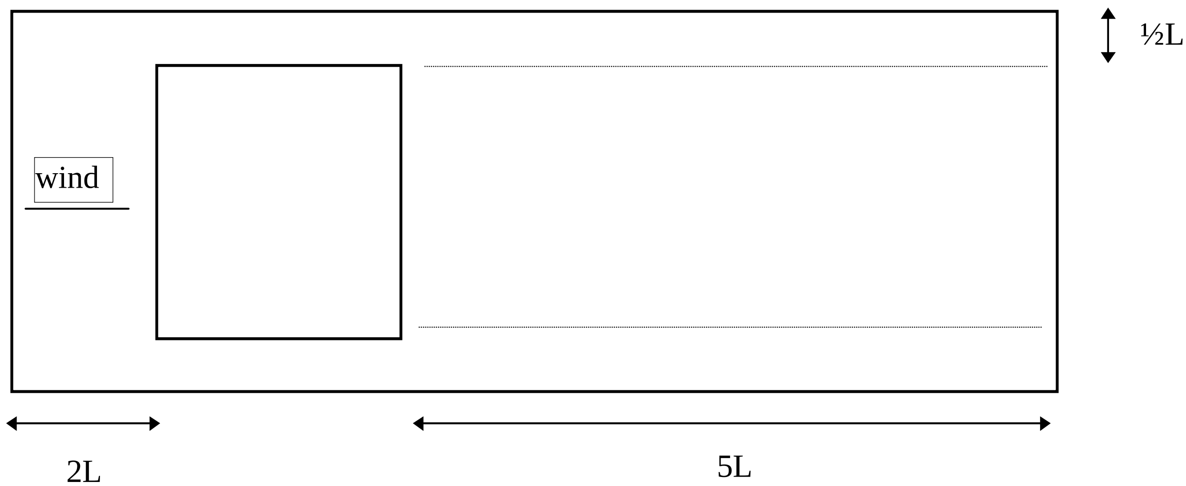


Figure 2. Area Affected by the Building Used to Determine Whether Building Downwash Needs to be Considered (L is the lesser of the building height or its projected width). Figure is not drawn to scale.

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.

2.12.2 Deposition

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). However, air dispersion models having deposition and plume depletion algorithms require particle distribution data that are not always readily available. 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

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 a 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

It should be noted that currently SCREEN3 is the only U.S. EPA guideline model that incorporates fumigation, and it is limited to maximum hourly evaluations.

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. Therefore, assuming that the gas exit velocity would be the same as the velocity in a stack without an obstacle is an improper assumption. 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 ISC3 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.

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 and 100-meter grid increments).

- Identify method to determine maximum short-term impact.

- Identify method to evaluate cancer risk in the vicinity of the facility for purposes of calculating cancer burden (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. It is helpful for the reviewing agencies to receive input, output, and supporting files of various model analyses on computer-readable media (e.g., CD, disk).

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)

See Appendix J form RAG-003 for an example of a table.

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)

See Appendix J form RAG-004 for an example.

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 (see Appendix J Form RAG-001):

- 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 (see Appendix J Form RAG-002):

- 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 are usually the most appropriate choice. (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 HHI) 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. 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

2.15.4 Meteorological Data

If meteorological data were not obtained directly from the District, the report must clearly indicate the 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 ISCST3 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.

(‡)Please contact the Office of Environmental Health Hazard Assessment for information on calculating and presenting subchronic lead results.

2.16 References

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3. Daily Breathing Rates

This section describes the analysis of ventilation rate data and activity patterns data to derive a distribution of daily breathing rates for adults and children. In brief, we evaluated data from Adams (1993) on ventilation rates in a cross-section of the population measured while performing specific tasks. Mean breathing rates for specific tasks in the Adams study were then assigned to similar tasks recorded in two large activity patterns surveys (Wiley et al., 1991a and b; Jenkins et al., 1992). Daily breathing rates were then calculated for each individual in the activity patterns surveys by summing minutes at a specific activity times the ventilation rate for that activity across all activities over a 24-hour period. These breathing rates were then used to develop a distribution of breathing rates for children and for adults. A simulated breathing rate distribution for a lifetime (from age 0 to 70 years) was derived from the children and adult distributions.

Discussion of point estimate defaults, as well as breathing rate distributions derived by others and described either in the open literature or in available documents, is included in this chapter. Descriptions of the databases and procedure we used to characterize breathing rate distributions and derive point estimates of breathing rates are presented. The algorithms used to determine inhalation dose and estimated cancer risk are also described below.

In this and subsequent chapters, we follow U.S. EPA's (1992) definitions of exposure and dose. Exposure refers to the condition of a chemical contacting the outer boundary of a human; the chemical concentration at the point of contact is the exposure concentration. Applied dose is the amount of chemical at the exposure barrier (skin, lung, gastrointestinal tract) available for absorption. Potential dose is simply the amount of chemical ingested, inhaled, or in material applied to the skin. For ingestion and inhalation potential dose is analogous to the administered dose in a dose-response experiment. The internal dose is the amount of chemical that has been absorbed and is available for interaction with biologically significant receptors. Doses can be expressed as amount of chemical per day (e.g., mg/day) or amount of chemical per unit body weight per day (e.g., mg/kg-day).

3.1 Introduction

Exposure to airborne chemicals occurs via inhalation, and subsequent absorption across the lung or the mucosa of the upper respiratory tract may result in adverse health effects depending on the chemical's toxicological properties and the concentration in air. The dose of a substance via the inhalation route is proportional to the concentration of the substance at low environmental concentrations and to the amount of air inhaled. The long-term dose is reflective of average daily breathing rates (m^3 or L/kg-day), and average concentration of the substance in air ($\mu g/m^3$). Short-term doses vary with fluctuations in the breathing rate according to the activity level of the individual at the time of exposure as well as with fluctuations in the concentration of the substance in air. Both a point estimate and a stochastic approach to assessing long-term inhalation dose and estimated cancer risk are described below. The point estimates and distribution of breathing rates presented in this chapter are not meant for an acute

1-hour exposure scenario. A distribution of hourly breathing rates would need to be constructed to use in calculating acute doses.

3.1.1 Point Estimate Approach to Inhalation Cancer Risk

In the current calculation of estimated cancer risk from inhalation exposure to carcinogens in air using the point estimate or deterministic approach, the modeled or measured concentration in air is multiplied by the cancer unit risk factor as follows:

$$C_{air} \text{ x Unit Risk Factor} = \text{Risk} \qquad \text{(Eq. 3-1)}$$

Implicit in the unit risk factor is the assumption that a 70 kg human breathes 20 m^3/day. Thus, in the current point estimate approach, a single estimate of breathing rate and body weight is used. Another way to apply a point estimate approach is to calculate dose first and then cancer risk using a cancer potency factor in units of inverse dose. This allows use of alternate breathing rate point estimates. If a different point estimate of breathing rate (other than 20 m^3/day for a 70 kg human) is used, then the dose of the chemical, calculated as in Equation 3-2 below, is multiplied by the cancer potency factor in units of inverse dose $(mg/kg\text{-}d)^{-1}$ to derive a cancer risk estimate. This is the method OEHHA is recommending as it allows alternate point estimates to be used in calculating dose and risk, and allows for separate dose calculations for susceptible subpopulations such as children.

In assessing the noncancer hazard from chronic exposure, a modeled concentration in air of a pollutant is divided by a reference exposure level (REL) in units of $\mu g/m^3$. (Reference exposure levels for chronic exposure are described in the document entitled, Air Toxics “Hot Spots” Risk Assessment Guidelines Part III: Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels (OEHHA, 2000).) The ratio is called the hazard quotient for that chemical. Hazard quotients for each chemical affecting a specific target organ are summed to derive the hazard index for that target organ. Breathing rate is not necessarily explicitly involved in calculating RELs or in the estimate of noncancer hazard index; rather the concentration of the chemical in air is the determining factor.

3.1.2 Stochastic Approach to Inhalation Dose and Cancer Risk

The stochastic 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 (see Section 1.3). In equation 3-2, the daily breathing rate (L/kg-day) is the variate which is varied for the stochastic analysis.

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

$$\text{Dose} = 0.001 \text{ x } C_{air} \text{ x } [BR/BW] \text{ x } 0.001 \text{ x A x } \frac{EF \text{ x } ED}{AT} \qquad \text{(Eq. 3-2)}$$

Where:

Dose =	dose by inhalation, mg/kg-d; represents potential dose; in rare cases where the potency factor has been corrected for absorption, and data are available to allow the dose equation to be corrected for absorption, then the dose is an internal dose.
0.001 =	mg/μg
C_{air} =	concentration in air (μg/m^3)
[BR/BW]=	daily breathing rate (L/kg body weight - day)
0.001 =	correction factor for m^3/L
A =	inhalation absorption factor, if applicable (default = 1)
EF =	exposure frequency (days/year)
ED =	exposure duration (years)
AT =	averaging time; time period over which exposure is averaged, in days (e.g., 25,550 days for 70 years for carcinogenic risk calculations)

Dose is proportional to the concentration in air, the breathing rate, applicable absorption factors, and the amount of time one is exposed (e.g., EF x ED). Section 3.5 focuses on characterizing the distribution of the variate [BR/BW], breathing rate per kg body weight. We describe a distribution of values for this variate useful for stochastic modeling of dose by inhalation. In order to account for any correlation between body weight and breathing rate, the breathing rate is expressed as liters of air per kg body weight per day. A conversion factor is provided in equation 3-2 to convert from liters to cubic meters.

In practice, the inhalation absorption factor, A, 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 cancer potency factor is calculated for lifetime exposure, generally assumed to be 70 years. When evaluating less-than-lifetime exposure, an exposure time adjustment is necessary. The factors EF and ED refer to exposure frequency in days per year and exposure duration in years. For the Air Toxics "Hot Spots" program residential cancer risk estimates, EF is set at 350 days per year following U.S. EPA (1991), and ED is set at three values, 9 years (U.S. EPA, 1991), 30 years (U.S. EPA, 1991) and 70 years. The point estimates for ED are discussed in Chapter 11. The averaging time is set to 25,500 days (70 years) because the cancer potency factors are based on lifetime exposure.

3.2 Methods for Estimating Daily Breathing Rates

Two methods have been reported in the literature to estimate daily breathing rates. These are described briefly below.

3.2.1 Time-weighted Average Ventilation Rates

The time-weighted average ventilation rates method 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 rates (liters/min) and time spent (min/day) at each activity level. While a spirometer provides accurate measures of ventilation rate, most apparati are too cumbersome to wear throughout the day while performing normal activities. Thus, measurements are taken for shorter time periods under specific conditions, e.g., running or walking on a treadmill. Estimates of time spent during a day at varying breathing rates are made difficult because the available measured ventilation rates for specific activities must be assigned to the much broader array of activities that people engage in over the day. Normal daily activities are categorized into sedentary, light, moderate, and heavy. Measured ventilation rates that correspond to activities considered light, moderate, or heavy are then assigned to each normal daily activity in the appropriate category. Activity pattern studies are used to estimate the time spent each day at the assorted daily activities. Point estimates as well as distributions of daily breathing rate can then be calculated.

The advantage of this method is that directly measured data on ventilation rates at various activity levels are used to characterize exposure to airborne substances. California-specific data are now available for both ventilation rates and activity levels with adequate sample size to obtain estimates of daily breathing rate. The disadvantage of this method is that it may be difficult to assign ventilation rates from a defined set of activities to the variety of daily activities. In addition, the data may be inadequate to address the tails of the distribution, e.g., the ventilation rates of individuals engaged in strenuous activity for long periods of time such as athletes or manual laborers. These individuals are at higher risk from exposure to airborne substances.

3.2.2 Estimates Based on Caloric Intake or Energy Expenditure

A second group of methods used to estimate daily breathing rates is based on caloric intake or energy expenditure. These methods assume that ventilation is proportional to energy expenditure and food intake. Estimating ventilation rate through caloric intake relies on estimates of daily food intake and the amount of oxygen (and therefore air) needed to burn the calories consumed, assuming the individual is neither gaining nor losing weight.

The advantage of this method is that in theory it should give accurate ventilation rates if the amount of O_2 consumed per kcal of food ingested and the caloric intake are known. Unfortunately, estimates of daily caloric intake based on food intake surveys such as the U.S.D.A.'s Nationwide Food Consumption Surveys may not be accurate because underreporting of foods consumed is a problem with such surveys (Layton, 1993). In addition, data may not be available to adequately address the tails of the distribution which describe individuals who are very active (e.g., athletes). Very active individuals are at higher risk from exposure to airborne substances because they require more oxygen and so breathe more air than a sedentary individual. It is also unlikely that food consumption surveys adequately capture the caloric intake of such active individuals.

The estimation of ventilation rates from energy expenditures would be accurate if the energy expenditures could be accurately quantified. A disadvantage to estimating ventilation rates via energy expenditure is that one needs to assign energy expenditures to various normal daily activities in order to arrive at a daily breathing rate. This is analogous to the disadvantage of assigning measured ventilation rates from a narrow group of activities to the variety of normal daily activities.

3.2.3 Current Default Values

Many regulatory agencies have used a default daily breathing rate of 20 m^3/day for a 70 kg human. This number is based on the time-weighted average ventilation rate method using assumptions for time spent at varying activity levels and measured breathing rates summarized in Snyder et al. (1975) and U.S. EPA (1985, 1989a). We estimate that 20 m^3/day for a 70 kg person represents approximately the 85th percentile on our distribution of adult daily breathing rates in L/kg-day. In the latest version of the Exposure Factors Handbook, U.S. EPA (1997) recommends a daily breathing rate of 11.3 m^3/day for adult females and 15.2 m^3/day for adult males as a mean value. The average value for men and women combined would be 13.3 m^3/day. U.S. EPA (1997) did not recommend a high-end value for either adult men or adult women.

3.3 Available Data on Breathing Rates

There are a number of sources of information on measured ventilation rates at various activity levels. These sources are useful for looking at exposure scenarios where the activity level is known, and for estimating daily breathing rates under a variety of exposure assumptions.

3.3.1 Compilations of Ventilation Rate Data

The book Reference Man (Snyder et al., 1975), a report by the International Commission on Radiological Protection (ICRP), presents ventilation rates based on about 10 limited studies. The U.S. EPA's Exposure Factors Handbook has a similar compilation of ventilation rates for men, women, and children based on about two dozen limited studies (U.S. EPA, 1989a). The American Industrial Hygiene Council's Exposure Factors Sourcebook (AIHC, 1994) also has a compilation and suggests specific ventilation rates, as well as a distribution of ventilation rates based on the information in U.S. EPA (1989a). Information from these sources is summarized in Tables 3.1, 3.2, and 3.3. The studies compiled in all of these sources have a small sample size and are limited in scope.

Using an assumption of 8 hour (hr) resting activity and 16 hr light activity and the ventilation rates in Table 3.1, ICRP recommends 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. 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 U.S. EPA (1989a) compiled ranges of measured values of ventilation rates at various activity levels by age and sex and categorized activity levels as light, moderate or heavy. Mean values are presented below in Table 3.2 as m^3/hr. U.S. EPA (1989a) recommends using 20 m^3/day for adults based on 8 hr resting and 16 hr light activity each day. Also, where appropriate U.S. EPA (1989a) recommends using a distribution of activity levels when known.

For children-specific scenarios, U.S. EPA (1989a) recommends using the ventilation data in Table 3.2 and specific scenario considerations to construct relevant exposure scenarios.

The AIHC Exposure Factors Sourcebook (AIHC, 1994) recommends a point estimate default daily breathing rate of 18 m^3/day for adults. This is based on the ventilation rates compiled in U.S. EPA's 1989 Exposure Factors Handbook and the assumption of 12 hr rest (sleeping, watching TV, reading), 10 hr light activity, 1 hr moderate activity, and 1 hr heavy activity each day. The ventilation rates in Table 3.3 which represent the AIHC's estimates of a minimum, most likely, and maximum breathing rates for adults and 6 year old children, are based on the U.S. EPA's 1989 Exposure Factors Handbook and an assumed triangular distribution. The "most likely" estimates for 6 to 70 year olds and under 6 year olds are 18.9 and 17.3 m^3/day, respectively. The AIHC also recommends a point estimate default value of 12 m^3/day for children 1 to 4 years old by adjusting the ventilation rate for 6 year olds by 0.75 and assuming 12 hr rest (sleeping, watching TV, reading), 10 hr light activity (play), and 2 hr moderate activity (vigorous play) each day.

Table 3.1 Minute volumes from ICRP's Reference Man (Snyder et al., 1975)[a]

	Resting *L/min (m^3/hr)*	**Light Activity** *L/min (m^3/hr)*
Adult M	7.5 (0.45)	20 (1.2)
Adult F	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

Table 3.2 U.S. EPA Exposure Factors Handbook (1989a) Estimates of Ventilation rate (m^3/hr)

	Resting	**Light**	**Moderate**	**Heavy**
Adult M	0.7	0.8	2.5	4.8
Adult F	0.3	0.5	1.6	2.9
Avg adult	0.5	0.6	2.1	3.9
Child, 6 yr	0.4	0.8	2.0	2.4
Child, 10 yr	0.4	1.0	3.2	4.2

Table 3.3 AIHC (1994) Point Estimate Defaults and Distribution of Breathing Rate[a] Expressed as m^3/day

	Males and Females 6 to 70 years	**Children Under 6 years**
Minimum	6.0	8.3
Most likely	18.9	17.3
Maximum	32.0	28.3

[a.] Data from U.S. EPA (1989a) with an assumed triangular distribution.

3.3.2 Layton (1993)

Layton (1993) published a study estimating breathing rates based on caloric intake and energy expenditures. The premise for calculating these estimates is that breathing rate is proportional to the oxygen requirement for burning the calories consumed. It is also understood that the calories consumed are largely used for daily energy expenditure. Only an insignificant fraction of daily caloric intake is stored as fat. The general equation for this method of estimating breathing rate is:

$$V_E = E \times H \times VQ \qquad \text{(Eq. 3-3)}$$

where:
- V_E = minute ventilation rate in L/min
- E = energy expenditure rate, kJ/min;
- H = volume of oxygen consumed per kJ;
- VQ = ventilatory equivalent (ratio of V_E in L/min to O_2 uptake in L/min)

Layton took three approaches to estimating breathing rates. The first approach used the U.S.D.A.'s National Food Consumption Survey (1977-78) data to estimate caloric intake. The National Food Consumption Survey uses 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 in these surveys and therefore adjusted the reported caloric intake upwards. The adjustment is based on studies examining the daily energy expenditure of an average person. The second approach to estimating breathing rates involved multiplying the basal metabolic rate (BMR) by energy expenditure factors reflecting that expenditure of energy associated with normal activity which is not accounted for in the BMR. In the third approach, breathing rates were computed for energy expenditures at specific activity levels and summed across a day. The results of Layton's approaches are presented in Table 3.4. Layton did not report distributions of breathing rates.

Table 3.4 Layton (1993) Estimates of Breathing Rates Based on Caloric Intake 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

3.3.3 Adams (1993)

The California Air Resources Board (CARB) sponsored a study in 1993 of measured ventilation rates in people performing various laboratory and field protocols (Adams, 1993). The primary purposes of the CARB breathing rate study were to 1) identify mean values and ranges of minute ventilation (V_E) for specific activities and populations and 2) to develop equations that would predict V_E based on known activities and population characteristics. The subjects in this study were 160 healthy individuals of both genders 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. Subjects completed resting and active protocols in the laboratory, and usually one or more field activities. Data on V_E, heart rate (HR), breathing frequency (f_B), and oxygen consumption were collected in the laboratory. Data collected in the field were limited to V_E, HR, and f_B.

The laboratory resting protocols consisted of 25 minute phases each of lying, sitting, and standing, with data collected during the last 5 minutes of each phase. The active laboratory protocols consisted of walking and running on a treadmill. Data were collected the last 3 min of a 6 minute duration at each speed.

All children completed spontaneous play protocols. Older adolescents (16-18 years of age) completed car driving and riding, car maintenance (males), and housework (females) protocols. Housework, yard work, and car riding and driving protocols were completed by all of the 19 to 60 year old adult females and by most of the senior (60-77 years of age) adult females. Adult and senior males completed car riding and driving, yard work, and mowing protocols. In addition, a subset of young/middle-aged adults completed car maintenance and woodworking protocols. Car riding and driving protocols were 20 minutes long; the others were 30 minutes long. Each protocol was done twice. Heart rate, V_E, and f_B were measured continuously during the field protocols using equipment that minimized restriction of normal movement.

Table 3.5, taken from the Adams (1993) report, provides mean V_E (L/min) for lying, sitting, standing data for young children (ages 3 to 5), children (ages 6 to 12), adult females, and adult males. Adams also presents V_E values for various walking and running protocols for adults in their report. These values are similar to those reported for similar activities in other studies. Results of the field protocols are summarized in Table 3.6 which provides mean V_E for the various activities.

These investigators found that HR correlated well with V_E only in the active laboratory protocols. Heart rate correlation with V_E dropped for field protocols. Mean HR at a given V_E for active field protocols were consistently higher than those found for the walking and running protocols in the laboratory. The investigators attributed the higher HR in field protocols to greater HR that occurs at a given V_E in activities requiring significant arm work (e.g., the field protocols) than in those involving leg work (e.g., the treadmill protocols). A wide variation in individual intensity of effort across subjects in the field protocols was also noted. This study also reflected the higher V_E per m^2 body surface area in children and young adolescents than in adults. The implication is that for a given activity and concentration in air, children are experiencing higher doses on a mg per kg body weight basis than adults.

Table 3.5 Adams (1993) Mean V_E (L/min) by Group and Activity for Laboratory Protocols

Activity	Young Child (age 3-5)	Child (age 6-12)	Adult F	Adult M
Lying	6.19	7.51	7.12	8.93
Sitting	6.48	7.28	7.72	9.30
Standing	6.76	8.49	8.36	10.65

Table 3.6 Adams (1993) Mean V_E (L/min) by Group and Activity for Field Protocols

Activity	Young Child (age 3-5)	Child (age 6-12)	Adult Female	Adult Male
Play	11.31	17.89		
Car driving			8.95	10.79
Car Riding			8.19	9.83
Yard Work			19.23	26-32
Housework			17.38	
Car Maintenance				23.21
Mowing				36.55
Woodworking				24.42

3.3.4 Linn et al. (1993)

Individuals whose jobs require hard physical work breathe more on a daily basis than others in sedentary jobs. Linn and colleagues used the heart rate measurements of 19 construction workers to estimate ventilation rates (VR) throughout a day on the job including some time before work and breaks. These investigators calibrated each individual by recording HR and VR at rest and at different levels of exercise. Least squares regression analysis was used to derive an equation predicting VR at a given HR for each subject. The subjects' heart rates were subsequently recorded beginning early in the morning at home and ending in the afternoon when the subjects stopped working. A diary of the subjects' activities was also kept including change in activity type, personal microenvironment characteristics, self-estimated breathing rate (slow, medium, fast) and breathing problems. The subject recorded in the diary from rising (about 5 AM) to getting to work (about 6 AM). From that point, a trained investigator took over the diary recordings, with the subject communicating the information via a hands-free transmitter. Each individual's VR prediction equation was used to calculate VR from the recorded HR data.

For the 19 subjects, a total of 182 hours of HR was recorded, of which 144 hours represents actual work time. The group statistics for VR are provided in Table 3.7. Predicted VR's were distributed log normally, with the arithmetic mean exceeding the geometric mean. The authors of the study note that the 1st and 99th percentiles are out of the calibration range for most of their subjects. Therefore, the means and 50th percentiles are more accurate. The construction workers predicted VR (overall mean = 28 L/min) exceed that of other workers measured in studies by this same group of investigators using the same methodology. The authors also note that the results of this study are in agreement with data of Astrand and Rodahl (1977) for manual workers.

Table 3.7 Ventilation Rates for Construction Workers Adapted from the API (1995) Analysis of Linn et al. (1993)

PID	BW	SA	mean V_E/m^2	V_E/kg BW
1761	81.6	2.01	12.56	0.31
1763	61.2	1.64	15.92	0.43
1764	74.8	1.94	13.82	0.36
1765	65.8	1.87	16.17	0.46
1766	77.1	1.89	10.80	0.26
1767	99.8	2.26	10.43	0.24
1768	70.3	1.85	10.96	0.29
1769	104.3	2.38	17.29	0.39
1770	81.6	1.97	14.01	0.34
1771	68	1.77	16.91	0.44
1772	117.9	2.35	18.36	0.37
1773	77.1	1.93	14.52	0.36
1774	68	1.81	14.56	0.39
1775	68	1.79	20.09	0.52
1776	81.6	2.0	12.97	0.32
1778	99.8	2.31	18.46	0.43
1779	79.4	1.97	22.10	0.55
1780	109.8	2.38	12.40	0.27
1781	74.8	1.82	13.47	0.33
ALL	82.15	2.00	15.12	0.37

PID = personal identification for each subject
BW = body weight in kg
SA = surface area in m^2
V_E = minute ventilation rate in L/min

3.3.5 U.S. EPA Exposure Factors Handbook (1997)

The U.S. EPA Exposure Factors Handbook (1997) recommendations are summarized in Tables 3.8 and 3.9. The U.S. EPA (1997) has made recommendations for daily breathing rates for specific age ranges, with separate rates for females and males above the age of 9 (Table 3.8). Recommendations for hourly rates for children, adults and outdoor workers are provided for resting, sedentary, light, moderate, and heavy activities.

The recommendations for infants and children’s average daily breathing rates are based on Layton (1993), using the first approach in his paper (Table 3.4). The average daily breathing rates for adult men and women are based on the averages of all three approaches used by Layton

(1993). The values which are averaged do not vary greatly. The Layton (1993) study is discussed above in Section 3.3.2. There are no recommendations for distributions or high end values.

The short term hourly mean inhalation rate recommendations for children are based on averaging values for resting, sedentary, light, moderate, and heavy activities from the studies of Adams (1993) (lab and field protocols), Layton (1993) (short-term data), Spier et al. (1992) (ages 10-12) and Linn et al. (1992) (ages 10-12). U.S. EPA (1997) discusses Linn et al. (1992) which recorded HR and activity diaries in healthy and asthmatic children and adults, and Spier et al. (1992) in which V_E was estimated from HR in elementary and high school students who kept activity diaries. The Adams (1993) study is discussed in detail above in Section 3.3.3. The mean short term hourly rate recommendations for adults are based on averaging values from Adams (1993) (lab protocols and field protocols), Layton (1993) (short term exposure and third approach) and Linn et al. (1992). The outdoor worker short term inhalation rates for mean and high end are based on Linn et al. (1992 and 1993). The values which are averaged for the recommendations do not vary greatly. There are no recommendations for distributions for any of the short-term, hourly ventilation rates for children, adults or workers.

Table 3.8 U.S. EPA Exposure Factors Handbook (1997) Recommended Values for Breathing Rate for Long-term Exposure

	Mean (m^3/day)
Infants	
<1 year	4.5
Children	
1-2 years	6.8
3-5 years	8.3
6-8 years	10
9-11 years	
Males	14
Females	13
12-14 years	
Males	15
Females	12
15-18 years	
Males	17
Females	12
Adults (19-65+)	
Females	11.3
Males	15.2

Table 3.9 U.S. EPA Exposure Factors Handbook (1997) Recommended Values For Breathing Rate For Short-Term Exposure

	Mean (m^3/hour)	Upper %tile (m^3/hour)
Adults		
Rest	0.4	
Sedentary Activities	0.5	
Light Activities	1.0	
Moderate Activities	1.6	
Heavy Activities	3.2	
Children		
Rest	0.3	
Sedentary Activities	0.4	
Light Activities	1.0	
Moderate Activities	1.2	
Heavy Activities	1.9	
Outdoor Workers		
Hourly Average	1.3	
Slow Activities	1.1	
Moderate Activities	1.5	
Heavy Activities	2.5	3.3

3.4 Ranges of Ventilation Rates

OEHHA/ATES staff used the raw data from the CARB-sponsored study (Adams, 1993) to evaluate ranges of minute ventilation (V_E) at various activities by gender and age. The program SAS® was used to perform univariate analysis to develop these ranges. The SAS® Univariate procedure provides basic descriptive statistics, such as the mean, standard deviation, variance, and sample size. PROC Univariate was also used in SAS® to characterize the distributional attributes of the V_E data such as skewness, kurtosis, and the percentiles of the distribution.

Since the body weights of individuals in Adams (1993) were available from the raw data, we divided the V_E for each individual by their body weight and expressed ventilation rates as L/min - kg body weight. This helps to account for correlation between ventilation rate and body weight. Analysis of variance was used to determine if combining the weight-adjusted ventilation rates across sexes or ages for the various protocols was appropriate. Variance in body weight explained much of the variance in ventilation rates. The purpose of combining groups is to increase the sample size and therefore the stability of the quantile estimates. If the difference between groups was significant at $p<0.1$, then the groups were not combined. However, in a number of instances it was possible to combine groups to increase the sample size.

Tables 3.10 through 3.14 provide the moments about the mean and selected percentiles of the distribution of breathing rate in L per minute per kg body weight for selected lab and field activities for male and female adults. The tables indicate when groups were able to be combined to determine the mean and moments of the distribution. Data sets were selected to represent ventilation rates at resting, light, moderate, moderately heavy, and heavy activities. The mean ventilation rate recorded while subjects were lying down was chosen to represent ventilation during sleep and rest. The mean ventilation rate recorded while subjects were standing was used to represent ventilation rate during light activity. Mean ventilation rate while doing yard work was used to represent ventilation rate at moderate activity levels. The mean ventilation rates measured while subjects were running were used to represent ventilation rate during heavy activity. All running speeds and both sexes were combined to obtain a mean and moments about the mean for heavy activity. Finally, we took the mean of the means of moderate ventilation rate and heavy ventilation rates to represent a ventilation rate during moderately heavy work. Mean ventilation rate recorded in the field protocol while subjects were driving a car was used for time spent in a car and for those whose occupations involve driving (e.g., truck drivers). As described in Section 3.5, these ventilation rates are used in conjunction with data from the CARB-sponsored Activity Patterns surveys (Wiley et al., 1991a and b) on the time spent by each individual at specific activities to characterize the distribution of daily breathing rate by gender and age group using the time-weighted average breathing rate approach.

Additional information on range and distribution of ventilation rates comes from the study by Linn et al. (1993) on ventilation rates of construction workers. Construction workers include individuals working hard manual labor for prolonged periods throughout the day. These individuals would be expected to have higher daily breathing rates than sedentary office workers, for example. Linn and colleagues present their data as means and offer the 1st, 50th and 99th percentile of the distribution of minute ventilation rates measured via the heart rates in each subject (see description above) (Table 3.15). The American Petroleum Institute developed ranges of ventilation rates from Linn's study (API, 1995). However, OEHHA has not used these data in developing distributions for breathing rate for two reasons. First, the breathing rates in the Linn study include time off work as well as time doing work. Staff were unable to satisfactorily adjust the Linn breathing rates for time spent actually working. Thus, we could not assign the ventilation rates from the Linn study to the time spent at work as recorded by construction workers in the activity patterns study (Wiley et al., 1991a). Secondly, the ventilation rates derived from heart rate measurements in the Linn study appear to be too low relative to breathing rates measured via spirometry in average individuals doing yard work in Adams (1993). After normalizing to body weight (Table 3.17), the mean ventilation rate from the 19 subjects in the Linn et al. study, 0.37 L/min-kg body weight, was just a little above that measured in Adams (1993) for average people doing yard work, 0.31 L/min-kg body weight. We believe that the Linn et al. (1993) data underestimate ventilation rate of individuals doing manual labor. One would anticipate that construction work is heavier work than yard work done by the average person (not professional gardeners). However, the Linn et al. (1993) data do serve as a useful check on a daily breathing rate for someone whose job involves heavy work. To that end, we used the information in the Linn study to justify developing a "moderately heavy" ventilation rate that is in between the moderate breathing rate and the heavy breathing rate described in the previous paragraph to represent ventilation rate for people in the construction (and similar) trades.

Table 3.10 ***V_E (L/Min) Per Kg Body Weight For Adults "Lying-Down Protocol" (Useful For Sleeping/Resting Activities)[1]***

	Women 19 to <60 years	**Men 19 to <60 years**	**Combined Men and Women**
Number of Subjects	20	20	40
Mean	0.12	0.107	0.114
SD	0.025	0.017	0.023
Skewness	0.331	-0.09	0.489
Kurtosis	0.133	-0.85	0.459
PERCENTILES			
1%	0.075	0.076	0.075
5%	0.076	0.078	0.077
10%	0.088	0.084	0.084
25%	0.108	0.093	0.100
50%	0.115	0.110	0.113
75%	0.137	0.121	0.126
95%	0.169	0.135	0.157
99%	0.173	0.140	0.173
Sample Maximum	0.173	0.140	0.173

1. OEHHA used ventilation rates during the lying-down protocol for time spent sleeping and napping. Men and women were combined as the means were not significantly different; the combined mean was applied to develop the daily breathing rate distribution.

Table 3.11 ***V_E (L/Min) Per Kg Body Weight For Adults "Standing Protocol" (Useful For Light Activity)*** [1]

	Adult Men and Women 19-59 years
Number of Subjects	40
Mean	0.131
SD	0.027
Skewness	0.850
Kurtosis	1.367
PERCENTILES	
1%	0.080
5%	0.086
10%	0.105
25%	0.114
50%	0.125
75%	0.144
95%	0.188
99%	0.206
Sample Maximum	0.206

Table 3.12 V_E (L/Min) Per Kg Body Weight For Adults "Yardwork Protocol" (Useful For Moderate Activity)[1]

	Adults 19 to <60 years
N	40
Mean	0.323
Std Dev	0.061
Skewness	0.555
Kurtosis	0.792
PERCENTILES	
1%	0.209
5%	0.228
10%	0.248
25%	0.281
50%	0.316
75%	0.364
95%	0.427
99%	0.496
Sample Maximum	0.496

[1] OEHHA defined yardwork as an activity with a moderate breathing rate. Protocol was combined for both sexes because there is no statistically significant difference in the yardwork breathing rates.

Table 3.13 V_E (L/Min) Per Kg Body Weight For Adults And Adolescents "Running Protocol" (Useful For Heavy Activity) [1]

	Adults & Adolescents 13-59 years
N	76
Mean	0.813
Std Dev	0.149
Skewness	-1.023
Kurtosis	3.059
PERCENTILES	
1%	0.182
5%	0.591
10%	0.653
25%	0.716
50%	0.818
75%	0.926
95%	1.031
99%	1.097
Sample Maximum	1.097

Table 3.14 V_E (L/Min) Per Kg Body Weight For All Ages And Both Sexes "Driving Protocol" [1]

	Adults and Adolescents, Both Genders 13 - 59 years
N	76
Mean	0.143
Std Dev	0.035
Skewness	1.529
Kurtosis	5.031
PERCENTILES	
1%	0.066
5%	0.098
10%	0.109
25%	0.120
50%	0.141
75%	0.162
95%	0.194
99%	0.289
Sample Maximum	0.289

Table 3.15 Group Ventilation Rates (L/Min) Based On Heart Rate Records For Construction Workers (Including Before-Work Time And Breaks), From Linn Et Al. (1993).

Group	Mean ± SD	1st Percentile	50th Percentile	99th Percentile
all subjects	28 ± 12	11	27	65
general/laborers	24 ± 11	8	22	61
Ironworkers	27 ± 11	10	26	54
Carpenters	31 ± 13	13	29	69
office site	23 ± 11	10	20	62
hospital site	31 ± 13	12	30	66

3.5 Use of Activity Patterns and Ventilation Rate Data to Develop Breathing Rate Distribution

3.5.1 CARB-Sponsored Activity Patterns Studies

CARB sponsored two activity patterns studies (Wiley et al., 1991a and b; Jenkins et al., 1992; Phillips et al., 1991) in which activities of 2900 adults and children were recorded retrospectively for the previous 24 hours via telephone interview. In the first study, activities of 1762 California residents 12 years and older were recorded. Time diaries were open-ended with activities named by the respondent recorded in a chronological fashion, along with the time each activity ended, and where the activity occurred. A fairly detailed categorization of job type was also included for each respondent. The activities were later coded for data analysis. Random digit dialing was used after grouping telephone exchanges into South coast region, San Francisco Bay Area, and the rest of the state. Samples were spread throughout the state by deliberate over sampling outside the Los Angeles area. Interviews were conducted over a one year period, roughly balanced across the seasons. In the children's activity patterns study, researchers ascertained the time spent at various activities for 1200 children under age 12. Samples were spread throughout the seasons. The methodology was similar to the adults activity patterns study except that an adult in the household served as a respondent to the telephone questionnaire for the children. Data from these 2 activity patterns studies and the CARB-sponsored study of ventilation rates (Adams, 1993) described in section 3.3.3 were combined to determine time-weighted average daily breathing rates.

3.5.2 Development of Daily Breathing Rate Distributions

We grouped activities recorded in the CARB-sponsored activity patterns studies (Wiley et al., 1991a and 1991b) into resting, light, moderate, moderately heavy, and heavy activities to reflect the breathing rates that could reasonably be associated with that activity for adults (Table 3.16); for children there were only resting, light, moderate, and heavy activities (Table 3.17). Job classification as reported in Wiley et al. (1991a) was used to determine activity levels while at work (Table 3.18). In one case, data were available in Adams (1993) that described ventilation rates for specific activities that correspond well to job categories (e.g., the car driving protocol in Adams (1993) is applicable to cab drivers/delivery workers/truckers). Otherwise we assigned the levels of activity that were most appropriate for that job classification. Most jobs are relatively sedentary in nature and so most people were placed in light activity while at work. Most non-work activities were also placed in the light category. When there were mixtures of job types in a CARB job classification, we used the highest reasonable activity level in that job category. In one case where jobs that belonged in a light activity category (e.g., writers) were also lumped in with those belonging in a heavy activity category (e.g., athletes), we assigned half light and half heavy ventilation rates to that group. Since these job categories constitute only a small fraction of the individuals in the study, the impact of this assignment on the distribution is minimal. For each individual, the time spent at each activity level (resting, light, moderate, moderately heavy or heavy) was summed over the day. A distribution of breathing rates was constructed from the sum of the products of mean ventilation rate assigned to each activity and the time spent at that activity for each individual in the study over a 24 hour (1440 minute) period.

Separate distributions were developed for adults (Table 3.19) and children (Table 3.20). The method used does not account for the variance in ventilation rate; however, that variance is small in Adams (1993) (about 0.2 times the mean) compared to the variance in daily activity from individual to individual in Wiley et al. (1991a and b) (about 5 times the mean). Thus, the interindividual variance in breathing rate is easily overwhelmed by the interindividual variance in activity. Dose via inhalation can be assessed separately for children and adults using the modeled concentration of a contaminant in air and the distribution of daily breathing rates per kg body weight.

For informational purposes, we have also included in Table 3.19 the predicted breathing rates for a 63 kg adult. Similarly, Table 3.20 presents the volume equivalent inhaled per day for an 18 kg child. As discussed in Chapter 10, Body Weight, OEHHA is recommending 18 kg and 63 as time-weighted mean point estimate default body weight values for evaluating risk from age 0-9 and 0-70, respectively. In the interest of simplicity, we are also recommending the use of 63 kg as a mean point estimate of body weight for evaluating risk from age 0-30. Equation 3-2 uses the information on breathing rate in units of L/kg-d.

Table 3.16 OEHHA's Categorization Of Non-Occupational Activities For Adults From A CARB-Sponsored Activity Pattern Study (Wiley Et Al., 1991a).

RESTING ACTIVITIES
Ventilation Rate = 0.114 L/min-kg

Activity No.	Activity Label
ACT45	Sleep
ACT46	Naps

LIGHT ACTIVITIES
Ventilation Rate = 0.131 L/min-kg

Activity No.	Activity Label
ACT06	Mins eating at work
ACT07	Mins for before-after work
ACT08	Mins for break
ACT10	Mins for food preparation
ACT11	Mins for meal cleanup
ACT14	Mins for clothes care
ACT18	Mins for pet care
ACT22	Mins helping teachers
ACT23	Mins for talking and reading
ACT26	Mins for medical care
ACT27	Mins for other child care
ACT32	Mins for personal services
ACT33	Mins for medical services
ACT34	Mins for govt-financial services
ACT35	Mins for car repair services
ACT36	Mins for other repairs
ACT37	Mins for other services
ACT38	Mins for errands
ACT40	Mins for washing and hygiene
ACT41	Mins for medical care
ACT42	Mins for help and care
ACT43	Mins meals at home
ACT44	Mins for meals out
ACT47	Mins for dressing
ACT48	Mins not assigned to activities
ACT50	Mins for student classes
ACT51	Mins for other classes
ACT54	Mins for homework
ACT55	Mins for library
ACT56	Mins for other education
ACT60	Mins for professional union
ACT61	Mins for special interests

LIGHT ACTIVITIES (CONT.)
Ventilation Rate = 0.131 L/min-kg

Activity No.	Activity Label
ACT62	Mins for political and civil
ACT63	Mins for volunteer-helping
ACT64	Mins for religious groups
ACT65	Mins for religious practice
ACT66	Mins for fraternal
ACT67	Mins for child youth family
ACT68	Mins for other organizational
ACT70	Mins for sports events
ACT71	Mins for entertainment events
ACT72	Mins for movies
ACT73	Mins for theater
ACT74	Mins for museums
ACT75	Mins for visiting
ACT76	Mins for parties
ACT77	Mins for bars-lounges
ACT78	Mins for other social
ACT83	Mins for hobbies
ACT84	Mins for domestic crafts
ACT85	Mins for art literature
ACT87	Mins for games
ACT88	Mins for computer use
ACT90	Mins for radio
ACT91	Mins for television
ACT92	Mins for records tapes
ACT93	Mins for reading books
ACT94	Mins for reading magazines
ACT95	Mins for reading newspapers
ACT96	Mins for conversation
ACT97	Mins for writing
ACT98	Mins for thinking relaxing smoking
ACT914	Mins for TV and eating
ACT939	Mins for tv-read

MODERATE ACTIVITIES
Ventilation Rate = 0.323 L/min-kg

Activity No.	Activity Label
ACT12	Mins for house cleaning
ACT13	Mins for outdoor cleaning
ACT16	Mins for other repairs
ACT19	Mins for other house stuff
ACT20	Mins for baby care
ACT21	Mins for child care
ACT24	Mins indoor play
ACT25	Mins outdoor play
ACT30	Mins grocery shopping
ACT31	Mins for durable shopping
ACT81	Mins for outdoor
ACT86	Mins for music drama dance
ACT 801	Mins for golf
ACT 802	Mins for yoga
ACT 803	Mins for bowling
ACT124	Mins for cleaning & laundry together

HEAVY ACTIVITIES
Ventilation Rate = 0.813 L/min-kg

Activity No.	Activity Label
ACT80	Mins for active sports
ACT82	Mins for walking hiking bicycling

CAR DRIVING
Ventilation Rate = 0.143 L/min-kg

Activity No.	Activity Label
ACT03	Mins for travel during work
ACT09	Mins for travel to work
ACT28	Mins for pick-up/drop-off
ACT29	Mins for travel to/from child care
ACT39	Mins for travel goods & services
ACT49	Mins for travel personal care
ACT59	Mins for travel education
ACT69	Mins for travel organizational
ACT79	Mins for travel social events
ACT89	Mins for travel recreation
ACT99	Mins for travel communications

YARDWORK
Ventilation Rate = 0.323 L/min-kg

Activity No.	Activity Label
ACT17	Mins for plant care

Table 3.17 OEHHA's Categorization Of Activities From CARB-Sponsored Children's Activity Patterns Study (Wiley Et Al., 1991b)

	RESTING ACTIVITY
	Ventilation Rate = 0.2 L/min-kg
Activity No.	**Activity Label**
act45	mins for sleep at night
act46	mins for naps
	LIGHT ACTIVITY
	Ventilation Rate = 0.3 L/min-kg
Activity No.	**Activity Label**
act01	mins unaccounted for
act02	mins for unemployment
act03	mins travel during work
act05	mins for paid work
act06	mins for eating at school/work
act08	mins for watching adult at work
act09	mins for travel to school/work meals
act10	mins for food preparation
act11	mins for meal cleanup
act14	mins for clothes care
act15	mins for car repair
act19	mins for pet care
act22	mins for helping/teaching
act23	mins for talking/reading
act26	mins for medical care
act27	mins for other child care
act28	mins watching someone provide child care
act29	mins for travel to child care
act32	mins for personal services
act33	mins for medical services
act34	mins for govt./financial services
act35	mins for car repair
act36	mins for other repair services
act37	mins for other services
act38	mins for errands
act39	mins for travel for goods/services
act40	mins for washing, hygiene
act41	mins for medical care
act42	mins for help and care
act43	mins for meals at home
act44	mins for meals out

LIGHT ACTIVITY (CONT.)
Ventilation Rate = 0.3 L/min-kg

Activity No.	**Activity Label**
act47	mins for dressing
act48	mins for watching personal care
act49	mins travel to pers care/unclear dest.
Act50	mins for student classes
act51	mins for other classes
act52	mins for unspecified daycare
act53	mins for unused
act54	mins for homework
act55	mins for library
act56	mins for other educ/breaks btwn classes
act57	mins hanging out before/after school
act58	mins watching education
act59	mins for travel to education
act60	mins for meetings of organizations
act68	mins for watching organizational activ
act69	mins for travel to organizational activ
act70	mins for sports activity
act71	mins for miscellaneous events
act72	mins for movies
act73	mins for theater
act74	mins for museums
act75	mins for visiting
act77	mins for bars/lounges
act79	mins for travel to social events
act83	mins for hobbies
act84	mins for domestic crafts
act85	mins for art
act87	mins for indoor games
act88	mins for watching recreation
act89	mins for travel recreation
act90	mins for radio
act91	mins for tv
act92	mins for records/tapes
act93	mins for reading books
act94	mins for reading magazines
act95	mins for reading newspapers
act96	mins for conversations
act97	mins for letters, writing
act99	mins for travel to passive leisure
act149	mins for washing clothes laundromat
act199	mins for travel to home/household act
act301	mins for pickup/drop off dry cleaners
act474	mins for washing and dressing
act549	mins for homework/watching TV
act711	mins for eating and amusements
act875	mins for playing/eating
act877	mins for playing/talking w/family

	LIGHT ACTIVITY (CONT.)
	Ventilation Rate = 0.3 L/min-kg
Activity No.	**Activity Label**
act879	mins for playing/watching TV
act914	mins for TV/eating
act915	mins for TV/doing something else
act934	mins for reading book/eating
act937	mins for reading/TV
act938	mins for reading/listening to music
act944	mins for reading magazines/eating
act954	mins for reading newspapers/eating
act971	mins for household paperwork
smoke	mins child was around a smoker

	MODERATE ACTIVITIES
	Ventilation Rate = 0.6 L/min-kg
Activity No.	**Activity Label**
act12	mins for cleaning house
act13	mins for outdoor cleaning
act16	mins for home repair
act17	mins for plant care
act18	mins for other household
act20	mins for baby care
act21	mins for child care
act24	mins for indoor play (childcare)
act25	mins for outdoor play (childcare)
act30	mins for grocery shopping
act31	mins for durable shopping
act76	mins for parties
act78	mins for other social events
act81	mins for outdoor leisure
act86	mins for music/drama/dance
act98	mins for other leisure/being a baby
act166	mins for boat repair
act167	mins for painting room/house
act169	mins for building a fire
act801	mins for golf
act802	mins for bowling, pool, pingpong, pinball
act803	mins for yoga
act811	mins for unspecified outdoor play

	HEAVY ACTIVITIES
	Ventilation Rate = 0.9 L/min-kg
Activity No.	**Activity Label**
act80	mins for active sports
act82	mins for walking/hiking/bicycling

Table 3.18 OEHHA's Assignment Of Activity Levels To Job Categories From CARB-Sponsored Activity Patterns Study (Wiley Et Al., 1991a)

LIGHT ACTIVITIES
Ventilation Rate = 0.131 L/min-kg

Job Code	Description
1	Managers, administrators and public officials (003-019)
2	Accountants, auditors, underwriters and other financial officers (023-025)
3	Management analysts
4	Personnel, training and labor relations specialists (027)
5	Purchasing agents and buyers (028-033)
6	Business and promotion agents (034)
8	Administrative assistants (037)
9	Armed forces officer or NCO
11	Doctors and dentists (084-085)
13	Optometrists (087)
14	Other health diagnosing occupations: podiatrists, chiropractors, acupuncturists, etc. (088-089)
17	Pharmacists and dietitians (096-097)
18	Therapists: physical therapists, speech therapists, inhalation therapists, etc. (098-105)
19	Health techs (hosp. lab techs, dental hygienists, etc.) (203-208)
20	Elementary/high school teachers (155-159)
21	College /university teachers (113-154)
22	Counselors, educational and vocational (163)
24	Lawyers and judges
25	Social scientists and urban planners: economists, psychologists, sociologists, urban planners (166-173)
28	Engineers, scientists, architects (043-083)
29	Computer programmers (229)
30	Other technicians (draftsmen, other lab techs, airline pilots air traffic controllers, legal assistants, etc. (213-228, 233-235)
31	Retail store owners (243)
32	Retail and other sales supervisors (243)
33	Retail sales workers and cashiers (263-276)
34	Real estate and insurance agents (253-254)
35	Stock brokers and related sales occupations (255)
36	Advertising and related sales occupations (256)
37	Sales representatives – manufacturing and wholesale (259)
39	Other sales occupations (257, 258, 283, 285)
40	Office/clerical supervisors/managers (303-307)
41	Secretaries, typists, stenographers, word processors, receptionists and general office clerks (313-315, 319, 379)
42	Records processing clerks: bookkeepers, payroll clerks, billing clerks, file and records clerks (325-344)
43	Shipping/receiving clerks, stock clerks (364-365)
44	Data-entry keyers (385)
45	Computer operators (308-309)
48	Bank tellers (383)
49	Teacher's aides (387)
50	Other clerical workers (316-318, 323, 345-347, 359-363, 366-378, 384, 389)

LIGHT ACTIVITIES (CONT.)
Ventilation Rate = 0.131 L/min-kg

Job Code	Description
51	Supervisors, protective services (413-415)
52	Supervisors, food services (433)
53	Supervisors , cleaning/building services (448)
54	Supervisors, personal services (456)
56	Health service (dental assistants, nursing aides, attendants) (445-447)
57	Personal service (barbers, hairdressers, public transportation attendants, welfare service aides) (457-469)
74	Supervisors, production occupations (633)
79	Precision inspectors, testers, and related workers (689-693)
87	Railroad (engineers, conductors, other operator) (824-826)

MODERATE ACTIVITIES
Ventilation Rate = 0.323 L/min-kg

Job Code	Description
7	Inspectors and compliance officers (035-036)
12	Veterinarians (086)
15	Nurses (RNs, LVNs, LPNs) (095, 207)
26	Clergy, social, recreation and religious workers (174-177)
38	Street and door-to-door sales workers, news vendors, and auctioneers (277-278)
47	Postal clerks, mail carriers, mail carriers, messengers, etc. (354-357)
55	Cooks, waiters and related restaurant/bar occs. (404, 434-444)
58	Cleaning and building service (maids, janitors, housekeepers, elevator operators, pest control) (416-427)
59	Child care workers (406, 408)
60	Fireman, policemen and other protective services occs. (416-427)
61	Farmers, farm managers/supervisors and other supervisors of agricultural/forestry work (473-477, 485, 494)
64	Graders, sorters and inspectors of agricultural products (488-489)
66	Nursery workers (484)
67	Groundskeepers and gardeners (486)
70	Other farming, forestry, and fishing occupations (483)
71	Supervisors, mechanics and repairers (503)
72	Supervisors, construction trades (553-558)
75	Mechanics and repairers of machinery (505-549)
80	Plant and system operators (water and sewage treatment plant operators, stationary engineers) (694-699)
84	Supervisors, material moving equipment operators (843)
85	Machine operators (703-779)
91	Production inspectors, testers, samplers and weighers (796-799)
92	Supervisors of handlers, equipment cleaners and laborers (863)
95	Service station attendants, car mechanic's helpers, tire changers, etc. (885) Helpers of other mechanics and repairers (864) Vehicle washers and equipment cleaners (887)

MODERATELY HEAVY ACTIVITIES
Ventilation Rate = 0.568 L/min-kg

Job Code	Description
76	Construction trades (carpenters, plumbers, roofers, etc.) (563-599)[1]
78	Precision production occupations (tool and die makers, cabinet makers, jewelers, butchers, bakers, etc.) (634-688)
89	Bulldozer and forklift operators, longshoremen, and other material movers (844-859)
94	Factory and other production helpers (873); Hand packers and packagers (888); EXCEPT construction (889)
96	Garbage collectors, stock handlers, baggers and other movers of material by hand.

HEAVY ACTIVITIES
Ventilation Rate = 0.813 L/min-kg

Job Code	Description
63	Farm workers (479)
90	Fabricators, assemblers and hand working operations: welders, solderers, hand grinders and polishers, etc. (783-795)
93	Construction helpers and laborers (865,869)

CAR DRIVING ACTIVITIES
Ventilation Rate = 0.143 L/min-kg

Job Code	Description
86	Motor vehicle operators (truck, bus taxi drivers) (804-814)

The following mixed category was assigned 1/2 light and 1/2 heavy breathing rate:

27	Writers, artists, entertainers and athletes (183-199)

A preliminary estimation of the best parametric model to fit the distributions described in Tables 3.19, 3.20 and 3.21 was done using the fitting function in Crystal Ball version 4.0. The Anderson Darling criterion was used since this procedure is more sensitive to the tails of the distributions. The following distributions are considered as possible fits for these data: Normal, Triangular, Log normal, Uniform, Exponential, Weibull, Beta, Gamma, Logistic, Pareto and Extreme Value.

The following procedure was used to confirm that the empirical distributions were adequately described by a parametric model and parameters determined by Crystal Ball . To determine if a variate is best characterized by a particular distribution, the data are ranked and the ranks are divided by *n* (sample size) to create values from 0 to 1; these values estimate the cumulative distribution function. The inverse cumulative distribution functions can be applied to these fractional ranks to obtain probability quantile scores which can be compared to the raw data (or the log transformed data) to judge the fit of the distribution. For example, if a data set has a normal distribution, the normal scores should be highly correlated with the original values, and a plot of the scores as a function of the original values should be close to a straight line. Also, if the data are log normally distributed the log transformation of the data should be highly correlated with the normal scores. Therefore, the highest correlation determines the best fit. For example, if the raw scores have a higher correlation than the log transformed, the data are considered normally distributed. The normal scores are computed as follows:

$$y_i = \phi^{-1}(r_i - 3/8)/(n + 1/4)$$

where ϕ^{-1} is the inverse cumulative normal function, r_i is the rank of the *i*th observation, and n is the number of observations for the ranking variable (Blom, 1958; Tukey, 1962). The distributions in Tables 3.19, 3.20 and 3.21 were determined by this method to be adequately fit by gamma distributions.

Table 3.19 Adult Daily Breathing Rates (L/Kg Body Weight - Day)

	All Adolescents (>12 years), and Adults Moments & Percentiles (Empirical Data)	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing rate equivalent for a 63 kg human, M^3/day (Empirical Data)**
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 Maximum	693		43.7

Table 3.20 Children's ($\leq$ 12 Years) Daily Breathing Rates (L/Kg Body Weight - 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 maximum	747.5		13.5

A breathing rate distribution was simulated for age 0-70 from the adult and children's breathing rate distributions, using Latin Hypercube sampling. The simulation was done using an Excel spreadsheet and Crystal Ball , Version 4. The adult and children's breathing rate distributions were entered as custom distributions with the adult breathing rate distribution truncated at age 70. The children's breathing rate distribution is multiplied by 0.17 and added to 0.83 multiplied by the truncated adult breathing rate distribution. The 0.17 and 0.83 represent the respective proportions of time that a person would be a child from age 0 up to 12 and an adult from age 12 to age 70. The effect of different rank order correlations between the children's and the truncated adult distribution were explored. The effect on the 95th percentile of the 0-70 distribution varied only a few percent between a correlation of 0 and 0.8. It was therefore decided to assign a rank correlation of zero. Ten thousand trials were performed. Goodness of fit tests were performed using Crystal Ball version 4. The Anderson Darling statistic is 110.2963 for a Gamma distribution with location, scale and shape parameters of 193.99, 31.27 and 2.46 respectively. In addition, the QQ plot for the Gamma distribution is nearly a straight line indicating a reasonable fit.

Table 3.21 Simulated Lifetime (Age 0-70) Daily Breathing Rates (L/Kg Body Weight – Day)*

	Moments and Percentiles from Simulated Data	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing Rate Equivalent for a 63 kg Adult, m^3/day**
Trials	10,000		
Mean	270.9	271.1	17.1
Std Dev	57.9	48.8	3.65
Skewness	2.18	1.22	
Kurtosis	9.43	5.17	
%TILES	**L/kg-day**		
2.5%	213.7	206.6	13.5
5%	217.1	211.3	13.7
10%	221.6	218.3	14.0
25%	232.9	235.2	14.7
50%	253.1	260.9	16.0
75%	289.0	297.1	18.2
90%	337.8	335.9	21.3
95%	393.4	364.9	24.8
97.5%	434.7	390.9	27.4

Figure 3.1 Simulated Age 0-70 Breathing Rate Distribution with Fitted Gamma Distribution

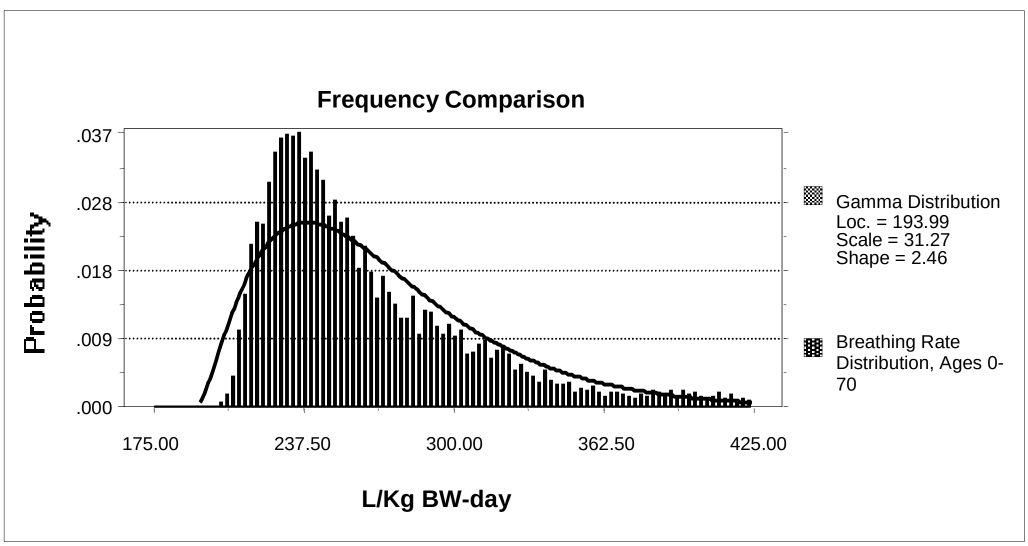
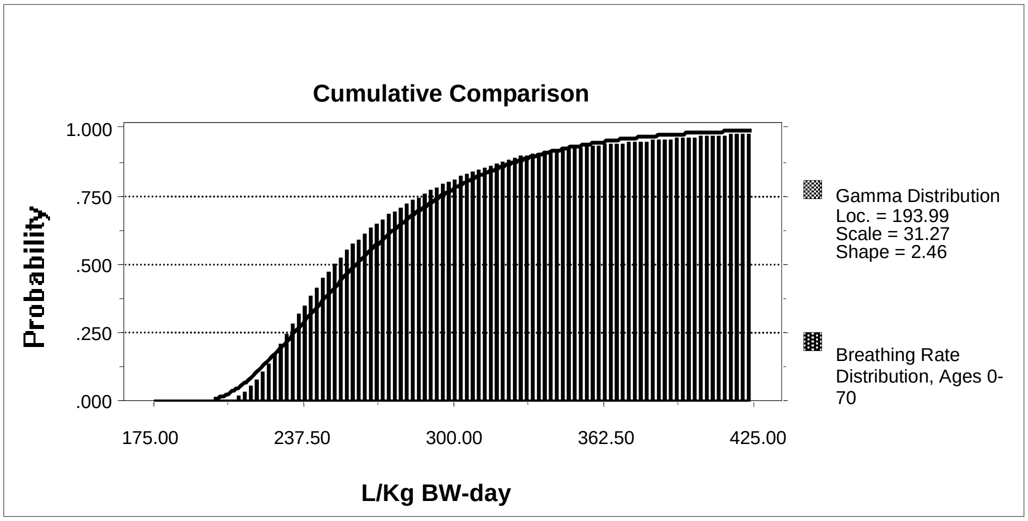


Figure 3.2 Simulated Age 0-70 Breathing Rate Cumulative Probability Distribution with Fitted Gamma Distribution



3.5.3 Evaluating the Validity of the Breathing Rate Distributions

In order to validate the breathing rate distributions, OEHHA examined data on daily energy expenditure. Since we breathe to obtain oxygen to burn calories that we expend, then breathing rate should be proportional to energy expended. In the last decade or so, studies of energy expenditure have been conducted using the doubly labeled water method. The analysis of these data is described in Appendix K. In sum, the use of short-term studies to develop distributions for use in chronic exposure scenarios presents the problem of being unable to characterize an individual over time. Since life changes will impact breathing rates, the distribution developed from short-term data may be an overestimate. However, we believe that the error introduced in this case is minimal. Our breathing rate distribution is narrow - there is only a slightly larger than 2-fold difference between the 5th and 95th percentiles of the adult breathing rate distribution and less than 2-fold difference in the children's. This range is consistent with the range of physical activity indices measured in a number of studies. Relatively longitudinal measurements of total energy expenditure by the doubly-labeled water method in a number of studies are consistent with the caloric equivalents of the OEHHA breathing rate distribution. While the OEHHA breathing rate distribution appears to overestimate energy expenditure in the elderly (over 65 years), it also appears to underestimate energy expenditure in young active men. The documented decrease in energy expenditure appears to occur in the 6th and 7th decades of life. Therefore, by comparison to measures of total energy expenditure, the OEHHA breathing rate distribution is a good approximation of what occurs over a 70 year lifetime.

Figure 3.3 Childrens Breathing Rate Probability Distribution with Fitted Gamma Parametric Model

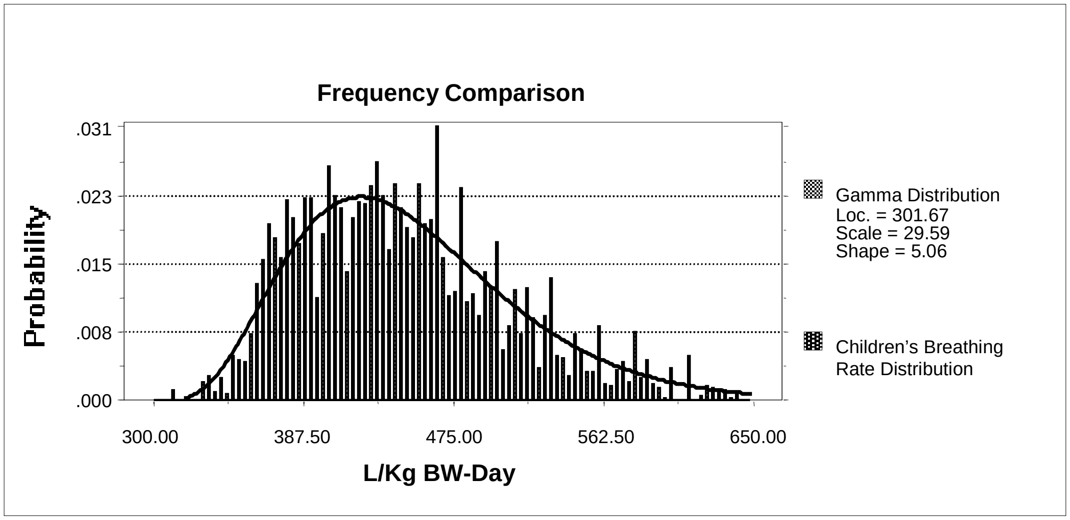


Figure 3.4 Childrens Breathing Rate Cumaulative Probability Distribution with Fitted Gamma Parametric Model

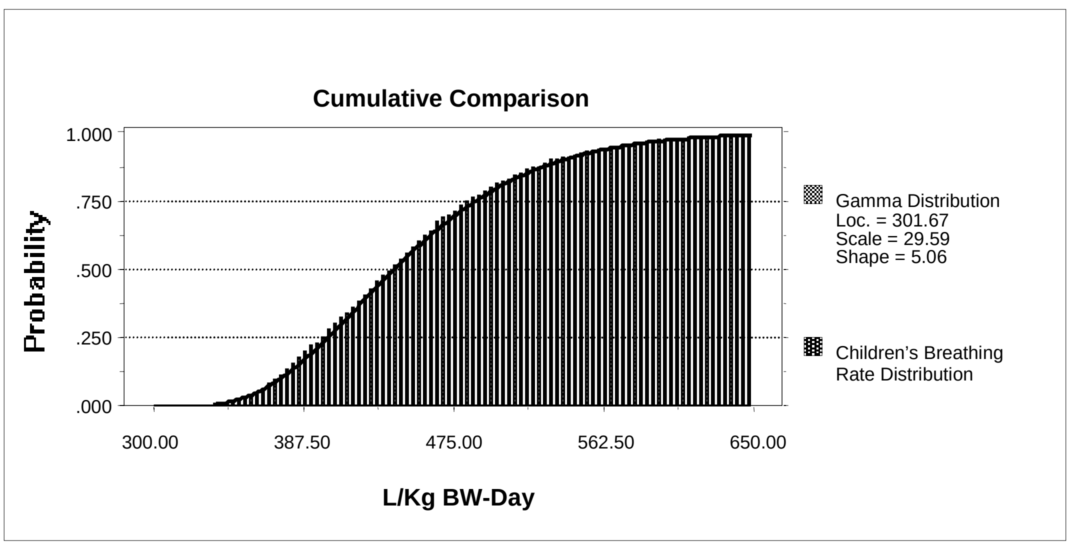


Figure 3.5 Adult Breathing Rate Probability Distribution with Fitted Gamma Parametric Model

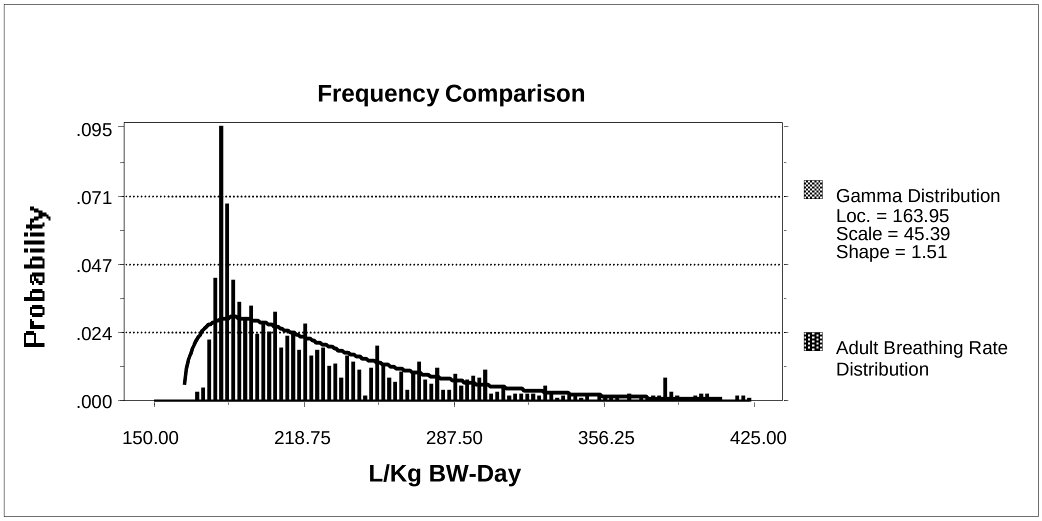
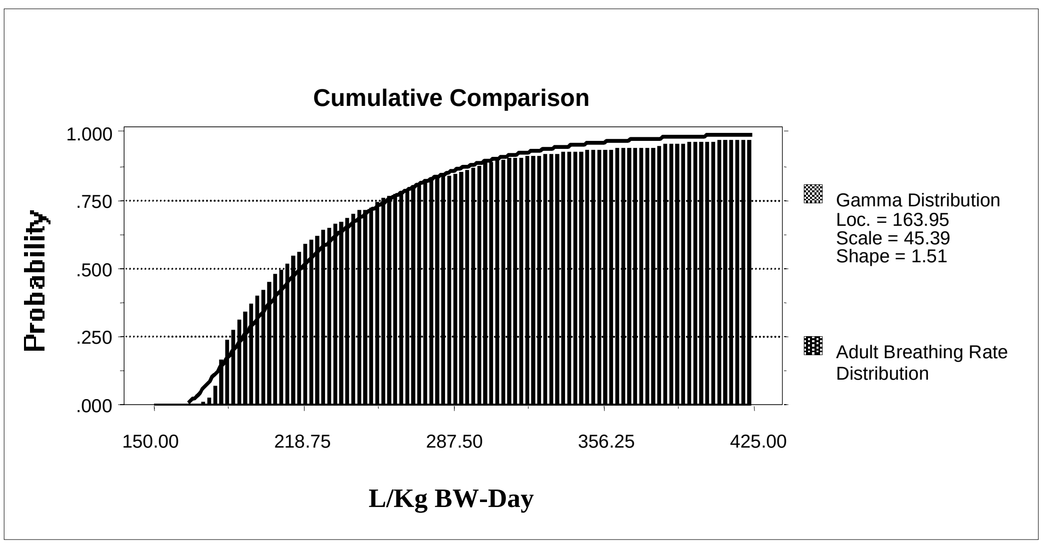


Figure 3.6 Adult Breathing Rate Cumulative Probability Distribution with Fitted Gamma Parametric Model



3.6 Recommendations

Table 3.22 Point Estimates For Daily Breathing Rates [a]

	Adults (>12 yrs)	***Children (≤12 yrs)***
Mean	232 L/kg-day	452 L/kg-day
High End	381 L/kg-day	581 L/kg-day

[a.] Taken from Distributions in Table 3.19 and 3.20.

Table 3.23 Point Estimates For 9, 30 And 70 Years (L/Kg Body Weight - Day)

	9 Year	**30 Year**	**70 Year**
Mean	452	271	271
High End	581	393	393

3.6.1 The Point Estimate Approach

For the point estimate approach, OEHHA recommends that the mean and high-end inhalation dose and cancer risk be calculated for 9, 30 and 70 years using the point estimates presented in Table 3.23. The point estimates of breathing rate for the 9-year scenario are the mean (452 L/kg-d) and 95th percentile (581 L/kg-d) of the breathing rate distribution for children. The point estimates of breathing rate for 30 and 70 year scenarios are the mean (271 L/kg-d) and 95th percentile (393 L/kg-d) of the simulated age 0-70 year distribution. Although it would be possible to generate mean and high end breathing rate point estimates from a simulated age 0-30 year distribution, the values would not be that much different from those of the 0-70 simulated distribution. In the interest of simplicity, it is therefore suggested that the same point estimate values be used for the 30 and 70-year scenarios. These recommendations apply to the Tier 1 and 2 approaches as outlined in Chapter 1.

It may be appropriate under certain circumstances to calculate separate risks for children or adults. The mean and high-end estimates presented in Table 3.21 may be used for these purposes. For this type of approach, children are defined as 12 years or younger.

Since inhalation is nearly always a dominant pathway, the high-end estimates must be used to calculate dose and risk. In addition, it may be appropriate to calculate the inhalation dose and cancer risk using the mean value from the daily breathing rate distribution and to present that along with the dose and risk based on the high-end estimates of daily breathing rate. The dose, derived by multiplying the modeled concentration in air by the breathing rate as in equation 3-2 above, is then multiplied by the cancer potency factor to estimate cancer risk.

A commonly used point estimate for daily breathing rate in risk assessment is 20 m^3/day for a 70 kg human (U.S. EPA, 1989a and 1991). This point estimate is equivalent to 286 L/kg-day and is about the 85th percentile on our distribution of daily breathing rates for adults. Our 70-year time-weighted average body weight is 63 kg. For comparison, the mean breathing rate from our distribution for a 63 kg body weight would be about 17 m^3 per day (see Table 3.21). The 95th percentile breathing rate for a 63 kg person is about 25 m^3 per day.

3.6.2 The Stochastic Approach

We are recommending the distributions of daily breathing rates depicted in Table 3.20 and Figures 3.3, 3.4 for the 9 year exposure scenario and in Table 3.21 and Figures 3.1, 3.2 for 30 and 70 years for use in a Tier 3 or 4 risk assessment. The parametric model recommended for the 9 year scenario is a gamma distribution with location, scale and shape of 301.67, 29.59 and 5.06, respectively. The parametric model recommended for the 0-30 and 0-70 year exposure scenarios is a gamma distribution with location, scale and shape of 193.99, 31.27 and 2.46, respectively. The distributions can be used in a Monte Carlo simulation or similar statistical method to evaluate a range of inhalation doses using Equation 3-2. The distribution is multiplied by the cancer potency factors to describe a distribution of inhalation cancer risks based on variability in exposure.

3.7 References

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4. Soil Ingestion Rates

4.1 Introduction

Humans may be exposed to airborne chemicals through indirect pathways of exposure. Airborne chemicals may deposit onto soil and pose a risk through incidental or intentional ingestion of contaminated surface soil. This section focuses on the soil ingestion pathway of exposure, and in particular on the default point estimates of soil ingestion rates. This pathway is not a major contributor to the risk for most chemicals in the Air Toxics "Hot Spots" program. However, there are some compounds (e.g., polychlorinated dibenzo-p-dioxins and furans, polycyclic aromatic hydrocarbons, some metals) for which soil ingestion may contribute a significant portion of the total dose and cancer risk estimate.

There is a general consensus that hand-to-mouth activity results in incidental soil ingestion, and that 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. Some children exhibit pica behavior which can result in intentional ingestion of relatively large amounts of soil.

4.1.1 Incidental Soil Ingestion

Incidental ingestion of soil or dust by adults and children occurs by mouthing hands or objects including food and cigarettes, which have soil on them. Since mouthing is a normal behavior in young children, some soil and dust ingestion can be expected. The potential for exposure via this pathway is greater in young children because hand-to-mouth behavior is frequent, and because on a kilogram body weight basis the amount of soil or dust ingested is greater than in either older children or adults.

4.1.2 Intentional Soil Ingestion

The consumption of nonfood items by young children is a common occurrence. Pica is a behavioral anomaly characterized by the ingestion of nonfood items including soil. It is generally accepted that pica behavior is most prevalent in children three years and younger, and rapidly declines by age six (Barltrop, 1966). A number of authors have reported that not all children with pica ingest soil and that only a subset of pica children ingest greater than average amounts of soil (Barltrop, 1966). Prevalence of soil pica is difficult to estimate because it depends on the definition of soil pica (arbitrarily defined by many as ingestion of greater than one gram soil per day), and because it is an erratic behavior (e.g., children do not consistently eat greater than one gram soil per day). Studies in the literature estimate that between 10 and 50% of children may exhibit pica behavior at some point (Millikan et al., 1962; Cooper, 1957; Barltrop, 1966; Bruhn and Panghorn, 1971; Vermer and Frate, 1979; Sayre et al., 1974; Kanner, 1937; Oliver and O'Gorman, 1966; Stanek and Calabrese, 1995a).

Calabrese and Stanek (1994) reanalyzed four studies of soil ingestion by children and reported that approximately 1.9% of children display pica behavior eating 1 g soil/day, and only about 0.19% ingest up to 10-13 g soil/day. Higher estimates of frequency of soil pica behavior from a later analysis by Stanek and Calabrese (1995a) are presented in section 4.6. Children exhibiting soil pica are a sensitive subpopulation at greater risk from exposure via the soil ingestion pathway.

4.2 Current CAPCOA Algorithm for Dose from Soil Ingestion

Currently, the algorithm used in the Air Toxics "Hot Spots" program (see CAPCOA, 1993) for estimating dose from soil ingestion is as follows:

$$\text{Dose} = \frac{\text{Csoil} \times \text{Isoil} \times \text{GI} \times \text{Bio} \times 10^{-6}}{\text{BW} \times 10^{3}} \qquad \text{(Eq. 4-1)}$$

where:

Dose = dose through soil ingestion (mg/kg body weight-day)
Csoil = concentration of contaminant in soil (μg/kg soil)
Isoil = lifetime average soil ingestion rate
GI = gastrointestinal absorption fraction if different from study used for toxicity criteria; unitless
Bio = bioavailability; unitless
1×10^{-6} = conversion factor (kg/mg)
BW = body weight (kg)
1×10^{3} = conversion factor (μg/mg)

OEHHA is recommending the same basic algorithm with the modifications discussed below. In particular, GI and Bio are being merged into one factor, termed the gastrointestinal relative absorption factor or GRAF. In addition, separate point estimate soil ingestion rates are being proposed for children and adults.

4.3 Proposed Algorithm for Dose via Soil Ingestion

4.3.1 Inadvertent Soil Ingestion by Adults

The dose from inadvertent soil ingestion by adults can be estimated using the following general equation:

$$\text{Dose} = \frac{\text{Csoil} \times \text{GRAF} \times \text{SIR} \times \text{EF} \times \text{ED} \times 10^{-9}}{\text{AT}} \qquad \text{(Eq. 4-2)}$$

where:

Dose = dose from soil ingestion (mg/kg body weight-day)
1×10^{-9} = conversion factor (μg to mg and kg to mg)
Csoil = concentration of contaminant in soil (μg/Kg soil)
GRAF = gastrointestinal relative absorption fraction, unitless; chemical-specific

SIR =	soil ingestion rate (g/kg BW-day)
EF =	exposure frequency (days/year), EF = 350 d/yr
ED =	exposure duration (years)
AT =	averaging time, period of time over which exposure is averaged (days); for noncancer endpoints, AT = ED $\times$ 365 d/yr; for cancer risk estimates, AT = 70 yr $\times$ 365 d/yr = 25,550 d

In this approach, it is assumed that the soil ingested contains a representative concentration of the contaminant(s) as modeled by the deposition model, and that the concentration is constant over the exposure period.

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 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.

4.3.2 Inadvertent Soil Ingestion by Children

As described in section 4.7, children have been divided into the following age groups with respect to soil ingestion rate: 1 through 6 years of age, and 7 to 18 years. Separate point estimates of soil ingestion rates are used for these age groups. In Section 4.7, OEHHA recommends soil ingestion rates for the 9, 30 and 70 year exposure duration scenarios suggested in Chapter 11. The exposure duration scenarios evaluate the first 9, 30 and 70 years of an individual's life. OEHHA is recommending that 18 kg be used for the body weight for the 0-9 year exposure duration determination of dose from soil ingestion (Chapter 10). For the 30 and 70 year exposure duration scenarios, OEHHA recommends that 63 kg be used for the body weight term (Chapter 10). These body weights have been incorporated into the recommended soil consumption rates (mg/Kg BW-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 4.7.

4.3.3 Inadvertent Soil Ingestion by Offsite Workers

When the zone of impact of a facility includes offsite workplaces, risk estimates for those offsite workers includes exposure from incidental soil ingestion for multipathway chemicals. Equation 4-2 can be used; however, the exposure is adjusted for the time at work by multiplying by 8/24 hours, 5/7days, 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. It may be an underestimate for those who work outdoors at the receptor location, and an overestimate for those who work indoors.

4.4 Soil Ingestion Studies

Soil ingestion data from the draft U.S. EPA Exposure Factors Handbook (1995, 1997), the American Industrial Hygiene Council (AIHC) Exposure Factors Sourcebook (1994), and several peer-reviewed journal articles were analyzed for applicability to estimating point estimate values and distributions of soil ingestion rates for children and adults. Analysis of the literature indicated that in general, two approaches to estimating soil ingestion rates were taken. The first method involves measuring the dirt present on an individual's hand and making generalizations regarding exposure based on observation of hand-to-mouth activity. Results of these studies, conducted prior to 1985, are associated with large uncertainty due to their subjective nature. We have not presented these studies in this document. The other method of estimating soil ingestion rates involves measuring the presence of non-metabolized tracer elements in the feces of an individual and soil with which an individual is in contact. These studies are discussed below.

4.4.1 Studies in Children

4.4.1.1 Binder et al. (1986)

These investigators measured tracer elements in feces to estimate soil ingestion by young children. Soiled diapers collected over a three day period from 65 children (42 males and 23 females) one to three years of age, 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, using the three tracer elements. Tracer elements were assumed to be neither lost nor introduced during sampling. The investigators obtained soil ingestion rates by dividing the product of mg tracer per gram feces and fecal dry weight in g/day by the concentration of that tracer in the soil. Daily soil ingestion based on aluminum and silicon and titanium are presented in Table 4.1. 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 Ti as a tracer. Binder et al. (1986) report that there may have been an unrecognized source of Ti that children were ingesting.

Table 4.1 Soil ingestion rates (mg/day) from Binder et al. (1986)

Tracer:	Al	Si	Ti	Minimum
Mean	181	184	1834	108
Std Dev	203	175	3091	121
Range	25-1324	31-799	4-17,076	4-708
Median	121	136	618	88
95th percentile	584	578	9590	386
geo mean	128	130	401	65

The advantages of this study include a relatively large sample size and use of the less-subjective tracer method in contrast to previous studies based on observation of mouthing behavior. However, there were several methodological difficulties with the protocol pointed out by Binder and colleagues. 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. Measuring fecal weights was difficult because the entire diaper (including urine) was collected, and as much stool as possible recovered from the diaper. The investigators used data on stool production by 13 to 24 month old children from a previous study to arrive at the 15 g/d estimate. This may lead to either over- or underestimation of soil ingestion rates. 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.

4.4.1.2 Clausing et al. (1987)

In a pilot study, fecal samples from 18 Dutch children ages two to four years attending a nursery school, and samples of playground soil at the school were analyzed for Al, Ti, and acid insoluble residue (AIR) content. Twenty-seven daily fecal samples were obtained over a five-day period while the children were at school. Stool produced outside of school hours was not collected. Soil ingestion was estimated using each tracer from average concentrations in the school yard soil and assuming a dry fecal weight of 10 g/day. These investigators also collected eight daily fecal samples from a group of six hospitalized bedridden children with no access to soil to use as a control group.

The investigators based their estimates of soil ingestion on the Limiting Tracer Method. In this method, the maximum amount of soil ingested by each subject corresponds to the lowest estimate from the tracers used. The method tends to bias in the negative and may underestimate soil ingestion rates. The mean from this study of 56 mg/day was calculated as the mean for the schoolchildren minus the mean for the control hospitalized children (Table 4.2).

The advantages of the Clausing study are that soil ingestion was evaluated in two groups of children, one serving as a control. There are several disadvantages of this study for our purposes. The food and medicine taken by the children were not analyzed for the content of tracer elements. Stool produced during non-school hours was not collected. The Limiting Tracer

Method likely underestimates soil ingestion rates. As with other studies, a short-term study of soil ingestion rates may not be representative of longer term soil ingestion rates. Finally, the small sample size results in statistical instability, and the Dutch children sampled may not be representative surrogates for the U.S. population.

Table 4.2 Soil ingestion results (mg/day) from Clausing et al. (1987)

	School Children	**Hospitalized Children**	**Difference**
mean	105	49	**56**
std dev	67	22	
range	23-362	26-84	
geo mean	90	45	

4.4.1.3 Van Wijnen et al. (1990)

Soil ingestion by children in four different environments (day care with and without gardens, campgrounds, hospitals) was evaluated using the Limiting Tracer Method. Fecal samples and soil samples from the play areas were collected and analyzed for Ti, Al and AIR (acid insoluble residue). Ti and Al were analyzed by inductively-coupled plasma-atomic emission spectrometry. Using an assumption of 15 g dry weight feces/day, and assuming minimal absorption of tracers, soil ingestion rates were calculated as the product of the concentration in feces and the amount of feces produced divided by the concentration of tracer in soil.

These investigators used the hospitalized children as a control group. The 95% confidence limit of the mean soil ingestion value was subtracted from the mean soil ingestion values obtained from the other groups. The investigators present a number of soil ingestion rates in the paper. Geometric mean soil ingestion rates ranged from 0 to 90 mg/day for day-care center children, and 30 to 200 mg/day for children at campgrounds.

This study sampled a number of children in several different environments. However, for our purposes there are several disadvantages. Tracer content of food and medicines was not evaluated. The Limiting Tracer Method tends to underestimate soil ingestion rates. The relatively small sample size per group and the short-term nature of the study are also limiting.

4.4.1.4 Davis et al. (1990)

A mass balance approach was used to evaluate soil ingestion in a random sample of 104 toilet-trained children between two and seven years of age studied over a seven-day period in the summer in southeastern Washington. The Al, Si, and Ti contents of foods, feces, urine, soil and house dust from each child’s home were analyzed using x-ray fluorescence spectrometry. Soil intake rates were corrected for the amount of tracer in vitamins and medicines.

The results (Table 4.3) indicate a large degree of variability. The means for aluminum, silicon and titanium as tracers were 39, 82, and 246 mg/d, respectively. The investigators in reporting the range include negative numbers. This is indicative of a basic difficulty in estimating soil ingestion rates in a mass balance approach. If fecal output does not correspond to the food/medicines sampled due to variation in transit time in the gut, then the calculation of soil ingestion rate will be inaccurate. Overcorrecting for the presence of tracer 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 than the food that was sampled, the soil ingestion rate can be biased in the positive. While this study's strengths include evaluation of demographic and behavioral information with respect to soil ingestion, the negative soil ingestion estimates are problematic.

Table 4.3 Soil ingestion results from Davis et al. (1990), mg/day

	Aluminum	**Silicon**	**Titanium**
Mean	38.9	82.4	245.5
Median	25.3	59.4	81.3
Std Error	14.4	12.2	119.7
Range	-279 to 903	-404 to 534.6	-5820 to 6182

4.4.1.5 Calabrese et al. (1989)

This study based estimates of soil ingestion rate on measurements of eight tracer elements (aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) using a method similar to Binder et al. (1986) but including a mass balance approach, and evaluating soil ingestion over eight days rather than three days. The study population consisted of 64 children between one and four years old in the Amherst, Massachusetts area. 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 tracer elements. Blanks of diaper and commode specimens using distilled water were collected to control for introduced tracer. Samples were analyzed for tracer content by inductively coupled plasma atomic-emission spectrometry following sample treatment. Care was taken to avoid contamination of food and waste samples with the eight tracers. Waste samples from a single 24-hour period were pooled into one sample for analysis. Soil samples represented composite samples from the three areas in which the child played the most.

In addition to the study of soil ingestion by children, these investigators also present a validation study in adults. Six volunteers, ages 25-41, ingested empty gelatin caps at breakfast and dinner on Monday, Tuesday, and Wednesday of week one, gel caps containing 50 mg sterilized soil at breakfast and dinner Monday, Tuesday, and Wednesday of week two, and gel caps containing 250 mg soil at breakfast and dinner Monday, Tuesday, and Wednesday of 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 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 300 mg 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 Al, Si, Y, and Zr had the best recoveries (closest to 100%) while Mn and Ba grossly exceeded 100% recovery. Both these elements are unreliable due to their relatively higher concentrations in food relative to soil. Zirconium as a tracer was highly variable and Ti was not reliable in the adult studies. The investigators conclude that Al, Si, and Y are the most reliable tracers for soil ingestion.

The results of the soil ingestion calculations for children based on excretory tracer levels minus food tracer levels (Table 4.4) 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 4.4 Soil Ingestion Results For Children Aged 1 To 4 Years From Calabrese Et Al. (1989) In Mg/Day

	Al	Si	Ti	V	Y	Zr
Mean	153	154	218	459	85	21
Median	29	40	55	96	9	16
SD	852	693	1150	1037	890	209
P95th	223	276	1432	1903	106	110
Max	6837	5549	6707	5676	6736	1391

This study is useful in several ways. The mass balance approach attempts to correct for ingestion of tracer such as Ti 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.

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.

4.5 Studies in Adults - Calabrese et al. (1990)

Although inadvertent soil ingestion by adults is recognized as a pathway of exposure to environmental contaminants, only one preliminary study quantifying soil ingestion in adults has been published. This study was originally part of the study in children published in 1989, and the methodology is described above in section 4.4.1.5. The soil ingestion rates for the 6 volunteer adults was estimated by subtracting out the tracer quantities in food and soil capsules from the amounts excreted. The four most reliable tracers were Al, Si, Y, and Zr. Median soil ingestion rates were as follows: Al, 57 mg; Si, 1 mg; Y, 65 mg; and Zr, -4 mg. Mean values were: Al, 77 mg; Si, 5 mg; Y, 53 mg, and Zr, 22 mg. The average of the soil ingestion means based on the four tracers is 39 mg. The preliminary nature of these data should be emphasized. The sample size is very small (n = 6). The study was not designed to look at soil ingestion by the adults but rather as a validation of the overall methodology.

4.6 Distributions of Soil Ingestion Estimates

4.6.1 Thompson and Burmaster (1991)

Thompson and Burmaster reanalyzed the original data from Binder et al. (1986) to characterize the distribution of soil ingestion by children. Soil ingestion estimates from Binder's study using Al and Si tracers were adjusted using actual stool weights measured in the original study instead of the assumed stool weight of 15 g/day. Ti was not used because the data could not be adjusted for presence of Ti in foods. Thompson and Burmaster reported that soil ingestion rates in children are lognormally distributed. They obtained lower soil ingestion rates than reported in Binder et al. (1986) attributable to use of the actual fecal weight data. Based on Al and Si tracers, Thompson and Burmaster report a mean of 91 mg/day, and a 90th percentile of 143 mg/day (Table 4.5). Use of actual fecal weight data may be construed as an improvement over the estimates in the original paper. However, difficulties in obtaining stool weights by the original investigators makes an adjustment questionable. In addition, the original Binder study has several methodological difficulties and there are newer data available using a mass balance approach. As with most soil ingestion studies, no discussion of pica children is included in the original study or in this reanalysis.

Table 4.5 Distribution Of Soil Ingestion Estimates For Children Presented By Thompson And Burmaster (1991); Data From Binder Et Al. (1986) Expressed In Mg/Day

Mean	91
Standard Deviation	129
Median	59
90th percentile	143

4.6.2 AIHC (1994) and Finley et al. (1994)

The AIHC Exposure Factors Sourcebook presented several distributions for children's soil ingestion rates including that of Thompson and Burmaster discussed in the previous section. AIHC-derived distributions were limited to data from zirconium (Zr) as a tracer in Calabrese et al. (1989) and Calabrese and Stanek (1994). Since various tracer elements give divergent soil ingestion estimates, it may not be valid to pick one tracer out of the eight used in the studies. Zr consistently gave relatively low estimates.

AIHC presents a distribution of soil ingestion estimates for adults based on a preliminary study by Calabrese et al. (1990). AIHC chose the data based on Zr as a tracer. The distribution presented by AIHC has a median value of 0 mg/day, and a maximum value of 216 mg/day. Since the Calabrese data are preliminary, it is premature to characterize the distribution of soil ingestion estimates using a single tracer from this study.

Finley et al. (1994) also constructed distributions based on the Zr data in Calabrese et al. (1989). The distribution was constructed using negative soil ingestion estimates for the 5th percentile (-70 mg/day), and the 10th percentile (-35 mg/day). The authors then truncated the distribution at 0 mg/day which was approximately the 36th percentile. Based on discussion in Sections 4.6.3 and 4.6.4 below, OEHHA does not recommend using the distribution in Finley et al. (1994) for stochastic modeling. The truncation of the distribution does not mitigate the problem of using negative numbers to construct the distribution. In addition, the validity of using only one element, Zr, from the dataset is questionable.

4.6.3 Stanek and Calabrese (1995a)

Stanek and Calabrese (1995a) reanalyzed the soil ingestion study by Calabrese et al. (1989). These investigators constructed daily soil ingestion estimates using food and fecal trace-element concentrations from Calabrese et al. (1989), and reported a soil ingestion distribution developed from data adjusted to in part account for problems associated with tracer selection in determining soil ingestion rates. A distribution of daily soil ingestion estimates, assumed to be lognormal, was constructed from the short-term study by extrapolating over 365 days. All soil ingested was assumed to come from outdoors.

There are a number of methodological difficulties in attempting to quantify soil ingestion. Food (and vitamins, medicines), soil, and fecal material are analyzed for specific tracer elements in a mass balance approach to soil ingestion estimates. The assumption implicit in analyzing food and feces for the tracer elements and in the calculation used to estimate soil ingestion is that the feces represents that formed from the food/medicines analyzed. However, transit time through the gut varies widely. The fecal sample may not represent the food/medicine sample. This input-output misalignment can underestimate soil ingestion even resulting 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.

Stanek and Calabrese (1995a) adjust the data from Calabrese et al. (1989) in a number of ways in order to generate a soil ingestion rate distribution. The issue of directly connecting food intake with fecal output arises (input-output misalignment). Stanek and Calabrese (1995a) in reconstructing soil ingestion estimates link the passage of food to feces by assuming a food transit time of 28 hours. This allows adjustment of soil ingestion rates for days when food samples were not taken the day prior to collection of feces (e.g., on Mondays and Fridays in the initial Calabrese study protocol). Further adjustments are made to account for days in which there was no fecal output; these adjustments link foods consumed prior to the day with the missing fecal sample to subsequent days' fecal outputs. Daily soil ingestion estimates were made for each element and each study subject from Calabrese et al. (1989) data. 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 of soil ingestion estimates are based on a "relative standard deviation" which incorporates judgment about the relative precision of a soil ingestion estimate based on the detection limit from a given tracer. 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 median of the remaining trace element estimates was defined as the best estimate of soil ingestion for the day for the subject. Estimates of soil ingestion could not be made for everyone for all eight days because of missing fecal samples. In addition, a given soil ingestion estimate is not necessarily based on all tracers studied because estimates that exceeded the outlier criteria were excluded. Thus, the number of days per subject with soil ingestion estimates ranged from four to eight, and the number of elements used per day to estimate soil ingestion for a given subject varied from one to eight. The investigators took both a mean and median of each subject's daily soil ingestion estimates. Cumulative distributions of the means and the medians were constructed. 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 12 mg/day or less for 50% of the children studied, and 138 mg/day or less for 95% of the children studied.

The investigators also used the daily soil ingestion rate estimates to create a distribution of soil ingestion rates extrapolated over a year. The daily soil ingestion estimates, representing the median or mean of any tracers not excluded on a given day, were used to characterize a distribution of values for 365 days assuming a lognormal distribution for each subject (Table 4.6). Negative estimates were replaced with a value of 1 mg/day. Order statistics corresponding to z scores for percentiles in increments of 1/365 were used with the assumption of lognormal distribution to form soil ingestion estimates for 365 days for each subject. The median of the distribution of average daily soil ingestion (average of estimates from different tracers in a day) predicted over 365 days is 75 mg, while the 95th percentile is 1751 mg/day (Table 4.6). The median of the distribution of median soil ingestion estimates is 14 mg/day while the 95th percentile is 252 mg/day. Soil ingestion rates vary widely; the range of upper 95 percentiles of the median soil ingestion rate estimates for 63 kids (exclusive of the one pica child) is 1 to 5623 mg/day.

Table 4.6 Soil Ingestion Distributions From The Stanek And Calabrese (1995a) Reanalysis Of Calabrese Et Al. (1989) Data - Fitting Lognormal Distribution To Daily Average (Row 1) Or Daily Median (Row 2) Soil Ingestion Estimates For 64 Individuals Extrapolated Over 365 Days

	Range	Median	90th%	95th%
Average daily soil ingestion rates for 64 subjects	1 - 2268 mg/day	75 mg/day	1190 mg/day	1751 mg/day
Median daily soil ingestion rates for 64 subjects	1-103 mg/day	14 mg/day	--	252 mg/day

Stanek and Calabrese (1995a) also evaluated the presence of soil pica using the distribution developed from their adjusted soil ingestion rates. An estimated 16% of children are predicted by this method to ingest more than 1 gram of soil per day on 35-40 days of the year. In addition, 1.6% would be expected to ingest more than 10 grams per day for 35-40 days per year.

Table 4.7 Estimates Of Percent Of Children Exceeding The Given Soil Ingestion Rates For Specified Number Of Days Per Year From Stanek And Calabrese (1995a)

	Days per year of excessive soil ingestion		
Soil Ingestion Rate	1-2	7-10	35-40
> 1 gram	63	41	16
> 5 grams	42	20	1.6
>10 grams	33	9	1.6

The advantages of Stanek and Calabrese (1995a) include a thorough reanalysis of the data in Calabrese et al. (1989) which itself is one of the most thorough studies of soil ingestion rates published. The Stanek and Calabrese report attempted to link the food samples with the fecal samples to more accurately estimate soil ingestion rates. In addition, the tracers were ranked according to usefulness, and criteria for excluding a soil ingestion estimate were incorporated into their reanalysis.

There are some methodological problems with the development of the distribution of soil ingestion rates that affect the usefulness of the distribution. The transit time in the gut was assumed to be the same for all subjects and not to vary within subjects. Thus, the correction for transit time is itself uncertain and may not adequately correct for input-output misalignment error. Indeed, negative soil ingestion estimates were still obtained; the authors replaced them with a soil ingestion estimate of 1 mg/day for characterizing the distribution. Nonetheless, making the assumption about transit time in order to link food and fecal samples better leads to more accurate soil ingestion rate estimates than ignoring transit time altogether. Longer-term studies would be useful to obviate the need for adjusting for transit time.

The outlier criterion used to eliminate element-specific estimates for individual subject days itself contains some judgments and assumptions regarding the relative accuracy of the tracers to detect soil ingestion, and the method is unique. The technique was employed to attempt to correct for the likelihood that ingestion of some tracers from sources other than food or soil occurred. There are large discrepancies between individual tracer elements' estimates of soil ingestion for the same subject on the same day. While we are critical of some aspects of their exclusion methodology (using the median as a reference point rather than the mean, no indication of how many data points were excluded or what those data points were), the effect of these exclusions is actually fairly small as indicated by comparing the distributions of the mean estimates when three or fewer elements are used following exclusion with the distribution of the mean estimates where no elements are excluded (Table 6 in Stanek and Calabrese, 1995a).

The annual soil ingestion distribution generated in the paper and presented in Table 4.6 is assumed to be lognormal. It is based on individual lognormal distributions for each of the 64 subjects generated by applying order statistics to soil ingestion estimates for each subject to generate 365 daily soil ingestion estimates for each subject. The assumption that the distribution of soil ingestion estimates over a year is lognormal for any individual is plausible, yet there are no data to support its use since there are only between four and eight estimates of the soil ingestion rate for each of the 64 individuals. Therefore estimates of the mean and variance of the lognormal distribution have large variance. This results in large variability in the annual soil ingestion estimates, and contributes to uncertainty. As with all studies, the relatively short duration of the study introduces uncertainty when extrapolating the results out to a year. It is not possible to ascertain from the studies available in the literature whether the variability in soil ingestion measured over four to eight days reflects the variability in soil ingestion rate over 365 days.

The nonrandomly sampled population (educated community in a college town) may not be representative of the U.S. population, and soil ingestion behavior may be affected by socioeconomic factors not present in this study population.

4.6.4 Stanek and Calabrese (1995b)

Stanek and Calabrese published a separate reanalysis combining the data from their 1989 study with data from Davis et al. (1990) and using a different methodology from that in Stanek and Calabrese (1995a). This methodology, the Best Tracer Method (BTM), is designed to overcome intertracer inconsistencies in the estimation of soil ingestion rates. The BTM involves ordering of trace elements for each subject based on the food:soil ratio. Tracers with a low food:soil ratio lead to more precise soil ingestion estimates because confounding from the tracer content of food is decreased. Available data from Calabrese et al. (1989), Calabrese et al. (1990), and Davis et al. (1990) soil ingestion studies were used to construct estimates of the food:soil (F/S) ratio for each trace element for each subject/week. Note that F/S ratios will vary from one subject to the next and week to week because it depends on what the subjects have eaten. 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. Distributions of soil ingestion estimates are presented based on the various ranked tracers for both children and adults from all three studies. In addition, data from the Davis et al. (1990) and Calabrese et al. (1989) studies on soil ingestion in children were combined to form another distribution. In contrast to the Stanek and Calabrese (1995a) distribution, negative values for soil ingestion estimates were included in the distributions in this paper. 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 estimate from the combined studies for children are presented in Table 4.8.

Table 4.8 Distributions Presented In Stanek And Calabrese (1995b) In Mg/Day

	50th%	**90th%**	**95th%**	**99th%**	**Ave ± SD**	**Sample Max**
Calabrese 89[a]	33	110	154	226	132 ± 1006	11,415
Davis 1990[b]	44	210	246	535	69 ± 146	905
Combined	37	156	217	535	104 ± 758	11,415

a. Data from Calabrese et al., 1989
b. Data from Davis et al., 1990

4.6.5 Summary of Utility of Existing Distributions to Air Toxics "Hot Spots" Program

The Calabrese et al. (1989) and Davis et al. (1990) data are the best available on soil ingestion in children. There are difficult methodological issues in estimating soil ingestion and in analyzing and interpreting soil ingestion data from different tracer elements. Stanek and Calabrese (1995a and 1995b) address these difficulties in their paper, acknowledge the uncertainties in their methods and attempt to ascertain the impact of these uncertainties on the distributions developed from their reanalysis of the Calabrese et al. (1989) data and the analysis of Davis et al. (1990) data. The distributions presented in the two Stanek and Calabrese papers (1995a and b) are very different. It is not possible given the existing studies to ascertain which of these distributions is more appropriate to use for site-specific risk assessments. At this time, OEHHA is not recommending a distribution for use in the Air Toxics "Hot Spots" program pending resolution of the various problems associated with estimating soil ingestion rates and characterizing an appropriate distribution. New studies are on the horizon and it is appropriate at this time for this program to wait until more data become available.

4.7 Recommendations

4.7.1 Incidental Soil Ingestion by Children

The U.S. EPA (1989, 1991) uses 200 mg/day as a soil ingestion rate for children one through six years of age. In their 1997 update of 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. For children seven to 18 years and for adults, U.S. EPA (1989, 1991) uses 100 mg/day as a soil ingestion rate. However, in the 1997 update U.S. EPA indicates that 50 mg/day is still a reasonable estimate for adults, although no new data became available to them to cause a shift in the assumption. Since the data are limited all around, OEHHA recommends using 200 mg/day for children through age six and 100 mg/day for everyone older than six including adults and dividing by the time-weighted average body weight for 0-9 years and 0-70 years. Development of a distribution may become more reasonable with further research. OEHHA is recommending using 8.7 mg/kg-day for the 0 to 9 year exposure scenario and 1.7 mg/kg-day for the 30- and 70-year exposure scenarios. For the 9-year scenario, the soil ingestion rate estimate is derived by taking (6/9 x 200 mg/day + 2/9 x 100 mg/day) and dividing through by a time-weighted average body weight of 18 kg for 0-9 years. The recommendation for 30 and 70 years is derived by talking (6/70 x 200 mg/day + 63/70 x 100) and dividing by the time-weighted average body weight of 63 kg for age 0 to 70. It would be possible to generate a separate soil ingestion point estimate for 30 years but in the interest of simplicity it was decided to recommend that the time weighted average for 70 years also by used for 30 years. OEHHA recommends using these numbers (Table 4.9) in a point estimate approach to calculate soil ingestion dose and risk for Tiers 1 through 4 risk assessments.

4.7.3 Incidental Soil Ingestion by Adults

Lack of data in adults makes the development of soil ingestion rates for individuals greater than 18 years of age very difficult. The preliminary data of Calabrese et al. indicate a soil ingestion rate of 39 mg/day for the six volunteers which is less than the current U.S. EPA value of 100 mg/day. Since the data are preliminary, as noted above OEHHA suggests adopting the current U.S. EPA estimate of soil ingestion rate of 100 mg/day for people seven years and older. In addition OEHHA does not currently recommend using the preliminary data of Calabrese et al. (1990) to develop a distribution of soil ingestion rates in adults. Development of a distribution awaits further research on soil ingestion.

4.7.4 Intentional Soil Ingestion (Pica) by Children

It may be appropriate in some risk assessments to separately evaluate the risk to pica children. These children represent a sensitive subpopulation because of their high soil ingestion rates. Stanek and Calabrese (1995a) provide information on soil pica frequency and approximate ingestion rates for those children (Table 4.7). The risk assessor should choose values from Table 4.7 to create a soil pica scenario for children under six years of age. For example, one could assume an exposure frequency of 35 to 40 days per year and an ingestion of 10 g/day (this would be for less than 2% of children according to the analysis of Stanek and Calabrese in Table 4.7) to build a potential pica exposure scenario.

Table 4.9 Soil Ingestion Estimates For Use In Risk Assessment

	9-year exposure scenario	30- and 70-year exposure scenario
Soil ingestion rate	8.7 mg/kg-day	1.7 mg/kg-day

4.8 References

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5. Breast Milk Consumption Rate

5.1 Introduction

Breast milk consumption is an indirect but important exposure pathway for some environmental contaminants. For example, some airborne toxicants (e.g., semi-volatile organic chemicals) deposited in the environment bio-magnify and become concentrated in human adipose tissue and breast milk lipid. Highly lipophilic, poorly metabolized chemicals such as TCDD, DDT and PCBs are sequestered in adipose tissue and only very slowly eliminated except during lactation. These toxicants in breast milk lipid appear to be in equilibrium with adipose tissue levels, and over time the breast-fed infant may receive a significant portion of the total maternal load. Hoover *et al.* (1991) found that for a toxicant such as TCDD, an infant's intake rate (pg/kg-day) via breast milk can be substantially greater than the mother's environmental intake rate (pg/kg-day). In order to estimate toxicant exposures through this pathway, an understanding of the amount of breast milk consumed by infants at different ages is needed. This is the emphasis of the following sections. Childhood exposures to toxicants via commercial milk are addressed in Chapter 7.

5.1.1 Terminology

Table 5.1 Breast-feeding terminology[a]

Term	Definition
Fully breast-fed	
Exclusively breast-fed	Breast milk is sole source of calories.
Almost exclusively breast-fed	Breast milk is primary if not sole milk source with no significant calories from other liquid or solid food sources.
Predominantly breast-fed	Breast milk is the primary if not sole milk source with significant calories from other liquid or solid food sources.
Partially breast-fed	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 breast-feeding	Minimal, irregular or occasional breast-feeding contributing minimal nutrition and few calories.
Extended breast-feeding	Breast-feeding beyond 12 months of age.
Weaning	Discontinuation of breast-feeding.

[a] Adapted from Labbok and Krasovec (1990)

This chapter evaluates breast milk intake among the breast-fed infant population and the entire infant population. Because different and sometimes contradictory terms for various breast-feeding populations are used in the literature, specific terms and definitions have been adopted for use throughout this chapter (Table 5.1). Note that fully breast-fed infants are those that receive breast milk as the primary if not sole source of milk. Many infants receive only breast milk during the day with a bottle of formula during the night. These infants would fit into the category of "almost exclusively breast-fed." Older breast-fed infants who do not receive significant amounts of formula but do receive supplementary solid foods would fit into the category of “predominantly breast-fed.” Distributions of intake levels for fully breast-fed infants and for the entire infant population are derived later in this chapter.

A few further words about units and nomenclature are provided to avoid confusion. Dose in toxicology and pharmacology is often normalized to the body weight of an individual: The amount received over a day is divided by the body weight, typically provided in kilograms. The units are “mg/kg-day” or “g/kg-day.” Analogously, breast milk consumption can be expressed in terms of amount received by the infant divided by the infant’s body weight in kilograms per day, e.g., in units g/kg-day or kg/kg-day. For comparison purposes, arithmetic mean, or the “average,” and standard deviations for milk consumption reported in the published literature are also presented in this chapter. They are expressed here as “mean ± standard deviation.” We calculate from raw data skewness as $n \sum_{i=1}^{n} [(x_i - x)/s]^3 / ((n-1)(n-2))$ and standard error as $s/\sqrt{n}$, where s is the standard deviation and n the size of the sample.

5.1.2 Existing Guidance and Reports

In the *Revised 1992 Risk Assessment Guidelines* of the California Air Pollution Control Officers Association (CAPCOA, 1993, p. E-II-20-21), breast milk intake is addressed via the food ingestion pathway. The formula presented for calculating lifetime exposure to a contaminant via human milk ingestion is

$$\text{Dose-Im} = \text{Cm} \times \text{BMI} \times \text{F} \times \text{YR} / (25{,}550 \times \text{ABW}). \qquad \text{(Eq. 5-1)}$$

Dose-Im is the dose averaged over the lifetime, expressed in units in mg/kg-day. Cm is the concentration of the contaminant in breast milk, which when not known is derived by taking into account the half-life of the compound in the body, the fraction partitioned to lipid, and other factors. BMI is the daily breast milk ingestion rate in kg/day, with a default estimate of 0.9 kg/day taken from Whitehead and Paul (1981) and Butte *et al.* (1984a). F is the frequency of intake in days per year with a CAPCOA default value of 365. YR is the breast-feeding period, with a default value of 1 year. ABW is the average infant body weight with a default value of 6.5 kg. The number 25,550 in the divisor is the number of days in a 70 year lifetime.

Smith (1987) provides a formula for calculating the concentration of highly lipophilic dioxins in breast milk from doses received by the mother. This formula is consistent with observations of partitioning of dioxins and furans among body tissues, and of breast milk lipid and maternal tissue levels, as discussed in Smith (1987).

$$\text{Cm} = \text{Emi} \times t_{1/2} \times f_1 \times f_3 / (0.693 f_2) \qquad \text{(Eq. 5-2)}$$

where:
- Emi = average maternal intake of contaminants from all routes
- $t_{1/2}$ = half-life of contaminant in mother
- f_1 = fraction of contaminant that is stored in maternal fat, 0.8
- f_3 = fraction of breast milk that is fat, 0.04
- f_2 = fraction of mother’s weight that is fat, 0.3

The values for f_1, f_2, f_3 were taken from Smith (1987). This approach has been adopted by CAPCOA which used similar values for f_1, f_2, f_3. An additional factor can be added to take into account absorption of the contaminant from ingested milk.

Under the CAPCOA model, the mother is assumed to give birth to the child at age 25. The mother's intake (Emi) from birth to age 25 is therefore used to calculate concentration in the milk. Obviously, maternal age at parturition varies considerably. The point estimate of 25 years was used as a representative age at parturition in the CAPCOA approach. It is noteworthy that in 1994 over 35% of births recorded in California were to women 30 years of age or older and over 12% were to women 35 years old or over (California Department of Health Services, 1996). Maternal age is an important consideration because older primiparous women have accumulated more environmental contaminants and thus have a greater Emi (see Section 5.5.2).

The DRAFT *Parameter Values and Ranges for CALTOX* developed by the California Department of Toxic Substances Control (DTSC, 1993) assumes a breast milk ingestion rate for infants up to 12 months of age of 0.11 kg/kg-day, with a coefficient of variation of 0.2. The central estimate is equivalent to 0.7 kg/day for infants weighing 6.5 kg.

The U.S. EPA (1989) *Exposure Factors Handbook* does not explicitly address exposures via the breast milk pathway. A recent update of the Handbook (U.S. EPA, 1997) developed by the U.S. EPA National Center for Environmental Assessment provides an extensive discussion of this pathway and recommends values for breast milk intake, lipid intake rate and lipid content. For breast milk intake, mean rates of 730 ml/day for infants under 6 months, and 678 ml/day for infants under 1 year of age have been recommended. These figures are the time weighted averages from 5 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). Upper-percentile rates of 1029 ml/day for infants aged 1-6 months, and 1022 ml/day for 12 months of age were also recommended. The upper percentiles were characterized as the "mean plus 2 standard deviations." These estimates can be converted from ml to grams of breast milk by multiplying by 1.03.

The *Exposure Factors Handbook* (U.S. EPA, 1997) also recommended values for intake rates of lipids in breast milk. Values for infants under one year were based on data of Butte *et al.* (1984a) and the analysis of the Dewey *et al.* (1991a) study by Maxwell and Burmaster (1993). A lipid intake of 26 ml/day was recommended, with an upper percentile value of 40.4 ml/day ("based on the mean plus 2 standard deviations"). A value of 4% was recommended for breast milk lipid content based on data of the National Research Council (1991), Butte *et al.* (1984a), and Maxwell and Burmaster (1993).

The American Industrial Health Council (AIHC, 1994) does not address the breast milk exposure pathway in its *Exposure Factors Sourcebook*.

A detailed analysis of the breast milk pathway, which addressed several of the key factors contributing to variable intakes among individual infants, was published by Maxwell and

Burmaster (1993). These researchers estimated a distribution of lipid intake from breast milk ingested by children under one year of age. They report that, at any given time, "approximately 22% of infants under one year of age are being breast-fed, 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 breast-fed 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).

The Maxwell and Burmaster study represents a careful distributional analysis of breast milk intake. There are, however, some features that limit its usefulness for evaluations of acute and chronic exposure of breast-fed 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 breast-feeding population are made for the fraction of current feeders on any given day rather than the fraction of infants who breast-fed at any time during their first year of life. For chronic exposure analyses it is important to consider the current in addition to prior intakes of individual infants. Finally, there are now data on breast-feeding in the Pacific states (U.S. census region) which appear to be more representative of the Californian population than the national figures used by Maxwell and Burmaster (1993).

For the point estimate approach, the basic CAPCOA algorithm (Eq. 5-3) is used to calculate chronic exposure. For the stochastic approach, the terms in the equation (Eq. 5-5) are altered to allow variation of breast milk intake as is discussed in Section 5.1.3. The chemicals to be analyzed in the breast milk exposure pathway are described in Appendix E and summarized in Table E.3. The algorithm for the point estimate approach to calculating dose via breast milk exposure is the same as that indicated by Equation 5-1, with the exception that breast milk ingestion rate is expressed as grams consumed per kilogram of infant body weight, instead of kg consumed.

Under the default assumptions, the infant consumes breast milk daily until one year of age at which point the infant is considered weaned. Exposure continues throughout life, which is assumed to end at age 70, the default life expectancy. Thus lifetime average daily dose from the breast milk pathway is given by

$$Dose_m = Cm \times BMI_{bw} / 70 \qquad \text{(Eq. 5-3)}$$

where $Dose_m$ = lifetime average dose received from contaminated breast milk
Cm = concentration of contaminant in breast milk, calculated as in Eq. 5-2.
BMI_{bw} = breast milk ingestion rate during the first year of life, in g/kg-day

The value of 70 in the divisor represents the assumed 70 year lifespan.

For acute and subchronic exposures, daily dose is given by:

$$Dose_m = Cm \times BMI_{bw} \quad \text{(Eq. 5-4)}$$

5.1.3 Conceptual Framework for Considering Variable Breast Milk Consumption Rate

Building on the work of the U.S. EPA (1995) and Maxwell and Burmaster (1993), we use a stochastic approach to evaluate parameters related to contaminant intake via the breast milk pathway. Intake distributions are derived for nursing infants as well as the entire infant population in California. The following issues are addressed: 1) variable breast milk intake among individuals; 2) correlation of intake with the infant's body weight (*e.g.*, large babies consume greater amounts of milk than small ones); 3) variable consumption rate over the breast-feeding period; 4) fraction of the infant population nursing at different ages; and 5) frequency of breast-feeding in the Pacific states.

Variability in intake is explicitly addressed through the distributional approach. To account for the correlation of intake and body weight, consumption is evaluated in terms of amount consumed per body weight, and studies where both breast milk consumption and body weight were reported for each individual were used in evaluating the parameter. Variable intake with time can be addressed by allowing consumption to be a function of time, and assessing the impact of different ways of averaging over time on estimates of consumption.

Average dose ($Dose_m$) received via the breast milk pathway of an agent at concentration Cm in mother's milk can be expressed as:

$$Dose_m = \int_0^{T_b} [Cm(t) \times BMI_{bw}(t)]\, dt \,/\, AT, \quad \text{(Eq. 5-5)}$$

where AT is the averaging time period and T_b is the age at weaning. $BMI_{bw}(t)$ is the consumption rate of milk in amount ingested per body weight per day (*e.g.*, g/kg-day). If lipid intake is of interest, the lipid concentration in mother's milk is inserted for Cm(t), lipid intake is inserted for $BMI_{bw}(t)$.

Concentration in mother's milk (Cm) is also affected by parity and maternal age. Although not taken into account in the above equations, it is should be noted that Cm will be greater for the first child compared to the second child and so on since lactation is the predominant mode of elimination of many highly lipophilic contaminants. Similarly, Cm will be greater in older mothers due to a longer period of maternal accumulation. We note that the initiation of breast-feeding in older mothers is higher than in other age groups and that the duration of breast-feeding is generally longer for infants of older mothers (see Section 5.5.2).

With respect to the term T_b in Eq. 5-5, Maxwell and Burmaster (1993) found that the 1989 national figures for the fraction of infants breast-feeding (f) was well described by a negative exponential (e.g., $f = a\,e^{-c\,t}$). We have found that this also holds for the most recent

(1995) data for the Pacific states region. The Pacific states data are used to describe the population distribution for T_b, (Section 5.3) and together with the information on variable intake in breast-feeding infants at different ages, to describe the distribution of milk and lipid intake over the entire infant population (Section 5.3.2).

5.2 Breast Milk Consumption Among Breast-feeding Infants

5.2.1 Literature Review and Evaluation of Breast Milk Consumption Studies

Breast milk intake studies were identified through computerized literature searches, references found in articles reviewed, and references from personal communications with researchers. The criteria used to identify studies for review were: 1) the use of 24-hour test weighings to measure milk intake (see below); 2) the analysis of primary data (*i.e.*, not review articles) and 3) the consumption of milk directly from the breast. The following studies were identified for review: Pao *et al.* (1980); Whitehead and Paul (1981); Hofvander *et al.* (1982); Dewey and Lonnerdal (1983); Butte *et al.* (1984a); Kohler *et al.* (1984); Salmenpera *et al.* (1985); Borschel *et al.* (1986); Matheny and Picciano (1986); Neville *et al.* (1988); Stuff and Nichols (1989); Dewey *et al.* (1991a; 1991b); Ferris *et al.* (1993) [referent group]; and Michaelson *et al.* (1994). In those studies that include reported health status of mothers and infants, 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. The studies are briefly described in Table 5.2 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.

Table 5.2 Studies of Breast Milk Intake

Study	Number of Infants*	Infant Age at Measurement and Study Population	Comments
Intake reported as amount per day:			
Pao *et al.* (1980)	22	1, 3, 6, 9 months. Southwestern Ohio. Predominantly white, middle class.	Summary results only. Exclusively and partially breast-fed infants. Weight provided separately. After 1 month of age few exclusively breast-fed infants.
Whitehead and Paul (1981)	48	1 - 8 months. Cambridge, England.	Summary results only. Exclusively and partially breast-fed infants.
Dewey and Lonnerdal (1983)	20	1 - 6 months. Davis, CA. University community.	Summary results only. Exclusively and almost exclusively breast-fed infants.
Kohler *et al.* (1984)	26	6, 14, 22, 26 weeks. Lund, Sweden. Suburban community.	Summary results only. Exclusively breast-fed infants.
Matheny & Picciano (1986)	50	2-16 weeks. Champaign-Urbana, Illinois.	Summary results only. Compilation of three studies from the same laboratory.
Neville *et al.* (1988)	13	Throughout 1st year. Denver, Colorado. Caucasian, mid- to upper-socioeconomic status.	Summary results only. Exclusively or almost exclusively breast-fed for at least 5 months and predominantly breast-fed until 12 months of age.
Intake reported on a body weight basis:			
Hofvander *et al.* (1982)	75	1, 2, 3 months (25 infants at each month). Uppsala, Sweden.	Individual data available. Exclusively breast-fed infants.
Butte *et al.* (1984a)	45	1, 2, 3, 4 months. Houston, Texas. Mostly Caucasian, mid- to upper- socioeconomic stratum; high educational status.	Summary results only. Exclusively and almost exclusively breast-fed infants.
Salmenpera *et al.* (1985)	31	4, 6, 9 and 10-12 months. Helsinki, Finland.	Summary results only. Exclusively breast-fed infants.
Borschel *et al.* (1986)	15	1, 2, 4, 6 months. Lafayette, Indiana. University community.	Summary results only. Breast-fed infants. Supplemental solid or liquid foods not reported.
Stuff and Nichols (1989)	45	16 - 36 weeks. Houston metropolitan area. Middle and upper income groups.	Data available on individual infants. Initially exclusively breast-fed; solid food introduced during identified time periods.
Dewey *et al.* (1991a; 1991b)	73	3, 6, 9, 12 months. Davis, California. Relatively high socioeconomic status. University community.	Data available on individual infants. Exclusively or almost exclusively breast-fed at least through 3 months and fully breast-fed through 12 months. Davis Area Research on Lactation, Infant Nutrition and Growth (DARLING study). Corrected for insensible water loss during nursing (e.g., evaporation).
Ferris *et al.* (1993)	10	7, 14, 42, 84 days. Connecticut; Massachusetts.	Data available on individual infants; exclusively and almost exclusively breast-fed infants of referent mothers in study comparing insulin-dependent, control and referent mothers.
Michaelsen *et al.* (1994)	60	2, 4, 9 months. Copenhagen, Denmark.	Summary results only. Exclusively and partially breast-fed infants. Corrected for insensible water loss.

* The value listed is that for the maximum number of mother-infant pairs in the study.

In reviewing and evaluating studies, several factors potentially affecting the accuracy of breast milk consumption estimates and their applicability to the general population were considered. These are outlined below.

5.2.1.1 Measurement of Volume of Breast Milk Consumed

In all reviewed studies, breast milk intake was measured by the test weighing method. Infants are weighed before and after breast-feeding for a given period of time (usually 24 hours) and the increases in weight from each feeding period are summed to give the total amount of milk consumed per day. The test weighing method has been consistently found to be reasonably accurate in measuring milk intake (Hofvander *et al.*, 1982; Neville *et al.*, 1988), with a small bias for underestimation. Validation studies by Brown *et al.* (1982) demonstrated that volumes obtained represent on average 95% of actual intake. Borschel *et al.* (1986) reported that intake measured by test weighing formula-fed infants was consistently lower than direct measurement (averaging 90% of direct measurement volume for 1, 2, 4 and 6 months). Some of the underestimation appears to be due to insensible water loss, described below.

5.2.1.2 Correlation with Age and Body Weight

Breast milk intake varies with age primarily due to changes in infant weight and to the addition of formula and/or solid foods to the infant's diet. One goal in selecting studies for analysis was to have adequate data on breast milk consumption at different ages during the first year of life.

Infant body weight is positively associated with breast milk intake. Dewey *et al.* (1991b) found a strong positive correlation between milk intake and infant weight at three months of age ($p<0.01$). Neville *et al.* (1988) reported that intake after the first month of age was significantly related to infant weight ($p<0.02$). Likewise, infant weights at 2, 6, 12 and 16 weeks of age were found to be significantly ($p<0.05$) correlated with breast milk intake by Matheny and Picciano (1986).

5.2.1.3 Insensible Water Loss

One source of underestimation in test weighing is the decrease in weight from insensible water loss (*e.g.,* evaporation losses). Insensible water loss during nursing leads to underestimates of milk intake of 1-5% (Brown *et al.*, 1982; Butte *et al.*, 1984a; Woolridge *et al.*, 1985; Dewey *et al.*, 1991b). In the articles reviewed on breast milk intake, a few investigators reported estimates for insensible water loss, while the majority did not. Dewey *et al.* (1991b) calculated insensible water loss to be 0.05 g/kg/min on average.

5.2.1.4 Effect of Maternal Factors on Breast Milk Intake

The correlations between breast milk intake and certain maternal factors (age, parity, pregnancy weight gain, weight, ideal weight, triceps skinfold, and weight change from one to three months postpartum) were investigated by Dewey *et al*. (1991b). No significant correlations were found.

5.2.2 Study Selection for Analysis of Milk Consumption Rates

5.2.2.1 Study Selection

The requirements for study selection were the fulfillment of the criteria for study review described in Section 5.2.1 above and the availability of intake data on a body weight and individual infant basis. Obtaining data for breast milk intake on an individual infant basis was also considered important because these data facilitate the exploration of methods to describe variability in milk consumption.

From the reviewed studies, primary investigators were contacted, where possible, to determine if data were available that met the above selection requirements. Data were obtained from Stuff and Nichols (1989); Dewey *et al.* (1991a; 1991b); Hofvander *et al.* (1982) and Ferris *et al.* (1993). Both Stuff and Nichols (1989) and Dewey *et al.* (1991a; 1991b) provided data on milk intake for infants three months or older. For data on infants aged 3 to 12 months, the Dewey *et al.* study was chosen because of the large sample size and because data were available through 12 months of age. The Stuff and Nichols (1989) dataset consisted of intake data beginning at 16 weeks with subgroups of infants introduced to solid foods at designated intervals and followed for an additional 12 weeks of breast-feeding. The Stuff and Nichols (1989) subgroup of infants breast-fed for the longest period breast-fed only through 36 weeks of age and consisted of only eight infants. The Dewey *et al.* study had the advantage that the data were from a California population.

For data on early infancy, the Hofvander *et al.* study was selected because it had a larger sample size (n = 25) compared to the referent group of healthy mothers in the Ferris *et al.* study (n = 10), and because the data were available for the first two months of life, a period for which there are no data in the Dewey *et al.* study. At the three-month age group, the Hofvander *et al.* study was not statistically different from the Dewey *et al.* study and both datasets were used for this age group in our analysis. The two selected studies are described further below.

5.2.2.2 Descriptions of Selected Studies

Dewey *et al*. (1991a; 1991b) measured breast milk intake, lipid concentration and body weight at 3, 6, 9 and 12 months of age in infants in the vicinity of Davis, California. This study, frequently referred to as the “DARLING” study (for Davis Area Research on Lactation, Infant Nutrition and Growth), measured breast milk consumption of infants whose mothers planned to breast-feed for at least 12 months and did not plan to introduce solid food before four months or feed more than 120 ml/day of other milk or formula throughout the first 12 months. Mothers who participated in the study were described as of relatively high socioeconomic and educational status. Mothers did not have any chronic illness and were not taking any medication on a regular basis. Infants were described as healthy and of normal gestational age and weight. Measurements were repeated on the same infants at different ages. For the first measurement at three months, intake of 73 mother-infant pairs was measured; at six months, 60 of the initial group were sampled; at nine months, 50 infants, and at 12 months, 42 infants. Dewey *et al.* also corrected milk intake for insensible water loss which they calculated to be 0.05 g/kg/min on average. This factor was multiplied by each infant's weight and by the total time of nursing for each infant. The product, in grams, was added to the milk intake measured during the test weighing period.

Hofvander *et al.* (1982) studied milk consumption in infants aged one, two, and three months. Milk intake of 75 infants (25 at each month) was measured. Measurements were not repeated at different ages on the same infant. The study was conducted in Uppsala, Sweden (an urban center). The mothers were recruited after discharge from the hospital after delivery on the condition that their infants were single born, full term, healthy and still exclusively breast-fed. No mothers refused participation in the study. The mothers in this study were described as "older and belonging to a higher socioeconomic group" than the mothers of bottle-fed infants who also participated in the study.

Each of these studies was also noted for practices which increased the accuracy of intake measurements. Dewey *et al.* calculated their 24-hour intake values from the average of a four-day test weighing period thus decreasing the effect of day-to-day intraindividual variability on the accuracy of the results. Additionally, the Dewey *et al.* study corrected for insensible water loss. For the Hofvander *et al.* study, there was minimal selection bias because all invited mothers agreed to participate in the study. Also, no auto correlation bias occurred because there were no repeated measurements. Although Hofvander *et al*. did not appear to correct for insensible water loss, the accuracy of test weighing was assessed by repeating the 24-hour test weighing procedure with selected mothers in the hospital two to five days after test weighing at home.

5.2.3 Data Analyses and Derivation of Distributions of Breast Milk Consumption Rate

Table 5.3 below presents summary statistics for breast milk intake from the Hofvander *et al.* (1982) and Dewey *et al.* (1991a; 1991b) studies for the different age groups. Raw data (g breast milk/day and individual infant body weight) provided by Dewey *et al.* were used to calculate consumption per infant body weight whereas the Hofvander data were supplied as consumption per infant body weight. The normal distribution described these data fairly well and fit much better than log normal distributions. Maxwell and Burmaster (1993) similarly found that the normal distribution best fit consumption in their analysis of amount consumed per day. Readers are referred to Maxwell and Burmaster (1993) for the demonstration and further discussion of the normality of the Dewey *et al.* (1991a and 1991b) breast milk intake data. Note the similarity in the Hofvander *et al.* and Dewey *et al.* data from the three-month age groups. The means are not statistically different, although the spread in the Hofvander *et al.* data for this age group is slightly greater than in the Dewey *et al.* data set.

Table 5.3 Breast Milk Consumption (g/kg-day) in Fully Breast-Fed Infants

Parameter	Approximate Age in Months						
	Hofvander et al. (1982)*			Dewey et al. (1991a)**			
	1	2	3	3	6	9	12
Mean	154	148	132	130	100	74	48
Standard Error	5.0	4.6	3.7	2.1	2.5	3.4	4.2
Median	157	146	129	131	102	75	44
Standard Deviation	24.8	22.9	18.3	18.1	19.2	24.2	27.4
Kurtosis	-0.099	0.515	-0.769	-0.23	-10^{-3}	-0.38	-0.11
Minimum	102	102	97.6	85.9	47.7	27.9	2.98
Maximum	202	199	162	174	134	128	120
Skewness	-0.42	0.50	0.03	-0.07	-0.36	-0.05	0.32
Sample size	25	25	25	73	60	50	42

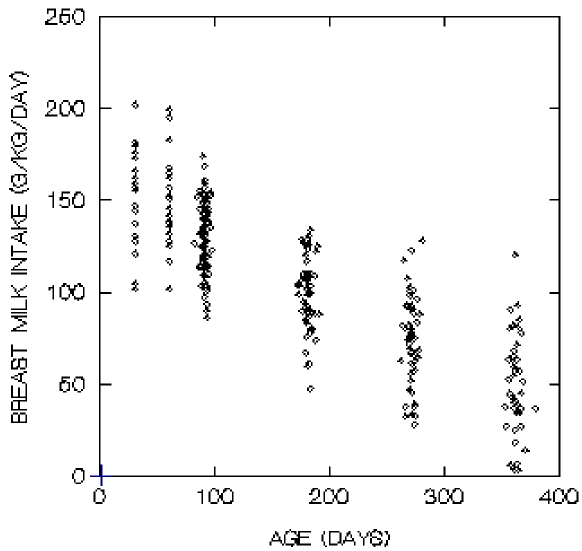
*Study conducted in Sweden measuring consumption in infants aged 30, 60, and 90 days.
**The DARLING study, conducted in Davis, California, measured consumption in infants approximately aged 3, 6, 9 and 12 months.

5.2.3.1 Statistical Description of Consumption as a Function of Age

Figure 5.1 presents the combined raw datasets of Dewey *et al.* (1991a) and Hofvander *et al.* (1982). There is 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) fairly consistent among the different age groups. There is an overall trend of decreasing consumption with increasing age, with daily intake greatest during the first month of life.

The relationship between milk consumption and age was explored in model fitting exercises. Ages in days were used in all of our calculations. The individual raw data from Dewey *et al.* (1991a; 1991b) gave the exact age of the infant for each milk intake measurement, and these pairs of age-intake data were used in fitting functions. The Hofvander *et al.* data were reported as measured at 30, 60 or 90 $\pm$ 7 days of age. For calculation purposes, it was assumed that infants in this study were exactly 30, 60, or 90 days of age when measurements were taken.

Figure 5.1 Breast Milk Intake by Age for Combined Dewey et al. (1991a) and Hofvander et al. (1982) Datasets.

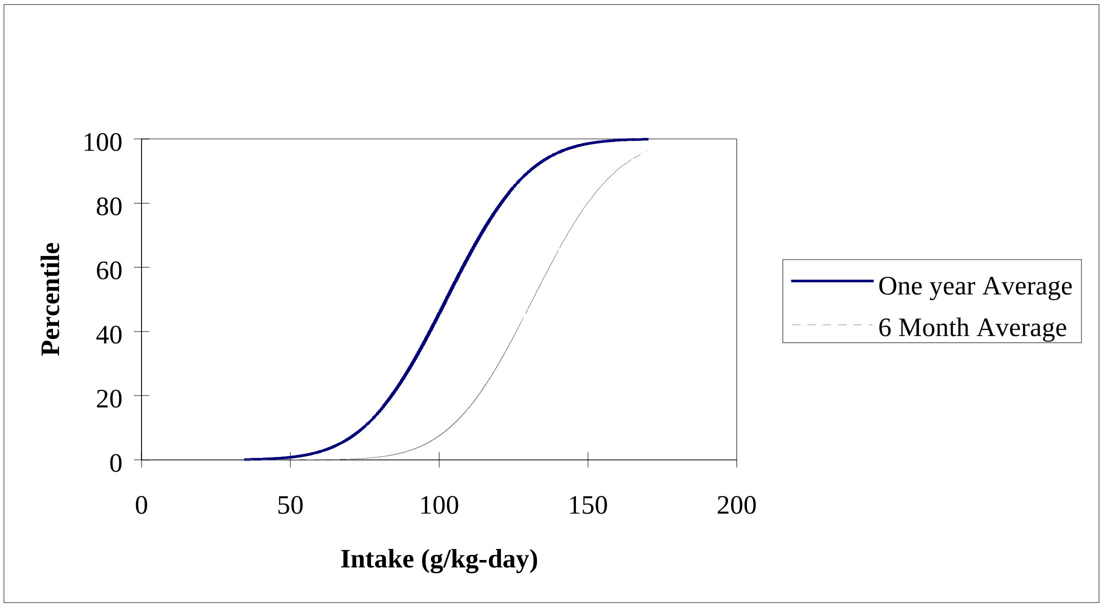


A linear relationship fits the age versus consumption rate data fairly well. From this combined data set, an intake averaged across breast-feeding infants during the first year of life is estimated to be 102.4 g/kg-day. Assuming a normal distribution of intake among the infants in this population (with 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 and graphically presented in Figure 5.2. 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 Distribution of daily breast milk intake (g/kg-day) for fully breast-fed infants during their first 6 months or year

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	95.5	103	109	113	116	120	123	131	140	143	146	150	154	159	167	182
12 months	66.5	74.3	79.7	84.1	87.7	90.9	94.0	102	111	114	117	121	125	130	138	153

Figure 5.2 Average Daily Breast Milk Intake for Fully Breast-fed Infants (Cumulative Distribution) from Hofvander et al. (1982) and Dewey et al. (1991a) Studies.



5.2.4 Comparison to Results Reported for Other Breast Milk Intake Studies

In Table 5.5, breast milk consumption in the Hofvander *et al.* and Dewey *et al.* studies is compared to consumption in studies of exclusively and almost exclusively breast-fed infants. Table 5.5 includes only studies for which data were available on a body weight basis (outlined in Table 5.2 above). While discussed below, results from Borschel *et al.* (1986) are omitted because infants in this study were not described as exclusively breast-fed. In the Ferris *et al.* study, infants were exclusively breast-fed at 42 days (n = 10) and almost exclusively breast-fed at 84 days (n = 10) (Neubauer *et al.*, 1993). Note that in Dewey *et al.* (1991a) three months was the only age at which all infants in this study were exclusively or almost exclusively breast-fed.

Table 5.5 Comparison of breast milk consumption values (g/kg-day) of Dewey et al. And Hofvander et al. to those for studies with exclusively or almost exclusively breast-fed infants [a]

Study	*Infant Age in Approximate Months*								
	1	*1.5*	*2*	*3*	*4*	*5*	*6*	*9*	*10-12*
Hofvander *et al.* (1982)	154 ± 25 (25)		148 ± 23 (25)	132 ± 18 (25)					
Dewey *et al.* (1991a)[a]				130 ± 18 (73)			100 ± 19[b] (60)	74 ± 24[b] (50)	48 ± 27 [b] (42)
Butte *et al.* (1984a)	159 ± 24 (37)		129 ± 19 (40)	117 ± 20 (37)	111 ± 17 (41)				
Salmenpera *et al.* (1985)[c]					125 ± 21 (12)		113 ± 17 (31)	108 ± 20 (16)	106 ± 19 (10)
Stuff and Nichols (1989)					114 ± 18 (45)	103 ± 22 (26)	107 ± 27 (8)		
Ferris *et al.* (1993) (referent group)		131 ± 22 (10)		112 ± 20 (10) [d]					
Michaelsen *et al.* (1994)			140 ± 24 (60)		124 ± 17 (36)				

[a] The number of mother-infant pairs is given in parentheses. Intakes are reported as arithmetic mean ± standard deviation.
[b] For age groups 6, 9, and 12 months the infants in the study by Dewey *et al.* were fully but not exclusively breast-fed.
[c] Salmenpera *et al.* (1985) reported values as ml/kg-day, which were converted to g/kg-day by OEHHA by multiplying by 1.03.
[d] Measurements were at 84 days infant age but categorized with the 3 month age group for comparison purposes.

Note that for the one-month age group, results of the Hofvander study are nearly identical to those of Butte *et al.* (1984a). They are also similar to other values for exclusively breast-fed infants during the first month reported in the literature. At 7 and 14 days, for the Ferris *et al.* (1993) referent group of healthy mother-infant pairs, intake was calculated as 148 ± 38 g/kg-day (n = 10) and 161 ± 42 g/kg-day (n = 9), respectively. Borschel *et al.* (1986) reported intake at one month as 158 ml/kg-day (163 g/kg-day) a time when it is likely that all infants in the study were exclusively or almost exclusively breast-fed. Comparisons could also be made with calculated estimates of average intake on an average body weight basis. Using group average intake and weights reported by Pao *et al.* (1980), an estimated intake per body weight is calculated as 177 g/kg-day at one month (n = 11). Using group average infant weight and intake reported by Kohler *et al.* (1984), an estimated intake of 160 g/kg-day at 6 weeks (n = 26) is calculated.

For the two-month age group, results from Hofvander *et al.* (1982) are consistent with those of Michaelsen *et al.* (1994) but somewhat higher than those reported by Butte *et al.* (1984a). Although eight infants in the Butte *et al.* study received one or more supplemental feedings, supplements for all but one appeared to be inconsequential. The degree, if any, to which these feedings affected summary results is not known. Borschel *et al.* (1986) reported intake at two months as 128 ± 7 ml/kg-day (132 ± 7 g/kg-day), but did not identify the 15 infants in this study as exclusively breast-fed or discuss supplemental feeding. However, nursing frequency was lower in this study compared to other reviewed studies (Butte *et al.*, 1984a; Dewey *et al.,* 1991b; Michaelsen *et al.,* 1994) which may suggest some supplementation with solid foods.

For the three month age group, results of the Hofvander *et al.* and Dewey *et al.* studies are somewhat higher than those for Butte *et al.* (1984a) and Ferris *et al.* (1993). Some of this difference may be explained by the fact that both of these latter studies included infants receiving small amounts from supplemental feedings at this age whereas infants in the Hofvander *et al.* and Dewey *et al.* studies were exclusively or almost exclusively breast-fed during this time.

It should be noted that only Dewey *et al.* (1991a; 1991b) and Michaelsen *et al.* (1994) corrected for insensible water loss which may explain their slightly higher reported consumption rates. A correction for insensible water loss would bring the data from Butte *et al.* (19984a) and Stuff and Nichols (1989) for the four-month age group in line with those of Michaelsen *et al.* (1994) but would correspondingly increase the values for the Salmenpera *et al.* study.

At six months, results of Salmenpera *et al.* (1985) are somewhat higher than those of Dewey *et al.* reflecting the fact that all infants in the Salmenpera *et al.* study were exclusively breast-fed, whereas at six months, none of the infants in the Dewey *et al.* study were exclusively breast-fed. At nine and twelve months, consumption rates differed markedly between the Salmenpera *et al.* and Dewey *et al.* studies. This difference reflects both solid food intake in the Dewey *et al.* study as well as that some infants in the Dewey *et al.* study were in the process of weaning.

5.2.5 Annual Average Intake for Exclusively versus Fully Breast-fed Infants

The analysis above produced a distribution of intake levels for fully breast-fed infants (defined in Section 5.1). Comparable estimates of intake levels for exclusively breast-fed infants can be derived from the Salmenpera *et al.* (1985) study (infants from 4 - 12 months of age) and the corresponding study of Hofvander *et al.* of infants from one to three months of age. Analysis of this combined dataset gives an estimated mean daily intake for exclusively breast-fed infants in their first year of life of 124 g/kg-day. Adjusting for insensible water loss results in an estimate of 130 g/kg-day, assuming 5% underestimation of milk intake from this source. These estimates are considerably greater than the rate of 102.4 g/kg-day obtained above for infants exclusively breast-fed through at least three months of age and receiving solid foods some time after three months (*i.e.,* from the combined Hofvander *et al.* and Dewey *et al.* dataset).

It should be noted that Salmenpera *et al.* (1985) reported a slower growth rate (in length) of exclusively breast-fed infants compared to infants who received complementary foods. The authors of this study could not determine whether the slower growth rate represented appropriate physiological growth or whether it indicated nutritional deficiency. Ahn and MacLean (1980) found that growth of exclusively breast-fed infants through the ninth month of life was comparable to the standard reference growth rates compiled by the National Center for Health Statistics.

5.2.6 Effect of Solid Food Introduction and Weaning on Estimates of Breast Milk Intake

The American Academy of Pediatrics regards breast-feeding as the optimal form of infant nutrition (American Academy of Pediatrics, 1982) and has recently changed their policy to recommend exclusive breast-feeding through the first six months of life, and the continuation of breast-feeding through at least 12 months of infant age with the introduction of solid foods in the second half of the first year of life (American Academy of Pediatrics, 1997).

The combined datasets used in this analysis describe breast milk consumption in exclusively breast-fed infants through at least three months and in infants breast-fed during the period of solid food introduction, some of whom continued to breast-feed through 12 months of age. In light of the new recommendations of the American Academy of Pediatrics, it would have been desirable to analyze data in which infants were exclusively breast-fed for the first six months (and introduced to solid foods in the latter half of the first year) since milk intake clearly decreases with the introduction of solid foods. However, no individual data for such infants were available. In Dewey *et al.* (1991a; 1991b), infants were introduced to solid foods some time after three months of age (mean 5.3 ± 1.1 months).

We calculated a mean breast milk intake value of 48 g/kg-day at 12 months from the Dewey *et al.* (1991a) study. Of the 42 infants in the study at this point, five consumed 6.5 g/kg-day or less with a minimum intake value at 2.98 g/kg-day. These infants can be considered "token breast feeders" (Table 5.1). Breast milk was not a significant source of nutrients or calories for these infants, and represented less than 5% of the RDA for this age infant. While there is a considerable range in intake for the other infants in this study (13.9 - 120.3 g/kg-day) who may have been in the process of weaning, these five infants appear to be essentially weaned and breast-fed solely for comfort. Also, the inclusion criteria for the Dewey *et al.* study (less than 120 ml/day of other milk) could not have been met for these five infants at 12 months. The marked decline in breast milk intake at 12 months (48 g/kg-day) is at least in part due to the inclusion of token breast-feeders in the analysis.

5.2.7 Representativeness of Estimates of Breast Milk Consumption

The mother/infant pairs included in our dataset were predominantly white, well-nourished and of relatively high socioeconomic and educational status, and therefore do not represent a cross-section of Californians. However, breast milk volume appears to be similar among all women except those who are severely malnourished as discussed below.

Breast milk production was found to be lower among poorly nourished mothers in underdeveloped countries (Jelliffe and Jelliffe, 1978; World Health Organization (WHO), 1985). But others have reported that milk intake in industrialized countries is similar to that of developing countries (Brown *et al.*, 1986; National Research Council, 1991). In their review of the literature, Ahn and MacLean (1980) concluded that "methodological difficulties resulted in conflicting information" but that studies generally agreed "that the milk output of mothers in both environments is comparable, except in populations of markedly undernourished women."

In most cases, volume of breast milk ingested is considerably less than the mother's potential supply (WHO, 1985).

Lower breast milk consumption reported by Jelliffe and others may actually reflect lower birth weights of infants in developing countries (Whitehead and Paul, 1981; Brown *et al.*, 1986). Brown *et al.* (1986) reported that while the absolute amount of milk produced appeared to be lower in marginally nourished Bangladeshi mothers, breast milk consumption relative to infant body weight was actually slightly greater than in exclusively breast-fed North American infants.

5.3 Breast Milk Consumption in the General Population

The distribution of breast milk intake for fully breast-fed infants derived above (see Figure 5.2; Table 5.4) can be used with data on breast-feeding duration to derive a distribution of breast milk intake for the general population (i.e., including infants who were never breast-fed). Data on the duration of breast-feeding, provided by Ross Products Division of Abbott Laboratories, are discussed below. These data were used to derive the distribution of breast milk consumption among the entire infant population (Section 5.3.2).

5.3.1 Duration of Breast-Feeding

The majority of American newborns are breast-fed. The Ross Mothers' Survey (1996), an annual nationwide mail survey, reported that in 1995, 59.7 % of newborns were breast-fed in-hospital nationwide and 21.6% of infants were breast-fed at six months of age. The survey has consistently found that the percent of mothers breast-feeding in the United States varies considerably with geographic region. The highest rates of breast-feeding are in the Mountain and Pacific states (U.S. census regions). In the Pacific states in 1995, 75.1% of newborns were breast-fed in-hospital, and 30.9% of infants were breast-fed at 6 months (Ross Products Division, Abbott Laboratories, 1996).

The Mothers' Survey, conducted by Ross Products Division of Abbott Laboratories (1996), is based on recall and is mailed to new mothers at the time that their infants are six months of age. Mothers are asked to recall whether they had breast-fed during month six and in the five previous months including in-hospital (i.e., during their hospital stay following delivery). In the 1995 survey, questionnaires were mailed to approximately 725,000 new mothers with a response rate of approximately 50%. Rates of breast-feeding reported in the Ross Mothers' Survey are consistent with rates reported in the National Surveys of Family Growth (Ryan *et al.*, 1991).

Additionally, Ross Products Division mails questionnaires to mothers when their infants are 12 months of age. As in the six-month survey, mothers are asked to recall whether they had breast-fed during month 12 and in the five previous months. The mothers who respond to the survey at 12 months are not necessarily the same mothers who respond at 6 months (personal communication, Ross Products Division, Abbott Laboratories).

In Table 5.6 below, data for the Pacific states from the 1995 surveys at 6 and 12 months of infant age are combined to show the percentage of infants being breast-fed from birth through

12 months (also shown in Figure 5.5). We note the discrepancy between months 6 and 7 which may, in part, be due to different mothers responding to the survey at 6 and 12 months and to difficulties in recalling earlier breast-feeding practices.

Table 5.6 Percentage of All Mothers Breast-feeding in 1995 by Age of Infant (Ages 0-12 months) in the Pacific Census Region*

Age	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Percentage	75.1	64.8	56.5	47.8	40.0	34.9	30.9	32.1	23.9	21.0	18.7	16.2	13.7

*Data provided by Ross Products Division, Abbott Laboratories. 1996.

In addition to geographic differences, breast-feeding patterns vary considerably with maternal age and education, race/ethnicity, and economic status (National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996). The initiation and duration of breast-feeding in all of these categories has steadily increased over the last five years. The increase has been most noteworthy among groups who have traditionally had the lowest prevalence of breast-feeding. We discuss these increases, in both initiation and duration, in Section 5.5 below.

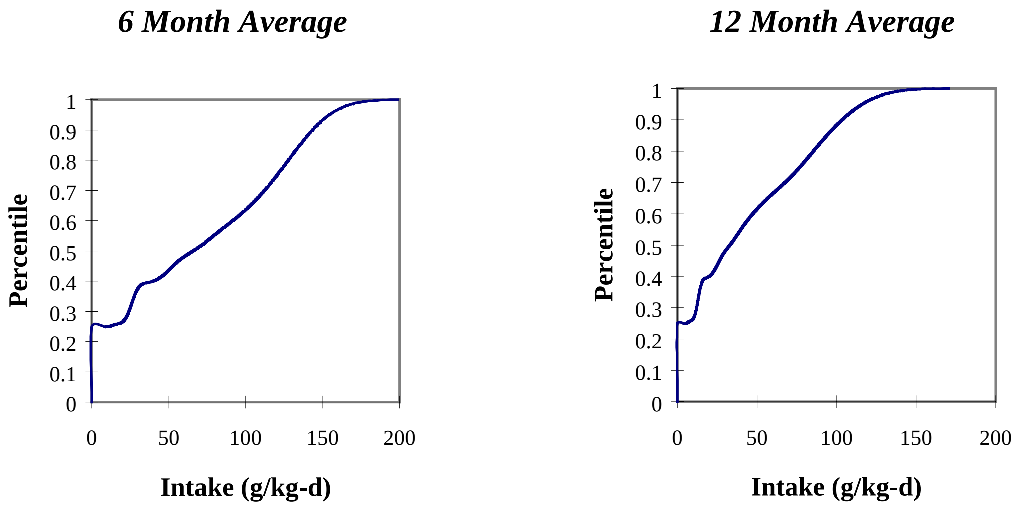
5.3.2 Distribution of Breast Milk Intake Among the Entire Infant Population

The data on intake of fully breast-fed infants and duration of breast-feeding in the Pacific states (Table 5.6) are used to derive distributions of breast milk intake among the entire infant population (breast-fed and never breast-fed infants) (Table 5.7 and Figure 5.3). In deriving risk estimates, the data in Table 5.7 are only to be used to assess risk (e.g., cancer burden) from the breast milk pathway spread over the entire (breast-fed and never breast-fed) infant population. It is to be noted that the distribution includes infants never exposed (i.e., never breast-fed) and therefore not contributing to the overall population risk. The arithmetic mean of this distribution is 43 g/kg-day for the first 12 months, and 69 g/kg-day for the first six months. Note that this distribution is not assumed to be normal and thus the means differ from the values for the 50th percentile shown in Table 5.7.

Table 5.7 Distribution for daily breast milk intake (g/kg-day) averaged over the first 6 months and 12 months of life for the general infant population (All infants, including never breast-fed)

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	0	0	0	0	11	24	28	66	103	112	120	128	135	143	154	173
12 months	0	0	0	0	5.6	12	14	33	57	68	77	86	94	103	116	137

Figure 5.3 ***Cumulative distributions for breast milk intake - All infants including never breast-fed - Average intake during 6 and 12 months***



5.4 Lipid Concentration and Distribution of Lipid Intake

5.4.1 Lipid Content of Breast Milk

Many agents of concern in breast milk are delivered primarily via the constituent breast milk lipid. The lipid composition of breast milk varies among individuals. Some researchers have reported monthly increases in breast milk lipid during the breast-feeding 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 5.8.

Table 5.8 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.

Inter- and intraindividual variation of lipid content over time should be considered when evaluating lipid intake for the infant population. For this report, the average lipid content of breast milk is assumed to be 4%.

5.4.2 Distribution of Lipid Intake

Under the assumption that 4% of breast milk is lipid, distributions for lipid intake are generated and tabulated below. Mean lipid intake for the fully breast-fed population during their first year of life is estimated to be 4.1 g/kg-day, with a standard deviation of 0.87 g/kg-day.

Table 5.9 Daily lipid intake (g/kg-day) via breast milk averaged over the first 6 or 12 months of life

Fully breast-fed infants

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	3.8	4.1	4.4	4.5	4.7	4.8	4.9	5.3	5.6	5.7	5.8	6.0	6.2	6.4	6.7	7.3
12 months	2.7	3.0	3.2	3.4	3.5	3.6	3.8	4.1	4.4	4.6	4.7	4.8	5.0	6.5	5.5	6.1

General population, including never breast-fed

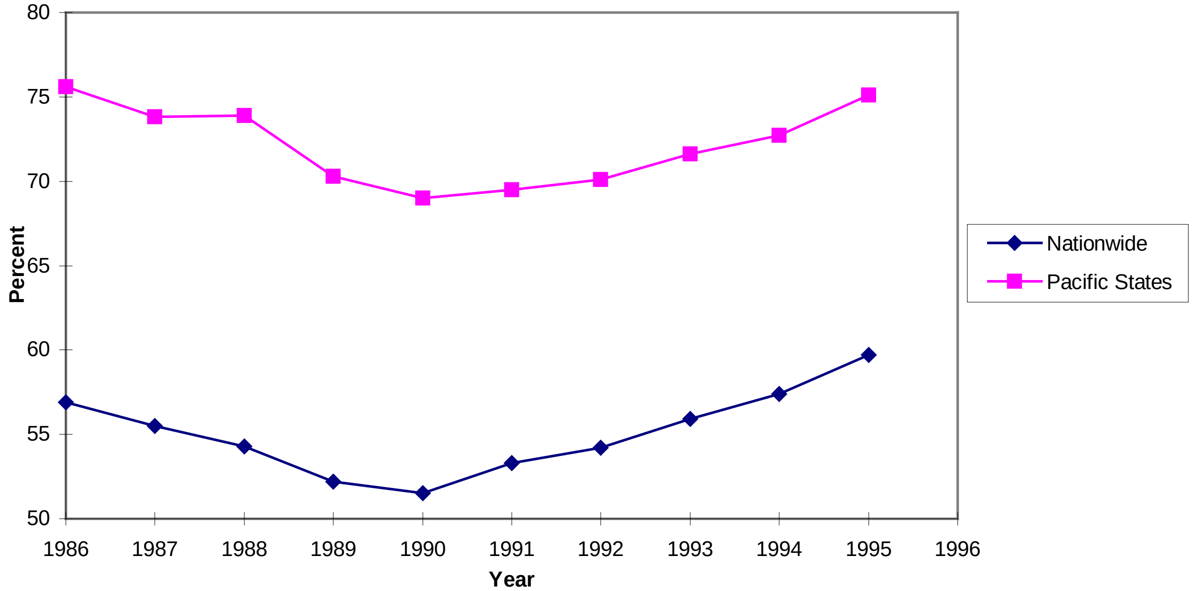
Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	0	0	0	0	0.4	1.0	1.1	2.6	4.1	4.5	4.8	5.1	5.4	5.7	6.2	6.9
12 months	0	0	0	0	0.2	0.5	0.6	1.3	2.3	2.7	3.1	3.4	3.8	4.1	4.6	5.5

5.5 Concluding Remarks

5.5.1 Trends in Breast-feeding

The number of mothers nationwide who initiated breast-feeding after hospital delivery steadily increased from 1991 to 1995 after a decline in breast-feeding from 1985-1990 (Ross Products Division, Abbott Laboratories, 1996). In 1995, the percent of mothers breast-feeding in-hospital (59.7%) was the same as in 1984, the peak year of a 13 year period of growth in the prevalence of breast-feeding. Increases in breast-feeding in the Pacific States parallel the nationwide trend. Figure 5.4 below shows the trend of mothers breast-feeding in hospitals nationwide and in the Pacific region for 1986-1995 (Ross Products Division, Abbott Laboratories, 1994, 1996).

Figure 5.4 Percentage of Mothers Breast-feeding in the Hospital After Infant Birth Nationwide and in the Pacific Region (1986-1995)



The percent of infants being breast-fed at 5-6 months of age similarly increased from 1991 to 1995. In 1995, 23.2% of infants were breast-fed at 5-6 months of age nationwide compared to 17.6% in 1990. A similar increase in duration was observed in the Pacific States. Table 5.10 details the initiation and duration of breast-feeding in the Pacific States by race/ethnicity for the years 1989 and 1995. While initiation and duration of breast-feeding has increased for all infants, the greatest increases are among African-American and Hispanic women, populations where breast-feeding rates have been the lowest.

Table 5.10 Percent of Breast-fed Infants of Different Ages in the Pacific Census Region by Race/Ethnicity

Population	***Infant Age (in months)***								
	1989 Survey[a]		***1995 Survey[b]***						
	0	***5-6***	***0***	***1***	***2***	***3***	***4***	***5***	***6***
All infants	70.3	28.7	75.1	64.8	56.5	47.8	40.0	34.9	30.9
Caucasian	76.7	33.4	80.4	70.0	62.0	53.1	45.1	39.5	35.4
Asian	--	--	74.7	66.8	57.7	47.5	39.4	33.8	29.5
Hispanic	58.5	19.7	67.9	56.6	47.6	39.4	32.3	28.0	24.4
African-American	43.9	15.0	59.1	50.9	43.2	35.5	28.8	24.3	21.4

[a] From National Research Council (1991).

[b] From Ross Products Division, Abbott Laboratories, personal communication, 1996.

Education and socioeconomic status have also been correlated with both initiation and duration of breast-feeding (National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996**)**. The 1995 Mothers' Survey (Ross Products Division, Abbott Laboratories, 1996) found that the largest increases in breast-feeding were among low-income, poorly educated women.

Because there are trends towards increases in breast-feeding, prevalence and duration of breast-feeding should be re-evaluated periodically.

5.5.2 Subpopulations of Special Concern

5.5.2.1 Infants Breast-fed for an Extended Period of Time

Although most infants in the United States are weaned during the first year, there is a population of infants who are breast-fed for an extended period of time. Sugarman and Kendall-Tackett (1995) found that among a group of American women (n = 179) who practiced extended breast-feeding, the age of weaning averaged between 2 1/2 and 3 years, with a high end value of 7 years 4 months. Forty-three percent of children in this sample were breast-fed beyond their third birthday. For this subpopulation of infants, exposure to environmental toxicants via breast milk would be greater than for infants with breast-feeding patterns similar to those studied in Dewey *et al.* (1991a; 1991b).

Documentation of extended breast-feeding is quite limited in this country both because there is little socio-cultural support for extended nursing and because many health care practitioners do not consider asking about it (Sugarman and Kendall-Tackett, 1995). However, recent increases in the duration of breast-feeding as well as efforts by public agencies and the American Academy of Pediatrics to promote and support breast-feeding (Section 5.53) would suggest that the numbers of infants being breast-fed beyond the first year of life may be increasing as well.

Exposures to infants who are breast-fed for an extended period of time should be further investigated and in some circumstances taken into account in non-default analyses.

5.5.2.2 Infants of Older Mothers

The Ross Mothers Survey found that both initiation and duration of breast-feeding increased with maternal age (Ross Products Division, Abbott Laboratories, 1996). In the 1995 nationwide survey, 52.6% of mothers ages 20-24 initiated breast-feeding in the hospital, and 15.8% were breast-feeding at 5-6 months of age. In comparison, 68.1% of mothers 30-34 years of age initiated breast-feeding in the hospital and 31.1% were breast-feeding at 5-6 months postpartum. Among mothers 35 years of age and older, 70% initiated breast-feeding and 35.8% were breast-feeding at 5-6 months postpartum (Ross Products Division, Abbott Laboratories, 1996). No data are available for the Pacific States, but it is likely that for each of these age groups, increases in initiation and duration reflect differences in breast-feeding rates between the Pacific States and the U.S. nationwide (shown below in Figure 5.6).

Older primiparous mothers have accumulated greater quantities of highly lipophilic, poorly metabolized toxicants in adipose tissue than younger mothers. During the breast-feeding period, infants of older primiparous mothers will receive greater daily doses of these contaminants from breast milk than infants of younger mothers. Furthermore, because older mothers tend to breast-feed for a longer duration than younger mothers (as noted in the paragraph above), their infants may receive much greater quantities of these environmental toxicants than infants of younger mothers.

There are increasing trends towards older women giving birth. In California, 35% of births recorded in 1994 were to women 30 years of age or older and over 12% were to women 35 years or older (California Department of Health Services, 1996). Thus, it is important to consider maternal age in assessing infant exposure to highly lipophilic, poorly metabolized contaminants.

5.5.2.3 Estimates for High-end Consumption

Under certain circumstances, information on the number of individuals exposed at various levels is of interest. For assessing large population exposures, Table 5.11 may be of use. It indicates the number of infants in California consuming at upper end breast milk and lipid intake levels.

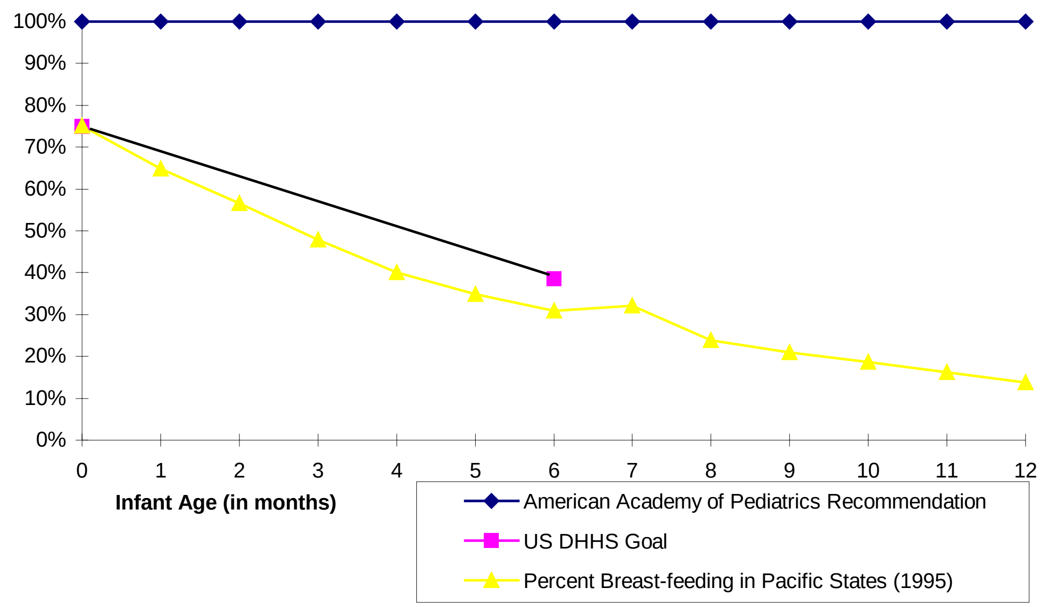
Table 5.11 Intake estimates for the general infant population in California

Number of infants at equivalent or greater intake	***Lipid Intake (g/kg-day)***		***Breast Milk Intake (g/kg-day)***	
	6 month average	***1 year average***	***6 month average***	***1 year average***
6,140 (99th percentile)	6.9	5.5	173	137
615 (99.9th percentile)	7.7	6.4	192	161

5.5.3 Promotion of Breast-feeding

Increases in the percent of mothers breast-feeding and in the duration of breast-feeding may partially result from recent efforts in the public health community to encourage breast-feeding. In 1984, the U.S. Surgeon General set a nationwide goal for increasing the initiation and duration of breast-feeding to 75% at the time of hospital discharge and to 35% at 6 months postpartum by the year 1990. The importance of breast-feeding was incorporated into the U.S. Department of Health and Human Services “Healthy People 2000” Program, which set a nationwide goal of increasing the initiation of breast-feeding to 75% in the early postpartum period and to 50% the proportion of mothers who continue breast-feeding their babies through five to six months of age. Most recently, the American Academy of Pediatrics (1997) has issued a new policy statement on breast-feeding in which it recommends exclusive breast-feeding for six months and continuation of breast-feeding through at least the first year of life. These goals and recommendations are shown in Figure 5.6 along with the prevalence of breast-feeding during the first 12 months of life in the Pacific States.

Figure 5.5 Percent Breast-feeding in Pacific states (1995) Compared to "Healthy People 2000" Program Nationwide Goal and Recommendation of the American Academy of Pediatrics.



Efforts have also been underway to change certain hospital practices that impede successful breast-feeding. Some of the practices associated with lower rates of breast-feeding include the separation of mother and infant, delays in getting the infant to the breast, and the provision of formula both in the hospital and in discharge packs (Wright *et al.*, 1996). In 1991, the World Health Organization and the United Nations Children's Fund launched the Baby-Friendly Hospital Initiative (BFHI), a ten step program to promote breast-feeding by changing hospital practices. Although the BFHI was immediately supported internationally, implementation of the program has been slower within the United States. As of 1995, over 200 U.S. hospitals had filed intents to be designated as "baby friendly" and other less formal efforts were underway at hospitals throughout the country (Wright *et al.*, 1996).

The effect of the BFHI on breast-feeding outcomes and its acceptance (both by means of certification and informal programs) in American hospitals will probably be documented in the next few years. Other programs to promote breast-feeding have also been initiated in recent years. Cohen and Mrteck (1994) reported that in a workplace program that provided lactation rooms for working women, these mothers breast-fed as long as non-working mothers. These efforts to support breast-feeding may also help to make breast-feeding more socially and culturally acceptable. Morse and Harrison (1987) found that among women who are successfully breast-feeding, it is the attitude of others which determines time of weaning, an attitude that they refer to as the "social coercion for weaning".

The 1997 American Academy of Pediatrics policy statement also delineates various ways in which the pediatric community can promote and encourage breast-feeding. These recommendations will likely result in more mothers breast-feeding and in greater numbers of mothers breast-feeding for longer time periods. Active support for breast-feeding by pediatricians, combined with the hospital and workplace programs discussed above, may significantly increase both the initiation and duration of breast-feeding.

5.5.4 Conclusion

Breast-feeding is an important indirect pathway of exposure for environmental contaminants, particularly persistent lipophilic chemicals. Significantly larger quantities of lipophilic environmental contaminants stored in maternal adipose tissue are delivered to breast-fed infants compared to non-breast-fed infants. For these reasons risks through breast milk consumption should be considered carefully when evaluating the risks from environmental releases of persistent, lipophilic toxicants. This chapter provides a framework and the values needed for estimating the range of exposures to such pollutants for breast-feeding infants and the general infant population.

The benefits of breast-feeding are becoming 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 milk contaminant exposures. It is also a public health goal to minimize the risk and to understand the magnitude of the risk. Because the patterns of breast-feeding are changing, the duration of breast-feeding and intake of breast milk at different ages should be re-evaluated periodically to ensure a sound basis for such calculations.

5.6 Recommendations

OEHHA recommends the following to estimate dose through breast milk.

5.6.1 Default Point Estimate for Daily Breast Milk Consumption During the First Year

As the default number for the point estimate approach to assessing dose and risk from breast milk consumption by breast-fed infants during the first year, use the mean and high-end estimates presented in Table 5.12 for fully breast-fed infants with Equation 5-3. Dose and risk evaluated using the high-end estimate should be presented if breast milk is a dominant pathway of exposure (see Chapter 1 for discussion of dominant pathways). Note that the intake rate for breast milk already incorporates body weight which is in the denominator of Eq. 5-1.

Table 5.12 Point estimates of breast milk intake for breast-fed infants

Infant Group	*Intake (g/kg-day)*
Fully breast-fed	
mean	102
95th percentile	138
Exclusively breast-fed	
During first year	
mean	127
95th percentile	161
During first 6 months	
mean	140
95th percentile	174
During first month	
mean	154
95th percentile	195

If the risk assessor wishes to calculate a point estimate for the cancer burden, which would include non-consumers, the intake distribution for the general population of infants, given in Table 5.7, might be of interest. The mean and upper 95^{th} percentile for daily intake during the first year for the general population are 43 and 116 g/kg-day, respectively. Average daily intake over the first six months (for consumers and non-consumers combined) is 69 g/kg-day; intake at the 95th percentile is 154 g/kg-day. Note that this distribution is not assumed to be normal and thus the means differ from the values for the 50^{th} percentile shown in Table 5.7.

5.6.2 Breast Milk Consumption Among Individuals during the First Year of Life

For a stochastic analysis of exposure and dose through the breast milk consumption pathway, use Equation 5-5 varying the breast milk intake rate. Use Table 5.13, or a normal distribution with mean 102.4 g/kg-day and standard deviation 21.82 g/kg-day, to characterize breast milk intake over the first year of life for breast-fed infants. With concentration information and weighting factors, this intake can be used to predict exposure and individual cancer risk for breast-fed infants. Note that the distribution incorporates body weight (the units are g/kg-day) and therefore the BW variate in the denominator of Eq. 5-1 is already taken into account.

Table 5.13 Recommended Breast Milk Consumption Among Individuals (Averaged Over an Individuals First Year of Life)

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
Intake (g/kg-day)	66.5	74.3	79.7	84.1	87.7	90.9	94.0	102	111	114	117	121	125	130	138	153

5.6.3 Consideration of Variable Age of Breast-feeding Mothers

Because accumulation of environmental toxicants is far greater in older primiparous mothers than in younger mothers, distribution of the age of breast-feeding mothers should be considered by OEHHA for incorporation with the breast milk consumption rate distributions.

5.6.4 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 breast-fed at various ages. The information on Pacific states (U.S. census region) data from Ross Products is useful for this purpose. This information has been incorporated to derive a distribution of breast milk intake for the general infant population, in Table 5.7. This information can be used as appropriate to analyze population-wide impacts of exposure via the breast milk pathway. It should be re-evaluated periodically to take into account recent trends in breast-feeding and the outcome of the breast-feeding promotion policies of the last decade.

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6. Dermal Exposure Assessment

6.1 Introduction

Uptake of chemicals through the skin could be significant for some of the contaminants listed under the Air Toxics "Hot Spots" Act. However, it should be noted that dermal absorption of chemicals that are originally airborne is a relatively minor pathway of exposure compared to other exposure pathways. Three different dermal exposure pathways are possible:

a. Uptake of chemicals which have settled onto surfaces, either as particles, droplets, or molecules adsorbed onto a surface (leaves, soil, furniture, etc.).

b. Direct uptake of chemicals from air, either as vapors or from airborne particles or droplets adhering to the skin.

c. Absorption of chemicals from water, after the chemicals have settled into or been absorbed by a body of water. This could involve transport from water-borne particles to skin or direct absorption of molecules dissolved in the aqueous phase by skin.

Dermal absorption will generally provide less exposure to airborne toxicants than inhalation exposure or eating or drinking substances that have been contaminated by airborne chemicals. The risk from dermal exposure in the environmental setting from airborne toxicants will be a small fraction of the risk from inhalation exposure or exposure via ingestion of contaminated crops, soil, breast milk and so on. The significance of each of the above exposure pathways varies by type of chemical, but pathway ***a***, uptake of chemicals from surfaces (in particles), is most relevant. This route applies to semivolatile organic chemicals like dioxins and PCBs, and some metals like lead. Competition between evaporation from the skin and dermal absorption results in a distribution of the chemicals between air, dust particle, and skin phases which depends on volatility, relative solubilities in the phases, temperature, and other factors.

Direct uptake of vapors across the skin, route ***b***, would be most important for volatile chemicals like perchloroethylene, which would remain mostly in the vapor phase. While it is known that dermal uptake is important at high concentrations in the air such as might occur in a workplace, inhalation is a much more important exposure route for volatile compounds in the general population. The other aspect of the air exposure route, direct adherence of airborne particles to skin, is not well documented. In general, contact with particles after they have settled onto surfaces can be expected to predominate. For this document, dermal exposures to particles will be estimated from the particle loads on surfaces and, for soils, an assumed mixing depth of 1 cm.

Exposure route ***c***, dermal uptake from water, is potentially relevant for low-volatility organic chemicals like PCBs or dioxins. However, direct dermal uptake of chemicals in water is minor compared to other routes of exposure for airborne chemicals.

6.2 Factors Providing Significant Variation in Dermal Uptake

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), type of surface contacted, chemical concentration (Nomeir et al., 1992), duration of exposure, ambient temperature and humidity (Chang and Riviere, 1991), and activities which limit exposure (e.g., washing the skin).

In many cases, the inherent variability in the exposure factors can be estimated, such as in total skin surface area of children and adults, or the variability in size of exposed body parts. In some cases, the actual variation is unknown, such as in the average time children of different ages spend in contact with soil. However, reasonable estimates can be made which should encompass the expected range of exposure frequencies and durations. In other cases, 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.

This discussion of the variability in dermal exposure estimates is limited to what can be reasonably quantified or estimated at this time, with more attention to the largest exposure routes and activities. Data are very limited for many variates that could be included in a model. The impact of these variates (e.g., ambient temperature, skin moisture content) is presently unquantifiable.

For the Air Toxics “Hot Spots” program, dermal exposure to chemicals in soil is estimated using the following equation currently in the CAPCOA guidelines (CAPCOA, 1993). We are recommending continued use of this equation:

$$\text{Dermal Dose in mg/kg-day} = (\text{Csoil} \times \text{SA} \times \text{SL} \times f \times \text{ABS}) / (\text{ABW} \times 1 \times 10^9) \quad \text{(Eq. 6-1)}$$

where:

Csoil =	Concentration of chemical in soil at specific receptor location (μg/kg soil)
SA =	Surface area of exposed skin (cm^2)
SL =	Soil loading on skin (mg/cm^2)
ABS =	Absorption fraction
ABW =	Average body weight (kg)
1×10^9 =	Conversion factors for chemical and soil (μg to mg, mg to kg)
f =	frequency of exposure, days/365 days

The term Csoil, concentration of the contaminant in soil, is derived in the Air Toxics “Hot Spots” program using air dispersion and deposition modeling. 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:

$$Csoil = [GLC\ (Dep\text{-}rate)\ (86{,}400)\ (X)]\ /\ [Ks\ (SD)\ (BD)\ (Tt)] \quad \text{(Eq. 6-2)}$$

where:
- Csoil = average soil concentration at a specific receptor location over the evaluation period (µg/kg)
- GLC = ground level concentration from the air dispersion modeling ($\mu g/m^3$)
- Dep-rate = vertical rate of deposition (m/sec) (see Chapter 2 for values)
- 86,400 = seconds per day conversion factor
- X = integral function accounting for soil half-life
- Ks = soil elimination time constant = $0.693/T_{1/2}$
- SD = soil mixing depth = 1 cm for dermal scenario
- BD = bulk density of soil = 1333 kg/m^3
- Tt = total averaging time = 70 years = 25,550 days

The integral function, X is as follows:

$$X = [\{Exp\ (-Ks \times Tf) - Exp\ (-Ks \times To)\}\ /\ Ks] + Tt \quad \text{(Eq. 6-3)}$$

where:
- EXP = Exponent base e = 2.72
- Ks = soil elimination constant = 0.693/ T1/2
- T1/2 = chemical-specific soil half-life
- Tf = end of exposure duration (days); 25,500 for a 70-year exposure
- T_0 = beginning of exposure duration (days) = 0 days
- Tt = total days of exposure period = Tf - T_0 (days)

Chemical-specific soil half-lives are presented in Appendix G. Tf = 25,500 days for a 70-year exposure or less for less-than-lifetime exposures.

The assumptions in the soil concentration algorithm include the uniform mixing of pollutants in the soil, and a constant concentration over the duration of the exposure. For the dermal exposure pathway and for ingestion of soil, the soil mixing depth is assumed to be 1 cm. The bulk density of soils is similar over a wide variety of soil types.

6.3 Exposure Factors and Studies Evaluated

6.3.1 Chemical-specific 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 dermal 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 are more soluble in the aqueous phase of stratum corneum and insoluble in the lipid phase, and thus penetrate skin poorly.

These principles of skin absorption rates are documented in U.S. EPA (1992), as summarized in Appendix F.

Cal/EPA has attempted to define appropriate values to use for dermal absorption estimates for occupational exposure to pesticides (Department of Pesticide Regulation (DPR) 1993) and for potential exposure to chemicals at hazardous waste sites (Department of Toxic Substances Control (DTSC) 1993, 1994). The guidelines in DPR (1993) and DTSC (1994) stress use of human data, where available, but do not provide clear guidance on inferred data distributions. They suggest use of point estimates for health-protective default values. The CalTOX computer program (DTSC, 1993), by contrast, provides a mechanism for screening health risks at hazardous waste sites. CalTOX incorporates explicit assumptions for distributions of all exposure parameters but is focused on dermal uptake of contaminants poured directly onto soil, and at concentrations higher than one would anticipate from airborne deposition.

Chemical-specific dermal absorption is discussed in Appendix F.

6.3.2 Concentration and Ttemperature Dependence of Uptake

The percent of an applied dose that is absorbed across the skin has often been observed to be inversely proportional to the concentration applied (Chang and Riviere, 1991; Wester and Maibach, 1985; Wester et al., 1993b). Total dermal uptake does not always decrease with increasing concentration on skin (Nomeir et al., 1992). Chang and Riviere (1991) also demonstrated the effect of variations in the air temperature and humidity. In vivo the absorption of moderately polar substances has also been related to stimulating blood perfusion and opening pores (Loomis, 1980), although it should be noted that hydration will slow the penetration of highly lipophilic chemicals (Feldmann and Maibach, 1965).

6.3.3 Skin Area Factors

The U.S. EPA guidelines on dermal uptake parameters for risk assessment (1992, 1995, 1997) for chemicals in soil provide for surface area and soil contact factors to vary by exposure scenario. The default values for soil contact include, for adults, a skin area of 5,000 to 5,800 cm^2, a soil to skin adherence rate of 0.2 to 1.0 mg/cm^2-event, and an exposure frequency of 40-350 events/year. The exposed surface area estimate assumes 25% of the body is exposed, roughly corresponding to wearing shoes, shorts, and a short-sleeved shirt. The event frequency range of 40 to 350/year is based on judgments (no actual data) regarding behavior involving soil contact such as gardening.

A considerable amount of data is available on the permeability of different skin areas for uptake of environmentally relevant chemicals (Maibach et al., 1971; Wester and Maibach, 1985; Finley et al., 1994a). In general, hands are least permeable, and face and neck are most permeable. Most exposure estimates have utilized a single value for presumed dermal uptake rate or percent, without distinguishing between the surface areas that might be involved under different scenarios.

6.3.4 Soil Adherence Factors

A review of the literature by Finley et al. (1994b) suggests a probability distribution for soil adherence to skin which is independent of age, sex, soil type, or soil particle size. Data from several different studies were used to simulate probability distribution functions (PDFs) with a bootstrapping Monte Carlo analysis for both adults and children. Finley et al. combined several studies for a single probability distribution function. This PDF is lognormally distributed with an arithmetic mean of 0.52 ± 0.9 mg soil/cm^2 of skin; the 50 and 95th percentiles are 0.25 and 1.7 mg soil/cm^2 of skin.

Dermal soil loading was estimated in the study of Kissel et al. (1996) by weighing the soil particles washed off the skin and collected by filtration, after various activities. Skin surfaces evaluated included hand, forearms, lower legs, face, and feet. Observed hand loadings varied over five orders of magnitude, from 0.001 to 100 mg/cm^2, mostly dependent on the type of activity. Hand loadings within the current regulatory default estimates, 0.2 to 1.0 mg/cm^2, were produced by activities resulting in direct and vigorous contact with soil such as rugby and farming. Several other outdoor activities resulted in less soil loading on hands. The worst case was represented by children playing in mud on a lakeshore, who accumulated 10 mg/cm^2 or more on hands, arms, legs, and feet, for a total body load of soil far in excess of the default values. The general conclusion of Kissel et al. is that current default soil loading estimates will greatly overestimate exposure to chemicals in soil for activities which do not result in direct soil contact; typical “background” geometric mean soil loading was on the order of about 0.01 mg/cm^2. It should be noted that this technique measures only net soil loading, ignoring any soil/skin chemical transfer which might occur from short-term residence of particles on skin during the activity.

6.3.5 Soil Layer Thickness

Transfer of a chemical from soil particles on skin to the skin surface is limited by the chemical’s diffusion rate (McKone, 1990). Diffusion through the soil phase, through the air, and through soil moisture are all possible. Fugacity-based interphase transport models were constructed by McKone to describe the rate of each of these processes for chemicals in soil particles and to predict the dermal uptake rates. It was shown that predicted dermal uptake of chemicals from soil depends on the Henry’s constant (vapor pressure/solubility in water), the octanol/water partition coefficient of a chemical, and the soil thickness on skin. If the Henry’s constant is very high, chemicals will be lost from soil particles (or the skin surface) quite rapidly, so net dermal uptake of chemicals added to soil will be low. If the Henry’s constant is very low, diffusion through the soil particle layer will be too slow to allow much dermal uptake unless the soil particles are very small. A high octanol/water partition coefficient is associated with tight binding to soil and low water solubility; these properties also limit the ability of a chemical to diffuse through the mixed lipid/water phases of the stratum corneum. The McKone model was used to predict that high soil loadings would not yield high dermal absorption for chemicals like

2,3,7,8-TCDD, because of transport limitations. An uptake of 0.5% of the soil content of TCDD was predicted with the model at a soil loading of 20 mg/cm^2 on skin, compared to a measured value of 1% in rats at this soil loading.

6.3.6 Clothing Penetration Values

Studies on penetration of pesticide residues on crops through clothing of the workers picking the crops provide relevant data on potential exposure to environmental chemicals on surfaces under a variety of conditions. Brodberg and Sanborn (1995) surveyed studies conducted by or submitted to the Department of Pesticide Regulation for evaluation of agricultural worker exposure to pesticides. Transfer of pesticides through clothing was estimated by measuring the difference in amounts of pesticides recoverable on an inner layer of clothing or an absorbent patch, compared to the total amount recovered on both inner and outer clothing or patches. The data varied from 10 to 34% with no penetration trends that could be ascribed to the crop, the type of activity (ground, tree, or bush harvest), or the chemical. As observed by Brodberg and Sanborn (1995), the low vapor pressure of these chemicals makes it unlikely that the chemicals moved through the clothes in the vapor phase. Rather, penetration of clothes by being carried on dust particles is likely, which could explain the lack of penetration trends noted above.

For two pesticides on peaches, there was an apparent difference in penetration of pesticides through the clothing on different parts of the body. The low penetration on hands (8 to 9%) is likely to be due to the low permeability of the nylon gloves worn, compared to the cotton/polyester clothing on the rest of the body. The highest penetration rates, for upper arms (42 to 48%) and shoulders (30 to 37%), is ascribed by Brodberg and Sanborn to the type of activity involved in reaching up for peaches, involving extra contact with both clothing and foliage.

Brodberg and Sanborn (1995) recommend a default value for penetration through clothing of 25%, to be used in the absence of more specific data. The current DPR Worker Health and Safety Branch default value is 10% clothing penetration (personal communication, 1996).

6.3.7 Behavioral Factors

People’s activities are the major determinant of their exposure to soil and dust (Wiley et al., 1991a,b; U.S. EPA, 1995; Kissel et al., 1996), but frequencies and durations of soil exposures are not well characterized. The Air Resources Board’s activity pattern studies in adults and children (Wiley et al., 1991a,b) reveal patterns of individual activities but do not provide direct information on contact with soils. Estimates of activities which would result in soil contact have previously been generated on the basis of what seemed to be “reasonable” scenarios. To incorporate the uncertainty in estimates of soil exposure, it is necessary to use the scenario concept, e.g., to estimate exposure for a preschool child who plays outdoors several hours each day, as well as for an adult who rarely engages in outdoor activities. This provides information on reasonable range of exposure.

6.4 Dermal Uptake Estimation Equations

6.4.1 U.S. EPA Exposure Estimates (1992, 1995)

The U.S. EPA (1992) suggested using the following equation for estimating dermal exposure to chemicals from soil:

$$ADD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \qquad \text{(Eq. 6-4)}$$

where:

- ADD = average daily dose (mg/kg-day)
- DA_{event} = absorbed dose per event (mg/cm^2-event)
- EV = event frequency (events/day)
- EF = event frequency (days/yr)
- ED = exposure duration (years)
- SA = skin surface area available for contact (cm^2)
- BW = body weight (kg)
- AT = averaging time (days); for noncarcinogenic effects, AT = ED, for carcinogenic effects, AT = 70 years or 25,550 days

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.

For estimating children's doses over a range of ages, the U.S. EPA Dermal Exposure Assessment (1992) suggests a summation approach to represent changes in surface area and body weight as a person grows. Assuming all other exposure factors remain constant over time, Equation 6-4 for uptake from soil would be modified to:

$$ADD = \frac{DA_{event} \times EF}{AT} \times \sum_{i=m}^{n} \frac{ED_i \times SA_i}{BW_i} \qquad \text{(Eq. 6-5)}$$

where Σ represents a summation of terms, and *m* and *n* represent the age range of interest.

6.4.2 Cal/EPA Department of Pesticide Regulation Guidance for the Preparation of Human Pesticide Exposure Assessment Documents (1993)

The DPR dermal absorption estimate procedure uses a default uptake value of 100% unless a pesticide registrant chooses to collect specific data (DPR, 1993). DPR has recently proposed 50% absorption as a default on the basis of a survey of previous pesticide absorption studies. Experimental absorption values are calculated from in vivo data as follows:

$$\text{Percent dermal absorption} = \frac{\text{Applied dose} - \text{Unabsorbed dose}}{\text{Applied dose}} \times 100 \qquad \text{(Eq. 6-6)}$$

or the absorbed portion may 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.

6.4.3 CalTOX (1993)

The CalTOX computer program (DTSC, 1993) incorporates variable parameters in each exposure pathway to estimate multimedia uptake of a chemical by all exposure routes, with the uncertainty assumptions explicitly presented. For the dermal uptake route, a soil/skin transport model is included (McKone and Howd, 1992). The basic uptake model is:

$$ADD = AR_s \times SA_b \times 0.3 \times 15 \times EF_{sl}/365 \times C_g \qquad \text{(Eq.6-7)}$$

where:

ADD = average daily dose in mg/kg-day, for one exposure event/day
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 $kg/cm\text{-}m^2$, 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:

$$AR_s = T_s \times \left\{ 1 - \exp\left[\frac{-K^s_p \times ET_{sl}}{T_s} \right] \right\} \qquad \text{(Eq. 6-8)}$$

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/hour
ET_{sl} = soil exposure time, in hours/day.

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.

6.4.4 *Frequency of Exposure to Soil*

Soil exposure frequency is the final parameter of significance in these exposure estimates. Existing survey data are not reliable because individual activity patterns have not been monitored long enough to document differences in individual behavior. A range of assumptions of soil exposure frequencies has been used in different contexts. The following summary (Table 6.1) is derived from the U.S. EPA Exposure Factors Handbook (1995):

Table 6.1 Assumptions of frequency of exposure to soil

Range, days/year	Population	Reference
350	all	U.S. EPA, 1989
247-365	all	U.S. EPA, 1984
180	all	Paustenbach et al., 1986
130	children < 2-5	Hawley, 1985
130	older children	Hawley, 1985
45	adults	Hawley, 1985

The various estimates may include different exposure assumptions -- i.e., colder vs. warmer climates. The U.S. EPA has considered Hawley's adult exposure frequency to be applicable to adults who garden or otherwise work outside one to two days per week during the warmer months. However, to maintain consistency with their earlier estimates, the U.S. EPA also continued the use of 350 days per year as an upper estimate of the frequency of soil exposures for adults.

6.5 Recommendations

The dermal exposure pathway generally contributes little to the risk of airborne substances under the typical facility operation and exposure scenarios in the Air Toxics "Hot Spots" program. We are recommending a simple point estimate approach to assessing dermal exposure. Under some circumstances, a more complex approach may be warranted. The analyst may then want to consult the CalTOX program and the U.S. EPA document *Dermal Exposure Assessment: Principles and Applications* (1992). We recommend estimating the dermally absorbed doses from soil using Eq. 6-1. For the point estimate approach, OEHHA recommends using the standard CERCLA default values for the variables in equation 6-1 (U.S. EPA, 1989, 1991). These are described in Table 6.2 below. For a 30- or 70-year exposure scenario, we recommend the values under “TWA 0-70” in Table 6.2. For a 9-year scenario, we recommend the values for children 1-6 years in Table 6.2. The suggestions below constitute a proposed “standard” evaluation useful in a Tier 1 (point estimate) risk assessment. Other estimation methods which are based on a specific exposure scenario may be presented in a Tier 2 risk assessment.

Table 6.2 Recommended point estimate defaults for dermal exposure.

	Children (1-6 yrs)	Adults (> 6 yrs)	TWA 0-70 years
surface area exposed (cm^2)	2000	average = 5000 high-end = 5800	average = 4700 high-end = 5500
soil loading (mg/cm^2)	average = 0.2 high-end = 1.0	average = 0.2 high-end = 1.0	average = 0.2 high-end = 1.0
Exposure frequency (d/yr)	350	average = 100 high-end = 350	average = 121 high-end = 350

The use of point estimates is proposed for the other factors in Equation 6-1,

Csoil = concentration of chemical in soil (mg/kg)
ABS = fractional dermal absorption of the chemical
AT = averaging time (days); for noncancer effects, AT = the sum of exposure terms, T_i (converted to days); for cancer, AT = 25,550 days (70 years).

A point estimate of concentration generated from the air dispersion and deposition modeling, Csoil, is used to calculate dose (see Equations 6-2 and 6-3). The point estimates representing concentrations at the point of maximum impact, maximum exposed individual resident and maximum exposed worker are used in the Air Toxics “Hot Spots” program. However, the concentration of the chemical in soil could be modeled for other receptor points of interest, and it could be appropriate to estimate risks at various mean concentrations. The algorithm for calculating soil concentration incorporates soil half-life.

The fraction of the applied chemical that is dermally absorbed, ABS, depends on both chemical-specific factors and scenario-dependent factors. As indicated in the discussions in section 6.3 above and in Appendix F, these can result in orders-of-magnitude differences in dermal uptake under different conditions. Data are inadequate to describe potential changes in fractional dermal absorption with changing scenario. The point estimate values to be used for dermal absorption estimates are discussed in Appendix F.

The averaging time (AT) depends on scenario and effect (cancer vs. non-cancer). In a cancer risk assessment the averaging time is 70 years, while the exposure duration may be 9, 30 or 70 years (see Section 11). Dermal doses estimated by these methods are equivalent to an internal dose by U.S. EPA definition (U.S. EPA, 1992).

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7. Food Intake

7.1 Introduction

Some of the toxic substances emitted by California facilities such as dioxin and metals can be deposited onto soil, surface water bodies and food crops. Persons consuming garden produce may be exposed to toxic substances directly deposited on the leaves or taken up through the roots. Home raised chickens, cows and pigs may be exposed through consumption of contaminated feed, pasture, soil, water and breathing of contaminated air. Humans may subsequently be exposed through consumption of contaminated meat and milk. In order to quantify the cancer and noncancer risks, the dose must be determined. Dose in this pathway is proportional to consumption rate and the concentration of the toxicant in the produce, meat, or milk. Probability distributions and default consumption rates for homegrown vegetables and fruits, chicken, beef, pork, cow's milk and eggs are discussed in this chapter. Homegrown produce, meat and milk are evaluated in the AB-2588 program because risk to the population surrounding a facility is being evaluated. While a facility could contaminate commercially grown produce, meat and milk, typically commercially-grown products come from diverse sources. Thus the risk to an individual from consuming commercial products contaminated from a single facility is likely to be quite small.

7.2 Algorithm for Food Intake Dose

7.2.1 Point Estimate (Deterministic) Algorithm

$$\text{Dose} = \frac{(Cf * IF * GI * L) * EF * ED \; 1 \times 10^{-6}}{AT} \qquad \text{(Eq. 7-1)}$$

where:

Dose =	(mg/kg-day)
Cf =	concentration of toxicant in food type F (μg/kg)
IF =	consumption (g/kg body weight per day)
GI =	gastrointestinal 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/year)
AT =	averaging time, period over which eposure is averaged (days).
ED =	exposure duration (years)

The gastrointestinal absorption factor is rarely used because the oral reference exposure levels and cancer potency factors are not adjusted for absorption.

7.2.2 Stochastic Algorithm

The algorithm for the stochastic method is the same as the point estimate algorithm. Distributions are substituted for single values.

7.3 Methods and Studies Available for Estimation of Per Capita Consumption

The USDA estimates the amount of food which disappears into the wholesale and retail markets (Putnam and Allshouse, 1992). The amounts exported, non-food uses and other food not available to the general public are subtracted from this total. Per capita consumption is then estimated by dividing by the population of the United States. This methodology fails to account for losses which occur during processing, marketing and home use (Putnam and Allshouse, 1992). Separate regions are not differentiated in these studies. California is more ethnically diverse than the rest of the country, and thus may have different food consumption rates from the average national consumption rates. Significant differences in food consumption patterns between ethnic groups have been documented (Kant et al., 1991). In addition, the different consumption rates of men, women or children cannot be determined with this method. These studies were not used because of these limitations.

The food frequency method asks subjects the frequency with which they consume foods on a checklist of 20 to 100 items over a previous period of time. This methodology has been used to study the relationship between disease and diet and is more successful in measuring intra-individual variability in food consumption than some other methods such as three day recall surveys (Block, 1992). However, food frequency surveys measure a limited number of items compared to other methods. Our desire was to determine consumption rate distributions of various types of vegetables and meats as accurately as possible for the California population. We were unable to find food frequency studies which specifically addressed the ethnically diverse population of California. We therefore chose not to use studies which employed the food frequency methodology.

The National Health and Nutrition Examination Surveys (NHANES) have been conducted by The National Center for Health Statistics periodically since 1971. At the time that OEHHA was deciding which data and studies would be most appropriate to use for food consumption distributions, the latest available results and raw data were from the NHANES II (1976-1980). NHANES II was designed to be representative of the entire United States and the data could not be subsetted in order to extract regional information. OEHHA chose not to use the NHANES II study because of the availability of more recent studies and the impossibility of extracting data specific to California or the Pacific region.

The United States Food and Drug Administration conducted the Nationwide Food Consumption Survey (NFCS) in 1935, 1942, 1948, 1955, 1965-66, 1977-78 and 1987-88. A series of food consumption surveys conducted by USDA in 1985, 1986, 1987, 1989, 1990 and 1991 were called Continuing Surveys of Food Intakes of Individuals (CSFII). The 1965-66, 1977-78, 1987-88 NFCS and the CSFII surveys determined individual food consumption. The earlier NFCSs only determined overall household food consumption. For this reason, and because of the availability of later surveys, these earlier surveys were not used by OEHHA.

The 1977-78 NFCS survey has been extensively used for risk assessment purposes (CalTOX, 1993; U.S. EPA, 1989). It is generally recognized as a well conducted study. We were concerned that current dietary patterns would not be reflected by 1977-78 NFCS and therefore chose to use more recent studies.

The 1985 CSFII surveys collected data on men age 19-50 years old, women 19-50 years old and their children 1-5, and low income women 19-50 and their children 1-5 years old. The 1986 and 1987 surveys collected data on women 19-50 and their children 1-5 years old. OEHHA did not use the 1985, 1986 and 1987 CSFII studies because the individual studies did not cover all segments of the population.

The USDA conducted the National Food Consumption Survey in 1987-88 which covered the entire U.S. population. The 1987-1988 survey has been criticized because of a 34% response rate (GAO, 1991). If a survey with a low response rate is to be used, it is necessary to establish that the non-responding group is not different from the responding group in some important respect. If the non-responders differ in some important respect such as ethnicity or socioeconomic status, the results will be biased. A test for non-response bias was not performed on the data, therefore OEHHA decided to exclude the 1987-1988 surveys from consideration.

The 1989-91 CSFII study surveyed a total of 5,238 individuals including men, women and children. The 1989-91 CSFII survey was designed to be representative of the population of the United States as a whole and a weighting scheme was devised to that end. However, the survey divided the country into various regions; one of the regions is the Pacific region (Washington, Oregon and California). The number of people surveyed in the Pacific region was sufficient so that the region which is dominated by the huge California population could be separately analyzed. OEHHA chose this study to determine food consumption distributions because it was relatively recent, and data specific to the Pacific region could be obtained. OEHHA used the raw data available on computer tape for our analyses.

The survey methodology for the 1989-91 CSFII study is similar to the other USDA food consumption surveys in which information was collected on individual food consumption. The survey used a one-day recall and two-day record administered one time over each of the four seasons. This study is multistage which means that random samples are selected from increasingly smaller groups in the population. The selection process in this study occurs within strata, in this case geographic groups, representing the entire U.S. population. In this type of survey each group, for example Hispanic females, has a known probability of being sampled. In order for the samples to be representative the size of each such group in the population must be determined so that the samples selected are representative of overall population. The sampling results from each group sampled can be weighted based on the group’s proportion of the entire population.

One disadvantage of the CSFII methodology is poor characterization of intra-individual differences. Three days of dietary intake survey may not be sufficient to capture typical intake (Anderson, 1986). This is not a particularly important limitation for the purposes of determining per capita mean intakes. However, the prevalence of low or high intakes may be incorrectly estimated (Anderson, 1986). This may mean that the tails of the food consumption distribution are less accurate. In addition, the estimate of total caloric intake is known to be low, particularly within some groups (Layton, 1993). If consumption levels estimated are underestimated, the health risks posed by the food consumption pathways may be underestimated. However, despite these limitations, this methodology appears to be the best available for our purposes.

OEHHA subsetted the Pacific region data from the CSFII data tapes. The total number of Pacific region subjects in various racial and ethnic categories are listed in Table 7.1. The CSFII sampling strategy was designed so the sample would represent the entire United States instead of the various regions. We wanted to use the Pacific region subset of the data to represent the Pacific region population. Although the proportion of Hispanics in the California population is higher than the proportion of Hispanics in the CSFII data, there is a reasonable proportion of sample population which is Hispanic. Developing an appropriate weighting scheme would have been complicated by the fact that Hispanics fall into the White, Black and “other” racial group categories. The proportion of Blacks in the CSFII sample is also somewhat less than the actual proportion of Blacks in the California population. The weighting scheme presented in the CSFII was not used because it was designed to be representative of the entire United States. The documentation for the CSFII recommends that if the weighting scheme is not used then only one person per household should be selected. OEHHA did not follow this recommendation because the number of subjects would have been too small for our purposes. The use of the data including more than one subject per household is a source of bias. The number of Asians surveyed in the Pacific region was inadequate to represent the Pacific region population. It was therefore decided to pool the surveyed Asians from the entire United States and to use this survey population to represent the Californian Asian population. No significant differences were found between consumption patterns of the surveyed Asians living in the Pacific Region and surveyed Asians living in other regions of the country.

Table 7.1 Pacific Region Sample, Ages 0-70 by Racial Group and Ethnicity

Group	Hispanic	Non Hispanic	Total	% of Total
White	154	677	831	80.3
Black	5	50	55	5.31
Asian/Pacific Islander	0	31	31	3.00
Non Pacific Region Asian/Pac. Islander	0	39	39	3.77
Aleut/Eskimo/American Indian	3	28	31	3.00
Other	42	6	48	4.64
Total	204	831	1,035	100
% of Total	19.6	79.9		

Daily consumption rates, in grams per day, for each individual were determined by summing consumption of each food group, per person, and dividing by the number of days the individual reported consuming the food group. The CSFII survey is quite comprehensive in the range of prepared and non-prepared foods listed. Foods that could only be reasonably obtained from commercial sources were not considered. However, some obviously commercial items for which consumption of home produce equivalent items could be reasonably substituted were included. The list of foods considered is located in Appendix D. The body weight of each individual subject was available as part of the CSFII data. The grams of food per day were divided by body weight in order to express consumption as g/day/kg body weight. Per capita consumption was calculated by multiplying the consumption rate by the ratio of consumers of a particular food group to the total number of participants. Subjects were stratified into two groups, ages 0-9, which is to be used for the 9-year residence time determination, and ages 0-70, which is to be used for both the 30-year and 70-year residence times. Roughly equal numbers of male and female subjects were in the survey.

An estimation of the best parametric model to fit the distributions is done using the fitting function in Crystal Ball® version 4.0 (Tables 7.2 and 7.3). The Anderson Darling criterion is used since this procedure is more sensitive to the tails of the distributions. The following distributions are considered as possible fits for these data: Normal, Triangular, Lognormal, Uniform, Exponential, Weibull, Beta, Gamma, Logistic, Pareto and Extreme Value. In a couple of cases the distributions fit by Crystal Ball® did not fit the tails or mean of the distribution very well. A lognormal distribution generated using the same 10^{th} and 90^{th} percentiles as the empirical data distributions appeared to be a better fit. The type of distribution that fit best is noted in Tables 7.3 and 7.5. Tables comparing the empirical distributions with the parametric models are presented in Appendix C.

7.4 Categorization of Produce

Exposure to radionuclides from produce consumption was considered by Baes et al. (1984). This study determined soil to plant concentration factors for various elements and metals. The physical processes through which plants are contaminated by airborne radionuclides are analogous to the processes through which airborne low volatility chemical contamination may occur. Therefore, OEHHA has chosen a categorization scheme similar to Baes et al. (1984) for the semi-volatile organic and heavy metal toxicants addressed in the AB-2588 program. The one exception to the Baes et al. (1984) scheme is that OEHHA has chosen to place the root vegetables in a separate category.

In the study, produce was divided into different categories based on the manner in which contamination from air deposition occurs. The leafy vegetable category consists of broad-leafed vegetables in which the leaf is the edible part, for example spinach. The vegetables in this category can be contaminated by deposition onto leaf surfaces. The root vegetable category has items that were placed into other categories by Baes et al. (1984). An example of a root crop is potatoes. OEHHA staff used this category for crops for which root translocation could be a source of contamination. The next category is the exposed produce, which is comprised of produce with a small surface area subject to air deposition. An example of exposed produce is strawberries. The last category of produce is protected, which includes items such as nuts in which the edible part is not exposed to air deposition. The produce items from the 1989-1991 CSFII were classified into these four categories. This information is presented in Appendix D.

Table 7.2 Empirical Distributions for Per Capita Food Consumption Among Ages 0-9 (g/kg bw/day).

Category of Food	Cons	Non-Cons	Mean	SD	Skew Ness	Kurt-osis	Min*	p01	p05	p10	P20	p30	p40	p50	p60	p70	p80	p90	p95	p99	Max*
Produce																					
Exposed	88	56	4.16	5.58	2.76	8.79	0.30	0.30	0.59	0.73	0.87	1.19	1.32	1.71	2.58	4.31	6.54	10.0	15.7	30.8	30.8
Leafy	60	84	2.92	3.69	2.56	7.77	0.15	0.15	0.39	0.52	0.75	0.93	1.04	1.29	1.97	2.59	4.86	8.16	10.9	20.0	20.0
Protected	41	103	1.63	2.16	1.82	2.28	0.14	0.14	0.23	0.30	0.34	0.40	0.52	0.60	0.73	1.16	3.04	4.66	6.66	8.21	8.21
Root	95	49	4.08	4.66	1.91	3.62	0.22	0.22	0.57	0.68	0.87	1.11	1.45	1.84	2.93	5.38	6.77	11.3	14.9	23.2	23.2
Meat																					
Beef	64	80	2.24	2.63	1.98	3.82	0.25	0.25	0.37	0.47	0.53	0.63	0.86	1.08	1.34	2.09	4.18	5.96	7.97	12.8	12.8
Chicken	42	102	1.80	1.96	1.47	1.84	0.25	0.25	0.30	0.31	0.40	0.45	0.57	0.72	0.99	3.01	3.41	4.29	4.77	8.32	8.32
Pork	40	104	1.31	1.46	2.17	4.64	0.20	0.20	0.23	0.27	0.33	0.43	0.55	0.73	1.05	1.35	1.88	3.14	5.10	6.50	6.50
Dairy	131	13	12.0~	18.7	3.89	20.6	0.52	0.69	1.00	1.73	2.38	2.88	3.63	5.44	7.83	9.74	13.6	31.2	51.9	78.1	145
Eggs	80	64	3.21	3.61	2.14	5.28	0.27	0.27	0.50	0.59	0.75	1.06	1.25	1.49	2.41	3.56	5.53	8.00	10.3	17.9	17.9

*Indicates sample minimum or maximum
Total of consumers and non-consumers equals 144 in each case. The same 144 subjects are represented in each food category.

Table 7.3 Parametric Models for Ages 0-9 Food Consumption Distributions (g/kg BW/day).

Category of Food	Distribution Type	Mean	Std. Dev.	Location	Scale	Shape	Anderson-Darling Statistic	$\mu \pm \sigma$
Produce								
Exposed	Gamma			0.00	35.79	1.90	0.4703	
Leafy	Lognormal	2.83	3.89				0.7527	exp (0.43±1.03)
Protected	Weibull			0.13	1.21	0.71	1.3865	
Root	Lognormal	4.08	5.91				1.4049	exp (0.84±1.06)
Meat								
Beef	Weibull			0.24	1.72	0.77	1.1036	
Chicken	Gamma			0.25	2.94	0.53	1.0286	
Pork	Weibull			0.18	0.97	0.78	0.2092	
Dairy	Lognormal	11.32	18.3				0.9195	exp (1.78±1.13)
Eggs	Weibull			0.26	2.67	0.82	0.9977	

Table 7.4 Empirical Distributions for Per Capita Food Consumption Among Ages 0-70 (g/kg BW/day).

Category of Food	Cons	Non-Cons	Mean	SD	Skew Ness	Kurt-osis	Min*	P01	p05	p10	p20	P30	p40	p50	p60	p70	p80	p90	p95	p99	Max
Produce																					
Exposed	725	310	3.56	5.12	4.57	31.9	0.05	0.13	0.28	0.44	0.66	0.93	1.42	2.00	2.57	3.53	5.13	7.93	12.1	25.5	59.5
Leafy	624	411	2.90	3.50	2.75	10.1	0.02	0.08	0.24	0.35	0.52	0.82	1.27	1.79	2.36	3.12	4.26	6.68	10.6	16.3	26.6
Protected	364	671	1.39	1.75	3.83	24.2	0.03	0.05	0.13	0.17	0.26	0.42	0.60	0.86	1.22	1.51	2.00	3.01	4.88	8.23	17.7
Root	707	328	3.16	3.81	3.17	16.1	0.03	0.09	0.27	0.41	0.62	0.89	1.40	1.88	2.58	3.51	4.91	7.29	10.5	17.7	34.7
Meat																					
Beef	606	429	2.25	3.07	6.30	70.1	0.04	0.07	0.23	0.32	0.46	0.63	0.91	1.34	1.85	2.43	3.50	5.15	6.97	11.1	44.6
Chicken	416	619	1.46	1.90	3.96	27.1	0.02	0.04	0.12	0.18	0.27	0.38	0.59	0.87	1.19	1.50	2.32	3.24	5.02	8.40	20.4
Pork	376	659	1.39	1.79	3.83	24.7	0.03	0.04	0.12	0.18	0.27	0.37	0.53	0.78	1.14	1.56	2.07	3.20	4.59	8.50	18.3
Dairy	891	144	5.46	8.96	6.33	65.1	0.04	0.16	0.43	0.59	0.95	1.40	2.12	2.87	3.95	5.45	7.58	11.7	17.4	48.0	137
Eggs	521	514	1.80	2.30	4.92	42.1	0.04	0.06	0.19	0.28	0.38	0.55	0.81	1.11	1.55	1.97	2.59	4.06	5.39	9.71	28.7

*Indicates sample minimum or maximum
Total of consumers and non-consumers in each case equals 1035. The same 1035 subjects are represented in each food category.

Table 7.5 Parametric Models for Ages 0-70 Food Consumption Distributions (g/kg bw/day)*

Category of Food	Mean	Std. Dev.	Distribution Type	Anderson-Darling Statistic	$\mu \pm \sigma$
Produce					
Exposed	3.43	6.16	Lognormal	1.11859	exp (0.51±1.20)
Leafy	2.97	4.95	Lognormal	10 ,90 %tile	exp (0.42±1.15)
Protected	1.39	2.43	Lognormal	1.6613	exp (-0.37±1.18)
Root	3.07	5.23	Lognormal	1.9557	exp (0.44±1.17)
Meat					
Beef	2.32	3.50	Lognormal	10,90 %tile	exp (0.25±1.09)
Chicken	1.44	2.19	Lognormal	10, 90%tile	exp (-0.23±1.09)
Pork	1.42	2.30	Lognormal	1.13	exp (-0.29±1.13)
Dairy	5.57	10.5	Lognormal	1.5102	exp (0.96±1.23)
Eggs	1.84	2.60	Lognormal	1.7077	exp (0.061±1.05)

*In three cases (Leafy, Beef and Chicken) the distributions fit by Crystal Ball were judged to be an inadequate fit and a lognormal distribution with the same 10th and 90th percentiles as the empirical distribution were judged to be a better fit.

7.5 Produce, Meat, Dairy and Egg Consumption Distributions

Produce, meat, dairy and egg consumption distributions are presented for ages 0-9 (Table 7.2) and ages 0-70 (Tables 7.4 and 7.5). As previously discussed produce has been divided into leafy, root, exposed and protected. Consumption is expressed in terms of gram/kilogram body weight/day in these tables. For informational purposes, we provide consumption expressed in g/day for the same age groups in Appendix C.

7.6 Calculating Contaminant Concentrations in Food

The previous sections focused on intake rates for a variety of foods, and included development of point estimates and distributions for those intake rates. Intake rates represent one exposure variate in the algorithm, estimating dose through ingestion of foods. In order to calculate human exposure to contaminants through the food chain, as in Eq. 7-1, concentrations of contaminants, Cf, must be estimated in food products. The following sections describe the algorithms and default values for exposure variates used in estimating concentrations in foods.

7.6.1 Algorithms used to Estimate Concentration in Vegetation (Food and 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 form the roots (µg/kg)

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 an animal feeding study. At the present time, 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 others have a GRAF of 1. There are no data available to describe differential absorption from fly ash particles as compared to feed for 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 this is 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.

7.6.1.1 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:
- Dep = deposition rate on impacted vegetation ($\mu g/m^2/day$)
- IF = interception fraction
- k = weathering constant (d^{-1})
- Y = crop yield (kg/m^2)
- 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:

$$Dep = GLC \times Dep\ rate \times 86{,}400 \qquad \text{(Eq. 7-4)}$$

where:
- GLC = ground level concentration of contaminant in air (g/m^3)
- Dep-rate = vertical deposition rate (m/sec)
- 86,400 = seconds per day

The ground level concentration is calculated in the air dispersion modeling (see Section 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 Section 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. Some information is available from studies of radioactive isotopes for pasture grasses. The empirical relationship for grasses is given by:

$$IFpg = 1 - e^{-2.88\ Y} \qquad \text{(Eq. 7-5)}$$

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% of the wet weight is water, then the IF for pasture grasses is approximately 0.7 (Baes et al., 1984). It is difficult to arrive at a wet yield value for exposed, protected, leafy and root vegetables. It is therefore recommended that the 2 kg/m^2 value be used for these categories of produce as well. There are no data on interception fraction for leafy vegetables and exposed produce. The interception fraction for leafy vegetables and exposed produce were modeled by Baes et al. (1984) using assumptions based on typical methods of cultivating leafy and exposed vegetables in the United States. Baes et al. arrive at an average interception fraction of 0.15 for leafy vegetables (which we round up to 0.2) and 0.052 for exposed produce (which we round up to 0.1).

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. U.S. NRC uses a weathering constant of 14 d^{-1}. 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 fruit (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.

7.6.1.2 Translocation from the Roots

The other half of Equation 7-2 represents the amount of contaminant that gets into the plant through root translocation from the soil. The equation for calculating concentration in the plant from root uptake is as follows:

$$Ctrans = Cs\ (UF) \qquad \text{(Eq. 7-6)}$$

where:
- Cs = concentration in the soil (see Section 4)
- UF = root uptake factor

The concentration in the soil is calculated as in Section 6, Equation 6.2, using an assumption of 15 cm mixing depth for the food ingestion pathway. This assumption is based on the fact that vegetable gardens and commercial operations till the soil turning the uppermost layers in and mixing the soil. There are some studies examining root uptake of contaminants from soil into crop plants. Some of these studies are useful in generating root uptake factors to estimate concentration in the edible portions of plants. Baes et al. present soil-to-plant elemental transfer coefficients for a number of elements derived from an analysis of studies in the literature, comparison with other elements from the same group, and comparison of observed and predicted concentrations in plants grown in soils with known concentrations. Where multiple references were available describing transfer coefficients for the same element, Baes and colleagues (1984) calculated the geometric mean. These transfer coefficients were calculated as the ratio of the element in dry plant tissue to the concentration in dry soil. The transfer coefficients were analyzed for vegetative portions of the plant (aerial portions except for reproductive tissue) and for reproductive or tuberous portions separately. These transfer coefficients were adjusted for wet weight of plant parts and wet weight of soil by Clement Associates (1988) for use with food consumption information that is reported on a wet weight basis. Clement Associates (1988) assumed a dry-to-wet weight fraction of 0.08 for leafy crops, 0.126 for exposed crops, 0.2 for root crops, and 0.8 for soil. We are recommending the numbers in Baes et al. (1984) adjusted as described in Clement Associates (1988) for use as plant uptake factors in Equation 7-6 (Table 7.6).

Table 7.6 Soil uptake factors for inorganics based on Baes et al. (1984) soil-to-plant transfer coefficients and adjusted for wet weight as in Clement Associates (1988).

Element	Soil UF Leafy	Soil UF Exposed & Protected	Soil UF Root
Arsenic	4×10^{-3}	9×10^{-4}	4×10^{-4}
Beryllium	1×10^{-3}	2×10^{-4}	2×10^{-3}
Cadmium	6×10^{-2}	2×10^{-2}	4×10^{-2}
Chromium	8×10^{-4}	7×10^{-4}	1×10^{-3}
Lead	5×10^{-3}	1×10^{-3}	2×10^{-3}
Mercury	9×10^{-2}	3×10^{-2}	5×10^{-2}
Nickel	6×10^{-3}	9×10^{-3}	2×10^{-2}

UF leafy = uptake factor for leafy vegetables; derived from Baes et al. (1984) as follows:
Bv × 0.08/0.8, where Bv is the soil-to-plant transfer factor for vegetative parts (leaf, stem)

UF exposed = uptake factor for exposed or protected produce; derived from Baes et al. as follows:
Br × 0.126/0.8, where Br is the soil-to-plant transfer coefficient for reproductive or tuberous plant parts.

UF root = uptake factor for root crops; derived from Baes et al. as follows:
Br × 0.2/0.8 where Br is the soil-to-plant transfer coefficient for reproductive or tuberous plant parts.

7.6.2 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 ingestion (μg/day)
Dfeed = dose through feed ingestion (μg/day)
Dpast = dose through pasturing/grazing (μg/day)
Dsi = dose through soil ingestion (μg/day)
Tco = transfer coefficient from ingested media to meat/milk products

7.6.2.1 Dose via Inhalation

The dose via inhalation is proportional to the concentration of the contaminant in the air and the amount of air breathed in a single day. Note that no attempt is made to account for absorption across the lung. This is in part due to the fact that the cancer potency factors and

Reference Exposure Levels have not been adjusted for absorption. It would not be justifiable to adjust the environmental dose if the toxicity criteria do not reflect absorbed dose. 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)

7.6.2.2 Dose via Water Ingestion

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 ingestion is proportional to the concentration of the contaminant in the drinking water and the amount of water ingested daily. In addition, the fraction of the water ingested 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 through survey of the cattle farmers in the impacted area. The dose via water ingestion 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 ingestion (μg/day)
WI = water ingestion rate (L/day)
Cw = concentration of contaminant (μg/L)
Fr = fraction of animals' water intake from the impacted source

Cw is calculated as in Section 8. Water ingestion rates for food animals are shown in Table 7.7. The fraction of the animals' water intake that comes from the source impacted by emissions is a site-specific variable.

7.6.2.3 Dose from Feed Ingestion, Pasturing and Grazing

Airborne contaminants may deposit on pastureland and on fields growing feed for animals. 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:

$$Dfeed = (1\text{-}G) \times FI \times L \times Cf \qquad \text{(Eq. 7-10)}$$

where:
Dfeed = dose through feed ingestion (μg/day)
G = fraction of diet provided by grazing
FI = feed ingestion 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 = food ingestion rate (kg/day)
Cf = concentration of contaminant in pasture (μg/kg)

Feed ingestion rates are given for food animals in Table 7.7. 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 7.7 Point Estimates for Animal Pathway

Parameter	Beef Cattle	Lactating Dairy Cattle	Pigs	Poultry
BW (body weight in kg)	500	500	60	2
BR (inhalation rate in m^3/d)	100	100	7	0.4
WI (water ingestion in kg/d)	40	80	8	0.2
FI (feed ingestion in kg/d)	8	16	2	0.1
%Sf (soil fraction of feed)	0.01	0.01	NA	NA
%Sp (soil fraction of pasture)	0.05	0.05	0.04	0.02

7.6.2.4 Transfer Coefficients from Feed to Animal Products

Meat and milk products become contaminated when food-animals inhale or ingest materials that are transferred to the meat or milk. The transfer coefficients presented in Tables 7.8 and 7.9 are taken largely from Clement Associates (1988). This document cites the work of Baes et al. and Ng and colleagues on the transfer of radionuclides through the forage-meat pathway, and uses the equations of Travis and Arms (1988) for calculating transfer coefficients for organic compounds.

Table 7.8 Feed-to-Meat Transfer Coefficients modified from Clement Associates (1988)

Chemical	Form	Tco (d/kg)	Source
Arsenic	NS	2.0×10^{-3}	Baes et al., 1984
Beryllium	NS	1.0×10^{-3}	Baes et al., 1984
Cadmium	NS	5.5×10^{-4}	Baes et al., 1984
Chromium VI	NS	9.2×10^{-3}	Ng et al., 1982
Lead	NS	4.0×10^{-4}	Ng et al., 1982
Mercury [a]	NS	2.7×10^{-2}	Ng et al., 1982
Nickel	NS	2.0×10^{-3}	Ng et al., 1982
PCBs [b]	Aroclor 1254	5.0×10^{-2}	Fries et al., 1973
PCDD/F as 2,3,7,8-TCDD[c]	--	4.0×10^{-1}	Jensen et al., 1981
PAH as benzo-a-pyrene	--	3.4×10^{-2}	OEHHA based on Travis and Arms, 1988

a. Based on observation in chickens.
b. Transfer coefficient derived from feeding study of Aroclor 1254; calculated from concentrations of Aroclor 1254 in milk fat.
c. Transfer coefficient derived from feeding study of 2,3,7,8-TCDD; calculated from a pharmacokinetic extrapolation of 2,3,7,8,-TCDD in beef fat at steady-state.
NS = form of chemical not specified.

Table 7.9 Feed-to-Milk Transfer Coefficients from Clement (1988)

Chemical	Form	Tco (d/L)	Source
Arsenic	sodium arsenate	6.2×10^{-5}	Ng et al., 1979
Beryllium	beryllium chloride	9.1×10^{-7}	Ng et al., 1979
Cadmium	NS	1.0×10^{-3}	Ng et al., 1979
Chromium VI	sodium chromate	1.0×10^{-5}	Van Bruwaene et al., 1984
Lead	NS	2.6×10^{-4}	Ng et al., 1979
Mercury	Mercuric nitrate	9.7×10^{-6}	Ng et al., 1977
Nickel	NS	1.0×10^{-3}	Ng et al., 1979
PCBs [a]	Aroclor 1254	1.0×10^{-2}	Fries et al., 1973
PCDD/F as 2,3,7,8-TCDD [b,c]	--	4.0×10^{-2}	Jensen et al., 1981
PAHs as benzo-a-pyrene [d]	--	1.6×10^{-2}	Travis and Arms, 1988

a. Transfer coefficient derived from a feeding study of Aroclor 1254, calculated from measured Aroclor 1254 in milk fat.
b. Transfer coefficient derived from a feeding study; calculated form a pharmacokinetic extrapolation of 2,3,7,8-TCDD concentration in beef fat at steady state.
c. Transfer coefficient is an average of three values.
d. Transfer coefficient calculated from regression equation in Travis and Arms (1988).
NS = chemical form not specified.

The concentration of contaminant in meat, milk, or eggs can be related to the total mass of the material ingested or inhaled per day. The transfer coefficient represents the ratio of the chemical concentration in meat, milk, and eggs to the mass of the chemical consumed. A basic formula for calculating transfer coefficient for radionuclides is taken from Ng et al. (1979) who studied the transfer of radionuclides through the meat and milk pathway:

$$TCo = \frac{Cm}{(Cf)\,(I)} \qquad \text{(Eq. 7-12)}$$

where:
- TCo = the transfer coefficient from feed to animal meat, milk, or fat in day/kg or day/L;
- Cm = chemical concentration in animal meat, milk, or fat (mg/kg or mg/L)
- Cf = chemical concentration in feed (mg/kg);
- I = reported daily intake of animal feed (kg/day)

In the ideal world, transfer coefficients would be obtained from animal feeding studies under steady-state conditions. However, there are few such studies available in the literature. Some information for inorganic chemicals can be obtained by extrapolating from work done with radionuclides, assuming that the transfer coefficient of the non-radioactive isotope of a compound is the same as the radioactive isotopes. There are studies on transfer of 2,3,7,8-tetrachlorodibenzo-p-dioxin in feed to beef and milk (Jensen et al., 1981; Jensen and Hummel, 1982), and another on transfer of PCBs (Fries et al., 1973). Transfer coefficients from these studies were presented by Clement Associates (1988). Travis and Arms (1988) published a regression equation based on octanol: water partition coefficient for transfer of organic chemicals from feed to animal products. The regression equation for transfer coefficient for feed to meat is:

$$TCo = 10^{-7.6+\log Kow} \qquad \text{(Eq. 7-13)}$$

where:
- TCo = feed to meat transfer assuming a fat content of 25%
- Kow = octanol:water partition coefficient

The regression equation for feed to milk transfer is:

$$TCo = 10^{-8.1+\log Kow} \qquad \text{(Eq. 7-14)}$$

and is based on an assumption of 4% milk fat.

These equations were utilized by Clement Associates (1988) in their calculations of transfer coefficients for a few organic chemicals. The authors of the Clement document adjusted the regression equations of Travis and Arms for a 17% beef fat content after cooking to obtain their feed to meat transfer by multiplying the Travis and Arms regression equation by (0.17/0.25). OEHHA has similarly calculated transfer coefficients for PAHs as benzo-a-pyrene and presented them in Tables 7.8 and 7.9, using a log Kow of 6.3.

In equation 7-12, the dose via various exposure pathways is multiplied by the transfer coefficients. OEHHA recommends that the feed-to-beef transfer coefficients be used for chicken and pork as well. In addition, these transfer coefficients should be used for feed-to-egg transfer. There is a lack of information on the latter, but the composition of eggs (high protein and fat) is similar to meat, and transfer coefficients might also be similar. Another assumption made in Eq. 7-12 is that the feed-to meat and feed-to milk transfer coefficients are also applicable to soil ingestion, water ingestion, pasturing and grazing, and inhalation. Given any data to the contrary, OEHHA is recommending that the feed-to-beef and feed-to-milk transfer coefficients be used for these other exposure pathways.

7.7 Default Values for Calculation of Food Contaminant Concentration

7.7.1 Body Weight Defaults

Reported body weights for dairy cattle have ranged from 350 to 800 kg for adult cows on a maintenance diet, with bulls reaching 900-1000 kg (National Research Council, 1966). Beef cattle have body weights in the range of 181 to 816 kg. Reports of body weight of shorthorn cattle have ranged from 79-359 kg (Johnson et al., 1958) to 568-620 kg (Balch et al., 1953). A default body weight value of 500 kg was established as a reasonable estimate within this range of reported values for both of these types of cattle.

Mean pig body weights of 30.9-80 kg at age 13-23 weeks have been reported (Agricultural Research Council, London, 1967). Mean pig body weights of 56.7-102.1 kg for meat-type pigs and 34-102 kg for bacon-type pigs have also been reported (National Research Council, 1964). A default estimate of 60 kg for pig body weight that falls within the reported range was established.

Mean body weights for chickens have been reported in the range of 1.8-2.5 kg for adult chickens and 0.25-1.5 kg during growth (National Research Council, 1966). A mean body weight of 1.6 kg has been reported for female chickens and male and female chicken body weights of 4.2 kg and 3.4 kg, respectively, were also reported (Sturkie, 1986). A default chicken body weight of 2 kg was selected as a value that falls in the range of those reported in the literature.

7.7.2 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 $\cong$ 6.07 ml/kg body weight) (Breazile, 1971). Using this relationship, the default animal body weight, and breathing cycle frequencies also provided in Breazile (1971), breathing rates were generated. 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 cattle (both types), pigs, and poultry are 100, 7, and 0.4 m^3/day, respectively. The default value for cattle falls within the range of that reported by Altman et al. (1958).

7.7.3 Feed Ingestion Defaults

Feed intake rates of 4.8-14.1 kg/day and 0.4-15.5 kg/day have been estimated for beef and dairy cattle, respectively (National Research Council, 1964; National Research Council, 1966). Another report estimated feed consumption at 6.1-17.5 kg/day for beef cattle and 15.0-25.0 kg/day for dairy cattle, with means of 12.2 and 16.9 kg/day, respectively (McKone and Ryan, 1989). Feed consumption for a 500 kg dairy cow walking 1 mile/day on a 1.8 Mcal/kg dry matter diet (pasture equivalent) has been estimated at 6.5 kg/day for non-pregnant cows, 11.2 kg/day for pregnant cows, and 15.9 kg/day for lactating cows (Agricultural Research Council, London, 1965). For beef cattle (~400 kg, walking 1 mile/day on a 1.8 Mcal/kg dry matter diet) estimates of feed intake were 6.9 kg/day for maintenance and 8.4-12.3 kg/day for growth diets. For non-lactating beef cattle, a default value of 8 kg/day was established as a value that falls within the reported range. For lactating cattle, the reported value of 16 kg/day was adopted (Agricultural Research Council, London, 1965).

Feed intake for pigs was reported to range from 1.0 to 3.2 kg/day (87% dry matter) for pigs of several types including castrates, gilts and pigs ready for slaughter (Agricultural Research Council, London, 1967). Feed intakes of 3.0-3.5 kg/day for meat-type swine and 0.54-5 kg/day for bacon-type swine have also been reported (National Research Council, 1964). A default value of 2 kg/day was chosen as a reasonable estimate in the range of the reported feed intakes from these literature sources.

Feed ingestion rates for chickens have reported to range from 0.027 to 0.125 kg/day (National Research Council, 1966). Feed rates for growing chickens ranging from 0.040 to 0.130 kg/day have also been reported, with the higher values reported for mature chickens (Wiseman, 1987). A value of 0.1 kg/day was determined as a reasonable point estimate, which falls in the range of the reported values.

7.7.4 Water Ingestion Defaults

Literature reported water intake rates are generally expressed in relation to dry matter ingestion on a weight basis. Water intake also generally increases with increasing temperature. Water intakes 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 ingested for shorthorn cows at 27°C and 3.2-3.8 kg/kg dry matter ingested 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 ingested have also been reported (Balch et al., 1953). Water intake at lower temperatures (-18 to 4°C) of 3.5 kg/kg dry matter ingested has also been reported (MacDonald and Bell, 1958). Friesian cattle water intake was estimated at 3.3-4.3 kg/kg dry matter ingested (Atkeson et al., 1934). 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. The resulting default water consumption rates for beef cattle and lactating dairy cattle are 40 and 80 kg/day, respectively.

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. A default water consumption estimate of 8 kg/day was chosen to represent an estimate falling in the range of these literature reported values.

Chicken water consumption has been reported to fall in the range of 1-3 times the food consumption on a weight basis (Agricultural Research Council, London, 1975). Two-fold water to feed consumption was established 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.

7.7.5 Soil Consumption Defaults

Soil consumption 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% of dry matter consumed, depending on the management system used, with those cattle with access to pasture having the greatest soil consumption. For cattle on feed, a reasonable estimate of 1% soil consumption was made. For cattle grazing pasture, soil intake estimates of 4-8% dry matter consumption have been made for cattle receiving no supplemental feed (Healy, 1968). Soil consumption varies seasonally, with the greatest soil ingestion during times of poor plant growth (14%) and the least soil ingestion during lush growth (2%). 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% 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% dry matter consumed. A reasonable estimate of soil consumption as percent of pasture consumed is 5%.

Soil consumption estimates have been made for pigs (Healy and Drew, 1970). A mean weekly soil consumption 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 consumption of 2 kg/day, the soil consumption as percent of grazed feed (pasture) ranged from 1.5 to 7%, with a best estimate of 4%. 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% soil from pasture ingestion.

As a digestive aid, chickens normally consume approximately 2% grit in their diet (McKone, 1993; NRC, 1984). This value was used as an estimate of the fraction of soil consumption 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.

7.8 Summary

OEHHA has used the 1989-91 CSFII survey data for the Pacific region (USDA, 1989-91) to generate per capita consumption distributions for produce, meat (beef, chicken, and pork), dairy products and eggs. The Pacific Region CSFII (1989-91) data used are more representative of the California population than surveys, which address the entire United States. The availability of body weight data for each subject in the survey enabled consumption to be expressed in gram/kg body weight/day. The variability in food consumption that was due to variability in body weight was thus accounted for.

7.9 Recommendations

7.9.1 Point Estimates

OEHHA is recommending that the default values presented in Table 7.10 be used for the point estimate approach (Tiers 1 and 2). These default values represent the mean and 95th percentiles of the distributions presented in Tables 7.2 and 7.4.

Table 7.10 Default Values for Per Capita Food Consumption (g/kilogram /day)*

Category of Food	Ages 0-9		Ages 0-70	
	Average	High End	Average	High End
Produce				
Exposed	4.16	15.7	3.56	12.1
Leafy	2.92	10.9	2.90	10.6
Protected	1.63	6.66	1.39	4.88
Root	4.08	14.9	3.16	10.5
Meat				
Beef	2.24	7.97	2.25	6.97
Chicken	1.80	4.77	1.46	5.02
Pork	1.31	5.10	1.39	4.59
Dairy	12.0	51.9	5.46	17.4
Eggs	3.21	10.3	1.80	5.39

*The average and high end values in this table represent the mean and 95th percentile, respectively, of the distributions in Tables 7.2 and 7.4.

7.9.2 Stochastic Approach

OEHHA is recommending that the food consumption distributions presented in Tables 7.3 and 7.5 be used to assess the risks from consumption of contaminated beef, chicken, pork dairy products and eggs. These parametric distributions are close to the empirical distributions and provide a useful description of the empirical distribution compatible with the use of the currently available software.

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8. Water Intake

8.1 Introduction

Water serves as a vehicle not only for waterborne nutrients but also for chemical toxicants and microorganisms. Airborne substances can deposit directly on surface water bodies used for drinking water and other domestic activities. (Material carried in by surface run-off is not considered at this time.) The equation to calculate the water concentration in the Air Toxics "Hot Spots" risk assessment model is:

$$Cw = GLC * \text{Dep-rate} * 86{,}400 * SA * 365 / (WV * VC) \qquad \text{(Eq. 8-1)}$$

where:
- Cw = Average concentration in water (μg/kg)
- GLC = Ground-level concentration of the pollutant ($\mu g/m^3$)
- 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 values can be obtained from the applicable Department of Water Resources (DWR) Regional office. The equation assumes that all material deposited into the water remains in the water column and that the deposition rate remains constant for the 70-year exposure duration.

Assessing exposure to toxic substances in water requires knowledge of the actual intake in exposed populations. Extremes of intake in both normal and susceptible subpopulations are pertinent to both risk assessment and risk management. Facilities in the "Hot Spots" program with bodies of water used for drinking within their zone of impact need to evaluate this pathway of exposure. Defining both total water and tap water intakes in the subject populations is thus a key objective in many environmental risk assessments. Tap water usually includes water used directly for drinking and used in making cold and hot beverages. "Total water" would include tap water, water in food, bottled beverages, etc. There is some degree of overlap since tap water may be used in a local bottling plant for instance. Typically when estimating exposures via drinking water, risk assessors assume that children and adults ingest 1 and 2 liters of water per day, respectively (NAS, 1977). These values have been used in guidance documents and regulations issued by the U.S. Environmental Protection Agency. The purpose of this section is to briefly assess data on individual water consumption rates for possible use in stochastic types of exposure assessments that employ distributions of water intake. In addition, point estimates of intake on a body weight basis are taken off the distribution for use in the point estimate approach of Tier 1 and 2. The water ingestion algorithm is:

$$DOSEwater = 1E\text{-}3*Cw*WIR*ABSing*Fdw*EF*ED/AT \qquad \text{(Eq. 8-2)}$$

where:

DOSEwater =	daily oral dose of contaminant, mg/kg-d
1E-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
ABSing =	GI tract absorption factor (default = 100%)
Fdw =	Fraction of drinking water from contaminated source (default = 100%)
EF =	Exposure frequency (days/year)
ED =	Exposure duration (years)
AT =	Averaging time (period over which exposure is averaged, in days) for noncarcinogenic effects, AT = ED* 365 d/year; for carcinogenic effects, AT = 70 years*365 d/year = 25,500 d

8.2 Empirical Distributions

8.2.1 Exposure Factors Handbook (U.S. EPA, 1997)

In U.S. EPA's Exposure Factors Handbook (U.S. EPA, 1997), three key studies are identified which provide the basis for U.S. EPA's recommendations regarding water intake: Canadian Ministry of National Health and Welfare (1981), Ershow and Cantor (1989), and Roseberry and Burmaster (1992). These studies were selected based on the applicability of their survey designs to exposure assessment of the entire United States population. U.S. EPA selected a value of 1.41 L/day (21 mL/kg-day) as the recommended average tapwater intake rate for adults. This value is the population-weighted mean of the data from Ershow and Cantor (1989) and Canadian Ministry of National Health and Welfare (1981). U.S. EPA selected the average of the 90th percentile values from the same two studies (i.e., 2.35 L/day or 34.2 mL/kg-day), as the upper limit value. U.S. EPA notes that the commonly used intake rate of 2.0 L/day for adults corresponds to the 84th percentile of the intake rate distribution among the adults in the Ershow and Cantor (1989) study. For a mathematical description of intake distribution, U.S. EPA recommends using the data of Roseberry and Burmaster (1992) who fit lognormal distributions to the water intake data reported by Ershow and Cantor (1989) and estimated population-wide distributions for water intake based on proportions of the population in each age group. However, U.S. EPA cautions against using Roseberry and Burmaster (1992) for post-1997 estimates since these distributions only reflect differences in the age structure of the U.S. population between 1978 and 1988. In addition to intake rates for adults, U.S. EPA also provides a table of intake rates for children, by age category, also from Ershow and Cantor (1989) and Canadian Ministry of National Health and Welfare (1981).

OEHHA agrees with U.S. EPA in the choice of studies on which to base recommended intake rates and distributions for the general U.S. population. However, for the purposes of this document OEHHA chose to analyze a subset of the Ershow and Cantor (1989) data. OEHHA analyzed the data from the "Western Region" which is dominated by the population of California, since these data are more applicable to California and the "Hot Spots" program.

8.2.2 Ershow and Cantor (1989), Ershow et al. (1991)

The Ershow and Cantor (1989) and Ershow et al. (1991) studies are the most extensive analyses of the 1977-1978 Nationwide Food Consumption Survey (NFCS) data with respect to drinking water. All food and beverage sources, as well as drinking water, are incorporated in the estimates of total water intake. Estimates of tap water intake include drinking water and tap water added in final home or restaurant preparation of beverages and foods. Data are presented by age group, sex, season, and geographic region, and separately for pregnant women, lactating women, and breast-fed children. The study involved 26,081 participants. The average intake for all participants (except pregnant, lactating, breast-fed) was 2,072 ± 803 g/day of total water including 1,193 ± 702 g/day of tap water. The analyses are presented in 72 tables. The more important values are for: a) total water intake by age group for all participants, all regions, all seasons; b) tap water for the same; c) total water and tap water for all participants, all seasons, western region; and d) total water and tap water intakes for pregnant women, lactating women, and breast-fed children. These intake estimates, converted to mL/kg-d (assuming 1g = 1 mL), are summarized in Tables 8.1 through 8.5. In Table 8.1, the overall values (mean ± SD) for total water and tap water were 2,072 ± 803 and 1,193 ± 702 mL/day, respectively. The 90th and 95th percentiles of total water intake (not normalized to the subjects' body weight) were 3,098 and 3,550 mL/day, respectively. For tap water intake, the 90th and 95th percentiles are 2,092 and 2,477 mL/day, respectively. In Table 8.2 the same information is presented in units of mL/kg body weight/day. The body weights were self reported. In Table 8.3, the Western Regional data which are based on about 1/6 th of the total data set, are about 6% higher for mean ± SD: 2,206 ± 886 and 1,263 ± 764 mL/day for total water and tap water intakes, respectively. The 90th and 95th percentiles for total water intake (not normalized to the subjects' body weight) were 3,368 and 3,852 mL/day, respectively. The 90th and 95th percentiles for tap water intake are 2,219 and 2,680 mL/day, respectively. Table 8.4 presents the same information as Table 8.3 but in units of mL/kg body weight/day. Note that when these data are analyzed by normalizing water intake to body weight of subjects in the study, the traditional assumption of 2 liters for a 70 kg body weight corresponds to about the 75th percentile on Ershow and Cantor's distribution (Table 8.4, 0.28 mL/kg-day), while the value of 2 L/day not normalized to body weight is about the 90th percentile on the intake distribution. Table 8.5 summarizes the intake estimates for pregnant women, lactating women, and breast-fed children. Although the NFCS dataset has several limitations, as noted by the authors, it represents the largest and most relevant survey extant. Its overall results are quite similar to other smaller surveys conducted in Canada (n = 970) and the U.K. (n = 3564). There is no comparable dataset based solely on California residents.

Table 8.1 Water Intake Estimates From 1977-1978 NFCS in mL/day (Ershow & Cantor 1989)[a]

Age Group	N	50%	75%	90%	95%	$\bar{x} \pm$ SD
Total Water						
< 1	403	1120	1339	1597	1727	1148 ± 332
1-10	5,605	1497	1843	2236	2507	1559 ± 507
11-19	5,801	1874	2369	2908	3336	1989 ± 719
20-64	11,731	2109	2663	3318	3793	2243 ± 839
65+	2,541	2109	2616	3132	3482	2199 ± 728
All	26,081	1950	2485	3098	3550	2072 ± 803
All Males	11,888	2132	2719	3414	3903	2261 ± 888
All Females	14,193	1823	2299	2816	3166	1919 ± 691
Tap Water						
< 1		240	424	649	775	302 ± 258
1-10		665	960	1249	1516	736 ± 410
11-19		867	1246	1701	2026	965 ± 562
20-64		1252	1737	2268	2707	1366 ± 728
65+		1367	1806	2287	2636	1459 ± 643
All		1081	1561	2092	2477	1193 ± 702
All Males		1123	1634	2205	2673	1250 ± 759
All Females		1049	1505	1988	2316	1147 ± 648

[a] All Seasons, All Regions, pregnant, lactating and breast-fed excluded. Assumes 1 mL = 1 g as originally reported.

Table 8.2 Water Intake Estimates From 1977-1978 NFCS in mL/kg body weight/day (Ershow & Cantor, 1989)[a]

Age Group	N	50%	75%	90%	95%	$\bar{x} \pm$ SD
Total Water						
< 1		152.5	190.9	238.4	274.0	163.1 ± 63.3
1-10		69.2	92.0	117.7	135.5	75.3 ± 32.2
11-19		35.4	45.5	56.8	64.4	37.5 ± 14.5
20-64		30.7	39.1	48.8	56.1	32.6 ± 12.5
65+		31.4	39.4	47.7	54.6	32.9 ± 11.5
All		34.5	47.7	70.8	93.6	41.8 ± 27.4
All Males		35.3	49.7	75.2	98.6	43.3 ± 28.1
All Females		34.0	46.2	66.4	88.9	40.7 ± 26.8
Tap Water						
< 1		35.3	54.7	101.8	126.5	43.5 ± 42.5
1-10		30.5	46.0	64.4	79.4	35.5 ± 22.9
11-19		16.3	23.6	32.3	38.9	18.2 ± 10.8
20-64		18.2	25.3	33.7	40.0	19.9 ± 10.8
65+		22.3	27.1	34.7	40.0	21.8 ± 9.8
All		19.4	28.0	39.8	50.0	22.6 ± 15.4
All Males		18.9	27.9	40.2	52.0	22.5 ± 16.0
All Females		19.7	28.0	39.3	48.8	22.7 ± 15.0

[a] All Seasons, All Regions, pregnant, lactating and breast-fed excluded. Assumes 1 mL = 1 g as originally reported.

Table 8.3 Western Regional Water Intake Estimates in mL/day (Ershow & Cantor, 1989)[a]

Age Group	N	50%	75%	90%	95%	$\bar{x} \pm$ SD
Total Water						
< 1	68	1127	1321	1727	1866	1166 ± 359
1-10	849	1554	1972	2329	2580	1629 ± 536
11-19	884	1954	2504	3183	3594	2073 ± 779
20-64	1896	2246	2907	3645	4154	2409 ± 934
65+	383	2268	2767	3299	3706	2347 ± 727
All	4080	2070	2675	3368	3852	2206 ± 886
All Males	1856	2259	2937	3709	4152	2413 ± 950
All Females	2224	1916	2442	3071	3510	2037 ± 791
Tap Water						
< 1		276	517	754	----	362 ± 227
1-10		710	1042	1367	1564	782 ± 420
11-19		902	1299	1764	2143	992 ± 282
20-64		1322	1901	2489	2986	1452 ± 814
65+		1433	1881	2490	2794	1543 ± 629
All		1153	1645	2219	2680	1263 ± 764
All Males		1213	1737	2357	2867	1329 ± 799
All Females		1102	1576	2152	2530	1209 ± 730

[a] All seasons, pregnant, lactating, breast-fed excluded. Assumes 1 mL = 1 g as originally reported.

Table 8.4 Western Regional Water Intake Estimates in mL/kg body weight/ day[a]

Age Group	**50%**	**75%**	**90%**	**95%**	$\bar{X} \pm$ **SD**
Total Water					
< 1	149.9	196.9	264.0	——	168.4 ± 71.1
1-10	74.7	97.5	127.6	145.9	80.5 ± 33.9
11-19	36.5	47.0	58.2	66.8	38.8 ± 14.9
20-64	33.0	42.6	53.7	62.2	35.4 ± 13.8
65+	33.8	41.4	50.8	56.8	35.1 ± 11.5
All	37.0	51.3	76.0	99.0	44.8 ± 29.3
All Males	37.7	52.2	79.5	107.8	45.9 ± 29.1
All Females	36.6	50.6	71.9	93.0	43.9 ± 29.5
Tap Water					
< 1	39.4	66.7	106.3	141.4	53.2 ± 50.9
1-10	33.5	48.7	69.5	87.8	38.7 ± 23.8
11-19	16.9	23.7	32.1	39.4	18.4 ± 10.7
20-64	19.4	27.3	36.5	44.4	21.4 ± 12.2
65+	21.2	28.3	37.2	41.6	23.1 ± 9.7
All	**20.6**	**30.3**	**43.0**	**53.8**	**24.2 ± 17.0**
All Males	20.1	29.6	43.2	54.2	23.9 ± 16.6
All Females	21.1	30.9	42.9	53.2	24.5 ± 17.2

[a] Ershow & Cantor (1989). Assumes 1 mL = 1 g as originally reported.

Table 8.5 Water Intake Estimates For Pregnant Women, Lactating Women and Breast-Fed Children[a]

Group	N	50%	75%	90%	95%	$\bar{x} \pm$ SD
Total Water			**mL/day**			
Control	6201	1835	2305	2831	3186	1940 ± 686
Pregnant	188	1928	2444	3028	3475	2076 ± 743
Lactating	77	2164	2658	3164	3353	2242 ± 658
Breast-fed[b]	100	315	633	902	1023	402 ± 352
			mL/kg/day			
Control		30.5	38.7	48.4	55.4	32. ± 1
Pregnant		30.5	40.4	48.9	53.5	32.1 ± 11.8
Lactating		35.1	45.0	53.7	59.2	37.0 ± 11.6
Breast-fed[b]		48.8	78.8	122.3	155.4	55.7 ± 48.1
Tap Water			**mL/day**			
Control		1065	1503	1983	2310	1157 ± 635
Pregnant		1063	1501	2191	2424	1189 ± 699
Lactating		1330	1693	1945	2191	1310 ± 591
Breast-fed		89	249	351	468	153 ± 175
			mL/kg/day			
Control		17.3	24.4	33.1	39.1	19.1 ± 10.8
Pregnant		16.4	23.8	34.5	39.6	18.3 ± 10.4
Lactating		20.5	26.8	35.1	37.4	21.4 ± 9.8
Breast-fed		11.8	37.8	55.8	60.1	21.7 ± 25.4

[a] Ershow et al. (1991)
[b] Ershow & Cantor (1989)
Assumes 1 mL = 1 g as originally reported.

8.2.3 Canadian Study (CEHD, 1981)

This study, conducted in the summer of 1977 and the winter of 1978, 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. For the population as a whole the average intake of tap water and tap water-based beverages was 1.34 L/day and the 90th percentile was 2.36 L/day. Tap water consumption was observed to increase with age with the most rapid increase occurring in individuals less than 18 years old. The Canadian study was not used because the climate of Canada tends to be colder than California and the raw data necessary to determine distributional characteristics were not available.

8.2.4 High Activity Levels / Hot Climates

In their Exposure Factors handbook, 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.

8.3 Modeled Distributions

8.3.1 Roseberry and Burmaster (1992)

Roseberry and Burmaster have fit lognormal distributions to some of the datasets of Ershow and Cantor (1989) discussed above. In tabulating the data they converted the units to mL/day and also adjusted the data to more closely approximate the age group distribution in the

U.S. population according to the latest Census figures (simulated balanced population). Table 8.6 gives the lognormal fits to the dataset most closely represented by Table 8.1 (i.e., all participants, all seasons, all regions). The values in the table are natural logarithms and could be used directly in a Monte Carlo simulation program such as Crystal Ball. In Table 8.7, the estimated percentiles from these modeled distributions are given for comparison with earlier tables. A comparison of Table 8.7 with Table 8.1 indicates that the modeled distributions are somewhat less skewed but overall fairly similar. Unfortunately the authors did not fit the model to the Western Regional data subset or the sex subsets. For all participants the best fits for total water and tap water intakes are the following lognormal distributions: exp (7.487 ± 0.405) and exp (6.870 ± 0.575) mL/day, respectively. The total water and tap water intake rates of simulated balanced populations can also be represented by lognormal distributions of exp (7.492 ± 0.407) and exp (6.864 ± 0.575) mL/day, respectively. The corresponding values for the 50th percentile of total water and tap water intake rates for all participants are 1785 mL/d and 963 mL/d, respectively. For the simulated balanced population the 50th percentile of total and tap water intake are 1794 mL/d and 957 mL/d, respectively.

Table 8.6 Summary of Best Fit Lognormal Distributions for Water Intake Rates (mL/day)[a]

Age Group	m	s	**R2**
Total Water			
< 1	1120.29	333.03	0.996
1-10	1393.82	487.93	0.953
11-19	1901.13	680.06	0.966
20-64	2085.99	868.91	0.977
65+	2096.03	779.69	0.988
All	1937.23	817.88	0.987
SBPb	1948.52	827.05	1
Tap Water			
<1	322.50	218.66	0.97
1-10	701.35	372.09	0.984
11-19	906.97	522.11	0.986
20-64	1264.66	657.30	0.956
65+	1341.16	676.32	0.978
All	1108.15	631.08	0.978
SBPb	1129.25	706.88	0.995

[a] Roseberry & Burmaster (1992)
[b] simulated balanced population

Table 8.7 Water Intake Estimates in mL/day from Modeled Distributions (Roseberry & Burmaster, 1992)

Age Group	2.5%	25%	50%	75%	97.5%	$\bar{x}$[a]
Total Water						
< 1	607	882	1074	1307	1900	1120
1-10	676	1046	1316	1655	2562	1394
11-19	907	1417	1790	2262	3534	1901
20-64	879	1470	1926	2522	4218	2086
65+	970	1541	1965	2504	3978	2096
All	807	1358	1785	2345	3947	1937
SBP[b]	808	1363	1794	2360	3983	1949
Tap Water						
<1	80	176	267	404	891	323
1-10	233	443	620	867	1644	701
11-19	275	548	786	1128	2243	907
20-64	430	807	1122	1561	2926	1265
65+	471	869	1198	1651	3044	1341
All	341	674	963	1377	2721	1108
SBP[b]	310	649	957	1411	2954	1129

[a] arithmetic mean
[b] simulated balanced population

8.4 Recommendations

8.4.1 Point Estimate Approach

The familiar default values of 2.0 L/day for an adult and 1.0 L/day for a child approximate the average intakes of total water and the 90th percentile of tap water intake observed in a number of independent studies when body weight is not taken into account. On a body weight basis, 2 L/day for a 70 kg body weight in the study used by Ershow and Cantor is approximately the 75th percentile on the distribution of Ershow and Cantor in Table 8.4.

The typical risk assessment in the Air Toxics "Hot Spots" program will likely look at a 9 year, 30 year and 70 year exposure duration. For the 9-year scenario, we recommend use of the mean and 95th percentile, 40 and 81 mL/kg BW-day, respectively, from the simulated distribution (Table 8.10; Figure 8.1) for the central tendency and high-end point estimates of water consumption rate. For the 30- and 70-year exposure scenarios, we recommend a time-weighted average tap water intake rate of 24 ml/kg-day as the central tendency estimate. This is the average tap water intake for all age groups (Table 8.4). For the 30- and 70-year scenarios, we recommend a high-end estimate of 54 ml/kg-day, which is the 95th percentile of tap water intakes for all age groupings (Table 8.4).

There may be circumstances where total water intake may need to be assessed, not just tap water intake. We have provided a distribution of total water intake for the readers' information. Mean and 95th percentiles may be used for appropriate age-groupings from Table 8.4 in assessing risks based on total water intake.

Table 8.8 Point estimates for tap water ingestion rates (mL/kg BW*day).

	9-Year Scenario (Children)	30 and 70 Year Scenarios
Average	40	24
High-end	81	54

8.4.2 The Stochastic Approach

While there are currently no ideal water intake distributions to use for California residents, the water intake rate distributions of Ershow and Cantor (1989) provide a reasonable basis for a stochastic assessment. We recommend the distribution for tap water for ages be utilized although in some cases values for both may need to be considered. Also 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. Also when using distributions it is appropriate to truncate them to avoid impossibly large or small values. For drinking water ingestion, one and 99.9 percentiles would seem suitable limits based on the Ershow & Cantor data sets cited above.

8.4.2.1 Empirical Western Regional distributions of Ershow & Cantor

For the 30-year and 70-year exposure scenario, the tap water intake distribution summarized in Table 8.4 for "all" age groups is recommended to represent water consumption for the Air Toxics "Hot Spots" risk assessments. Roseberry and Burmaster (1992) did not fit the Ershow and Cantor (1989) Western Regional dataset to a lognormal model. In Table 8.9 we compared the empirical percentiles for tap water consumption for all in Table 8.4 with the percentiles of a lognormal model with mean and standard deviation of 24.2 ± 17.0. OEHHA therefore recommends using the lognormal parametric model, $\exp(2.99 \pm 0.63)$, to assess the age 0-30 and age 0-70 year exposure scenarios.

Table 8.9 Comparison of Available Percentiles from Empirical Distribution with Lognormal Parametric Model.

	Mean	STD	Skew	Kurt-osis	p05	p10	p20	p30	p40	p50	p60	p75	p80	p90	p95
Empirical	24.2	17.0								20.6		30.3		43.0	53.8
Lognormal model			2.46	14.1	7.11	8.93	11.8	14.3	17.0	19.7	23.2	30.5	33.7	44.8	56.1

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 8.10. The distribution was fitted to a lognormal parametric model with an arithmetic mean and standard deviation of 40.3 ± 21.6, μ ±. σ is exp(3.57 ± 0.50). The Anderson Darling Statistic is 0.65. Thus the higher tap water intake rates of young children are incorporated into the distribution.

Table 8.10. Simulated tap water distribution for use in the 9-year exposure scenario (ML/kg body wt/day)

Mean	STD	Skew	Kurt-osis	p05	p10	p20	p30	p40	p50	p60	p70	p80	p90	p95
40.3	21.8	1.77	8.42	15.6	18.7	23.2	27.2	31.3	35.4	40.2	46.1	54.0	67.5	81.4

Figure 8.1 Simulated Water Consumption Distribution Ages 0-9 with Lognormal Parametric Model, Frequency Comparison

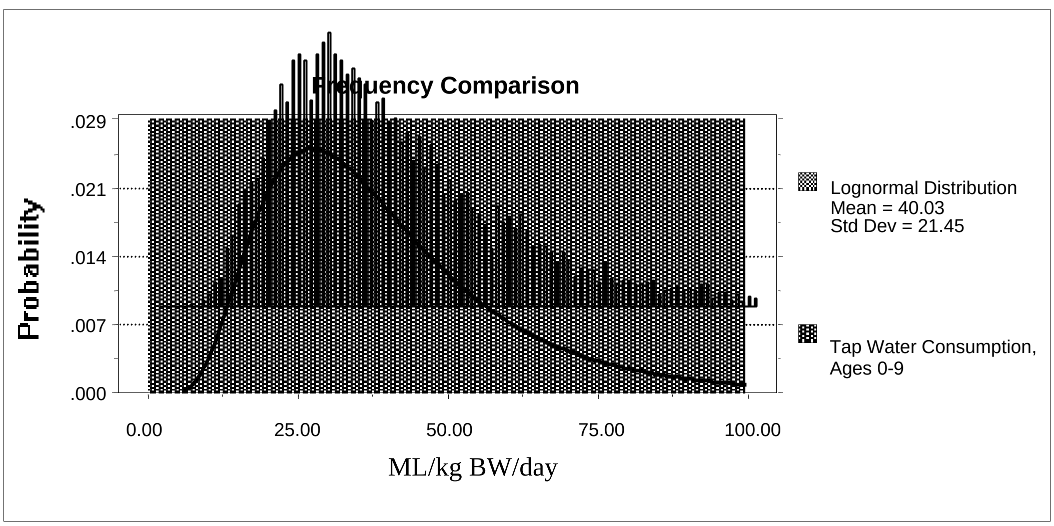


Figure 8.2 Simulated Water Consumption Distribution Ages 0-9 with Lognormal Parametric Model, Cumulative Probability Comparison.

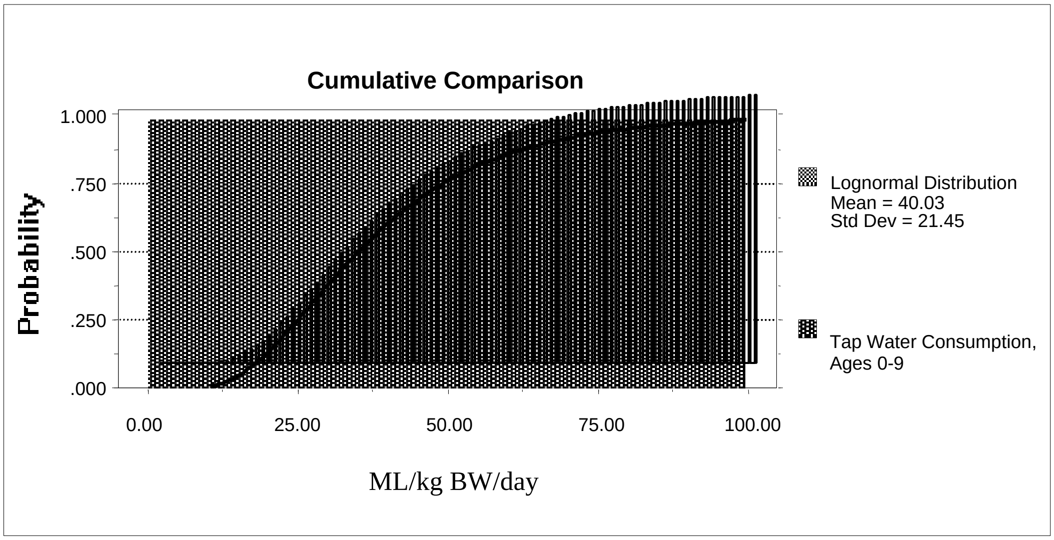
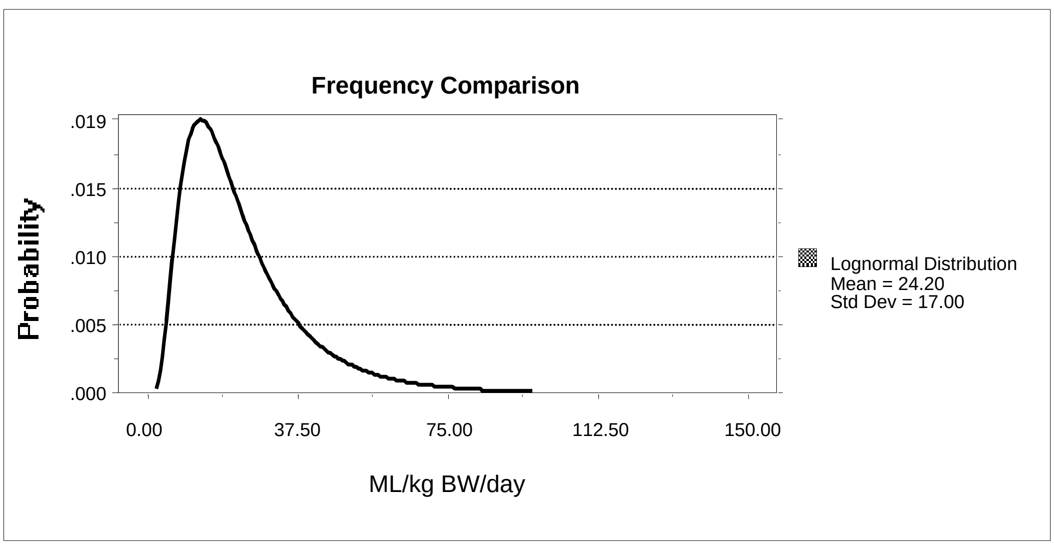


Figure 8.3 Lognormal Parametric Model Water Consumption Probability Distribution Ages 0-70



8.4.2.2 Pregnant, Lactating, Breast-fed Subpopulations

Comparison of water intake rates of potentially sensitive subpopulations of pregnant, lactating women and breast-fed babies in Table 8.5 (Ershow et al., 1991; Ershow & Cantor, 1989) with those in Table 8.4 indicate that the use of the values in Table 8.4 would be protective of these sensitive subpopulations.

8.4.2.3 High Activity Levels / Hot Climates

OEHHA is concerned that the high-end point estimate of 54 mL/kg-day (30- and 70-year scenarios) may not be sufficient to protect individuals living in extremely hot climates. Under such circumstances, OEHHA recommends using water consumption point estimates between 6-11 L/day, depending on the climatic conditions and activity levels. Expressed on a body weight basis, this is equivalent to 86-157 mL/kg BW/day, assuming an average adult male body weight of 70 kg. Specific data on water intake of children under these conditions were not available, therefore OEHHA recommends using the same estimates for the 9-, 30- and 70-year exposure scenarios.

8.5 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, mostly fresh water, near facilities emitting air pollutants. The consumption of fish from contaminated bodies of water can be a significant exposure pathway, particularly for lipophilic toxicants such as dioxins. Commercial store-bought fish generally come from a number of sources. Thus, except in the rare event that fish in these bodies of water are commercially caught and eaten by the local population, the health risks of concern are due to noncommercial fishing. Therefore, the noncommercial fish consumption rate is a critical variate in the assessment of potential health risks to individuals consuming fish from waters impacted by facility emissions. The term “fisher” refers to persons who catch noncommercial fish or shellfish. The term fisher may include both subsistence and sport fishers, but also may include others who do not fit easily into these categories.

It should be noted that the AB-2588 risk assessment process currently addresses contamination of fish only by bioconcentration and not by bioaccumulation. Bioconcentration is the purely physical-chemical process by which chemicals tend to apportion themselves between water and fish lipids, depending on the lipophillicity of the chemical. Bioaccumulation is the process through which chemical concentrations in fish increase as the chemical moves up the food chain. This process occurs because there are fewer organisms feeding off of more organisms at each level in the food chain, thus concentrating the chemical contaminants. The bioaccumulation process may cause higher fish contaminant concentrations than bioconcentration. The AB-2588 program is currently investigating the feasibility of applying the models for bioaccumulation which currently exist (Thomann et al., 1991) to the risk assessment process. It should be noted that on-site information on the fish species caught and its position in the food chain would have to be collected to assess bioaccumulation.

Estimates of noncommercial fish consumption by fishers tend to be comparable or greater than estimates of commercial fish consumption rates for the general population (Puffer et al., 1982a-b; SCCWRP and MBC 1994; U.S. EPA, 1994). The higher intake rate of noncommercial fish consumption by fishers creates a sensitive subpopulation relative to the general population when a facility’s emissions impact a fishable body of water. Because noncommercial fish consumption rates may 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, 1994). For instance, subsistence fishers, as well as certain cultural groups, can have particularly high consumption rates relative to the general population (U.S. EPA, 1994). Use of national averages can seriously underestimate risks to these subpopulations.

The majority of bodies of water impacted by facility emissions are freshwater. Although regional air contaminants depositing into the ocean, bays and estuaries are a significant problem, the risks predicted from a single source are relatively insignificant due to tidal flows and dilution. Since most of the contaminated bodies of water of concern in the "Hot Spots" program are freshwater, the ideal study to use to determine consumption rates would be a study of California freshwater noncommercial fish consumption. Unfortunately, there are no such studies available. However, comprehensive studies have been conducted in California surveying consumption rates of saltwater fishers (Puffer et al., 1982a-b; SCCWRP and MBC, 1994). These studies encountered an ethnically diverse array of fishers, which may better approximate the consumption patterns for the California population, relative to studies that surveyed more homogeneous populations. Based on a comparison between these studies and consumption surveys conducted in the Great Lakes, it appears that the consumption rates and distributions between fresh and saltwater fishers are consistent.

In the "Hot Spots" program, cancer risks from various exposure pathways are summed to determine an overall cancer risk to the population exposed by a facility. This is done despite the fact that while all of the people living within the zone of impact are exposed by the inhalation pathway, only some of the people in the zone of impact are likely to be exposed through consumption of noncommercial fish (or homegrown produce or meat). Therefore, the summation of cancer risks reflects theoretical cancer risks to the individuals living within the zone of impact that have exposure via all the pathways included in the risk assessment.

OEHHA recognizes that the distributions and single point estimates for noncommercial fish consumption for the fisher subpopulation cannot fit all situations addressed by the Air Toxics "Hot Spots" program. Demographics, socio-economic factors, fish yield, presence or absence of fish stocking, availability of alternative bodies of water and local climate are other factors which could cause higher or lower noncommercial fish consumption than the OEHHA estimates. However, conducting a site-specific noncommercial fish consumption survey in most cases, would not be a cost-effective alternative to use of the values presented in this chapter. However, factors which might significantly reduce or increase the estimated quantity of noncommercial fish consumed should be described in the risk assessment.

9.2 Algorithm for Dose via Fish Ingestion

In the Air Toxics "Hot Spots" program, the concentration in fish, Cf, is a product of the modeled concentration in water and the bioconcentration factor for the chemical of concern.

$$Cf = Cw \times BCF \qquad \text{(Eq. 9-1)}$$

where: Cf = concentration in fish (μg/kg)
Cw = concentration in water (μg/kg)
BCF = chemical-specific bioconcentration factor for fish

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. This is due to 1) the complexity of accounting for chemicals deposited on surfaces in the watershed of a body of water and then carried into that water by runoff, and 2) the relatively small impact of the fish ingestion pathway in the facility-specific risk assessments conducted for the Air Toxics "Hot Spots" program. On a regional basis, there is little doubt airborne chemicals contribute significantly to water contamination. However, when evaluating risks posed by emissions from a specific facility, the contribution from noncommercial fish ingestion tends to be small and is generally considerably smaller than the inhalation pathway. The majority of facilities in the Air Toxics "Hot Spots" program do not impact fishable bodies of water. The failure to account for runoff will tend to underestimate risk in some cases. However, in order to assess runoff extensive (and expensive) on-site data would have to be collected. The concentration in the water in the much simpler model recommended here is a function of what is directly deposited into the body of water. This is calculated as follows:

$$Cw = Dep\ (SA)\ (365)\ /\ (WV)\ (VC) \qquad \text{(Eq. 9-2)}$$

where:

	Cw =	concentration in water (μg/kg)
	Dep =	amount deposited/day ($\mu g/m^2$/day) = GLC x dep-rate x 86,400
	GLC =	modeled ground level concentration ($\mu g/m^3$)
	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.

There are a number of methodological difficulties in evaluating BCF. In addition, the BCF for one species of fish may not apply to another. OEHHA has utilized outside expertise in choosing BCF values to use for site-specific risk assessment (Cohen, 1996). The results of the expert evaluations are provided in Appendix H.

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:

$$\text{Dose} = (Cf \times I_{fish} \times GI \times L \times EF \times ED) / (AT \times 10^6) \qquad \text{(Eq. 9-3)}$$

where:

where:	Dose =	dose of contaminant via ingestion of fish (mg/kg-day)
	Cf =	concentration in fish (µg/kg)
	I_{fish} =	noncommercial fish ingestion rate (g/kg BW-day)
	GI =	gastrointestinal absorption fraction, unitless
	L =	fraction of noncommercial fish caught at contaminated site, unitless
	EF =	Exposure frequency (days/year)
	ED =	Exposure duration exposure duration (years)
	AT =	Averaging time; time period over which exposure is averaged in days (e.g. 25,550 days for 70 years for carcinogenic risk calculations)
	10^6 =	conversion factor (µg/mg) (kg/gm)

The value of Cf is calculated using equations 9-1 and 9-2. The gastrointestinal absorption fraction is generally 1 because the reference exposure levels and cancer potency factors are rarely adjusted for absorption. In addition, data do not usually exist to adjust absorption in humans from fish. The factor, L, is a site-specific factor; the risk assessor must evaluate site-specific data to ascertain what fraction of the noncommercial fish consumed by an individual comes from the impacted body of water. If such data are unobtainable, then L should be set to 1. We provide both point estimates and a distribution of noncommercial fish consumption rates normalized to body weight at the end of this chapter.

9.3 Studies Evaluated for Noncommercial Fish Consumption Rate

OEHHA conducted a comprehensive review of available studies on consumption of fish and shellfish in the United States and in California inclusive of national (general population) surveys as well as studies focusing on fishers (Gassel, 1996). Studies which measured consumption of commercially purchased fish were not applicable to site-specific risk assessment in the Air Toxics "Hot Spots" program because, as noted above, consumption of commercially purchased fish is, for the vast majority of facilities, not an exposure pathway that needs consideration in the "Hot Spots" program.

The most recent comprehensive study of noncommercial fish consumption in California is the Santa Monica Bay Seafood Consumption Study (SCCWRP and MBC, 1994). This study was undertaken to describe the demographic characteristics of fishers that fish the Santa Monica Bay, to assess their noncommercial seafood consumption rates, and to identify ethnic subgroups that may have high rates of seafood consumption. Surveys were conducted at 29 sites on 99 days, from September 1991 to August 1992. Fishers on piers and jetties, private boats, party boats, and beaches were interviewed using a questionnaire. Interviewers were able to administer the questionnaire in English, Spanish, and Vietnamese. One interviewer also spoke Chinese and

Tagalog. This study focused on consumption of 8 common species of fish, but consumption of other types of fish was also quantified. Among the survey questions, fishers were asked to estimate how much of a species he/she consumed per meal, compared to a wood model representing a 150 gram (0.33 pound) portion of a fish fillet. In addition, fishers were asked the number of times they had consumed each of the species in the 4 weeks prior to the interview. The latter estimate of noncommercial fish consumption was not limited to sport fish from the Santa Monica Bay, but specifically excluded fish purchased from a store. 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 noncommercial 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.

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-b). 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. While this study was quite extensive, providing consumption data from over 1,000 individuals representing various ethnic groups in the survey population (i.e., Caucasian, Black, Mexican-American, and Oriental/Samoan), only English speaking fishers were included in the study. In addition, seafood consumption patterns may change over time. The Santa Monica Bay Fish Consumption Study was more recent and interviewed a number of different ethnic groups in their native languages.

The fish consumption rate distribution generated in the Puffer et al. (1982a-b) study has been criticized by U.S. EPA (1997) for failure to take into account avidity bias. Price et al. (1994) examined the problem in two creel surveys conducted by Pierce et al. (1981) and Puffer et al. (1981). Avidity bias arises in creel surveys 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. Price et al. (1994) attempted to correct for the bias by assigning sampling weights for each individual as the inverse of fishing frequency. When this procedure is applied to the fish consumption distribution of Puffer et al. (1982a-b) the median and 90^{th} percentile are adjusted from 37 and 225 g/day to 2.9 and 35 g/day, respectively. The mean and 95^{th} percentile were not discussed by Price et al (1994). The SCCWRP and MBC, 1994 study is not discussed by U.S. EPA (1997) or by Price et al. (1994), but the survey methodologies are similar and the study did not take into account avidity bias.

The methodology that Price et al. (1994) used to adjust the Puffer et al. (1982a-b) and Pierce et al. (1981) studies was criticized by U.S. EPA (1997) as underestimating fish consumption. Price et al. (1994) assign sampling weights based on the inverse frequency of fishing, which U.S. EPA (1997) points out is not strictly proportional to the probability of sampling as the number of sampling days increases. 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. OEHHA was not able to determine the exact procedure that Price et al. (1994) followed from the information presented in the paper. We could not therefore assess the validity of the procedure.

West et al. (1989a-c) conducted a stratified random survey of Michigan residents with annual fishing licenses. Those with one day fishing licenses from both in state and out of state were excluded thus eliminating some infrequent fishers. The West et al. (1989a-c) study included children and other family members in the survey. The researchers did not generate a distribution but determined a mean of 16.1 g/d for sport fish consumption. 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, it is possible that avid anglers were more frequently represented among respondents that returned surveys.

Murray and Burmaster (1994) used the raw data of West et al. (1989a-c) to generate a distribution for total fish and noncommercial fish. Burmaster et al. (1994) used the short-term data for adults to generate a distribution for consumers of noncommercial fish. The distribution is based on the 7-day recall data on fish consumption. Persons who did not consume noncommercial fish during the recall period were excluded from the distribution. Although Burmaster et al. (1994) do not describe it in these terms, the distribution represents a distribution of fish consumption by people who fish above a certain frequency. It is not possible given the nature of the data to determine the average fishing frequency of those excluded from the survey. The short-term recall survey methodology does not capture usual consumption for each individual as Burmaster et al. (1994) discuss. For chronic risk assessment, it would be better to have a survey that captured usual consumption. However, most if not all distributions used in risk assessment suffer from this problem. Burmaster et al. (1994) determined that a lognormal model fit the empirical data well. The mean and 95th percentile of the angler fish consumption for self-caught fish are 45 and 98 g/d, respectively, based on the empirical data.

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. 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. We did not utilize this study to determine fish consumption rates because of the small number of subjects in the study population, and therefore a lack of statistical power.

The California Department of Health Services is currently conducting an extensive intercept study of the San Francisco Bay. However, these survey data are not yet available.

9.4 Determination of Fish Consumption Distribution

9.4.1 Choice of Study

The data from the Santa Monica Bay Seafood Consumption Study (SCCWRP and MBC, 1994) were determined to be most appropriate for our estimation of average daily noncommercial fish consumption for marine fish. The study was chosen because it was the most recent well-conducted study of a California population. We obtained the raw data on consumption rate in g/day and number of times fished in the last month in Santa Monica Bay by subject number. A problem with this study is that it does not address the fish consumption rates of children, which presumably would be less.

9.4.2 Statistical Correction for Unequal Sampling Probabilities

Samples obtained from intercept surveys 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 Santa Monica Bay study, the estimates need to be adjusted for sources of unequal sampling probabilities, including: (1) fishing frequency, leading to avidity bias (U.S. EPA, 1997), (2) different frequencies of site selection, (3) different proportions sampled relative to all those then at the site, and (4) different intensities of sampling days on the weekend compared to week days.

9.4.2.1 Calculation Methods

The calculations provide estimates of fish consumption rates in the form of empirical distribution of fish consumption for all anglers and the mean and its standard error for each distribution. In addition to the surveyed distribution, two bias-corrected distributions are calculated. The present analysis uses a probability sampling approach (Jessen, 1978), which Thomson (1991) used to correct for avidity bias to estimate the mean and its standard error for fish consumption rates. For computational simplicity we assume that the angler population was "sampled with replacement" as an approximation. In other words, those sampled once may be sampled again with the same probability as all others in the angler population. Seven of the people surveyed had actually been surveyed previously, an observation supporting the assumption of replacement. Also, for the large population of anglers in this survey, any effect of the removal actually occurring instead of replacement is expected to be small.

The bias-corrected estimation of the empirical distribution of fish consumption rates requires estimates of the probability of each individual being sampled and the consumption rate for that individual. The four-factor sampling probability is proportional to: (1) the fishing frequency obtained in each interview, (transcribed from the answer to the question, "How many times have you fished in the last 28 days?" plus one time for the interview; thus, the number of previous fishing trips are combined with the fishing trip on the day of the interview.); (2) the number of times the contact site was sampled during the year; (3) the proportion of successful interviews at that site on the day of contact, where the denominator was the maximum of (a) those in the census at the beginning of the day's interviews at the site and (b) the number of attempted interviews; (4) the number of weekend days sampled during the year divided by 2 or the number of weekdays sampled during the year divided by 5, whichever applies to the day of contact. The number of weekend days sampled in this study was equal to the number of weekdays sampled.

For the four-factor corrected case, the product of these four quantities gives an overall proportionate measure of size of the probability of sampling each individual for each of the quantities. To construct the corrected empirical distribution, the individual records are first sorted by consumption rate. Each individual contribution to the empirical distribution is proportional to the reciprocal of the measure of size, and the constant of proportionality is fixed by requiring that all these reciprocal contributions must sum to one. These contributions are accumulated by consumption rate to obtain the corrected empirical distribution. This gives the cumulative proportion of all those sampled who consume at a rate less than the specified value. This cumulative proportion is also an estimate of the cumulative proportion for the entire angler population that is being sampled.

For comparison, the correction for avidity, using only the first factor, is calculated similarly, using the reciprocal of fishing frequency to determine the proportional contribution. The uncorrected case uses equal contributions from all individuals

The mean rate of fish consumption for the overall angler population is estimated as (Jessen, 1978; Section 8.7):

$$Z_m = E(Z) / E(N) = \Sigma(Z_i / M_i) / \Sigma(1 / M_i) \qquad \text{(Eq. 9-4)}$$

where: $E(\cdot)$ = the estimate of $(\cdot)$,
Z = the random variable for total rate of fish consumption over all individuals,
Z_i = the rate of fish consumption for the *i*th person sampled,

N = the random variable for the total number of anglers,
Σ is the sum over n, the number of anglers sampled.

The variance of the mean consumption rate is estimated as:

$$\mathrm{var}\{Z_m\} = Z_m^{\ 2}\,[\,(s_{Z/M})^2 / Z_m^{\ 2} + (s_{1/M})^2 - 2\, s_{(Z/M)(1/M)} / Z_m]\,/n \qquad \text{(Eq. 9-5)}$$

where:

$(s_{Z/M})^2 = M_m^{\ 2}\,\{\Sigma\,(Z_i / M_i)^2 - (\Sigma\, Z_i / M_i)^2\,/n\}/(n-1)$,
$(s_{1/M})^2 = M_m^{\ 2}\,\{\Sigma\,(1 / M_i)^2 - (\Sigma\, 1 / M_i)^2\,/n\}/(n-1)$,
$(s_{(Z/M)(1/M)})^2 = M_m^{\ 2}\,\{\Sigma\,(Z_i / M_i)\,(1 / M_i) - (\Sigma\, Z_i / M_i)\,(\Sigma\, 1 / M_i)\,/n\}/(n-1)$.
M_m = the mean measure of size of the probability over those sampled.

9.4.2.2 Results for the Santa Monica Bay Study

The empirical distribution curves for the rate of fish consumption for all anglers who caught fish are shown logarithmically in Fig. 1. For comparison to the correction using all four factors, points of two other empirical distributions are shown. The points of the two bias-corrected curves are generally close to each other while the points of the uncorrected curve for anglers surveyed are substantially to the right of the corrected relationships in the upper tail.

Fig. 2 shows the same relationships using z-scores of the angler proportions on the vertical axis. The z-scores are the standard normal variates that correspond to each proportion. The bend in each curve shows that the empirical distributions depart substantially from log-normality, which would produce straight-line relationships.

The results for the estimates of the mean and its standard error are given in Table 9.1 for the three distribution curves. The uncorrected mean is about 70% greater than the value of the corrected means, which differ by only about 3%. The standard error of the uncorrected mean is about the same as that of the mean corrected for avidity. The standard error of the mean corrected for four factors is about twice that of the mean corrected only for avidity.

Table 9.1 Comparison of Four Factor Correction, Avidity Bias Correction Alone and Uncorrected Santa Monica Bay Survey Data

Correction	**Mean**	**Standard error**
Four-factor corrected	30.5	8.6
Avidity corrected	29.4	4.4
Uncorrected	49.7	4.7

9.4.2.3 Discussion

The uncorrected mean is higher than the corrected means because the correction for avidity bias is crucial to compensate for the increase of fish consumption rates with frequency of fishing, a relationship that was calculated but not given here. The marked differences in the upper tails of the corrected distribution curves compared to the uncorrected curve are similarly explained. The increase in standard error of the distribution corrected by four factors is because some of the sites were selected seldom, so the four-factor correction required giving them greater weight.

The determination of the most appropriate denominator for the proportion successfully interviewed at each site is problematic. The population at each site sometimes fluctuated markedly during the half-day interviewing period, but the only data taken for this purpose were the initial census and the number of interviews attempted. The use of the maximum of these two numbers was chosen because the proportion of successful interviews sometimes exceeded the initial census. As a sensitivity check, a four-factor corrected distribution was also computed using the number of attempted interviews as the denominator, which caused that proportion in that distribution to fall at most 2.5 percentage points below the chosen distribution at about the median value.

9.5 Statistical Treatment

OEHHA evaluated the distribution of fish consumption rates from the Santa Monica Bay study after correcting the data for bias as described. We fit the corrected data with a parametric model using Crystal Ball® version 4, an Excel® add-on program that performs Monte Carlo simulations. This lognormal parametric model matches the percentiles of the empirical data reasonably well (Table 9.6; Figures 9.3 and 9.4). The Anderson Darling Statistic is 133.

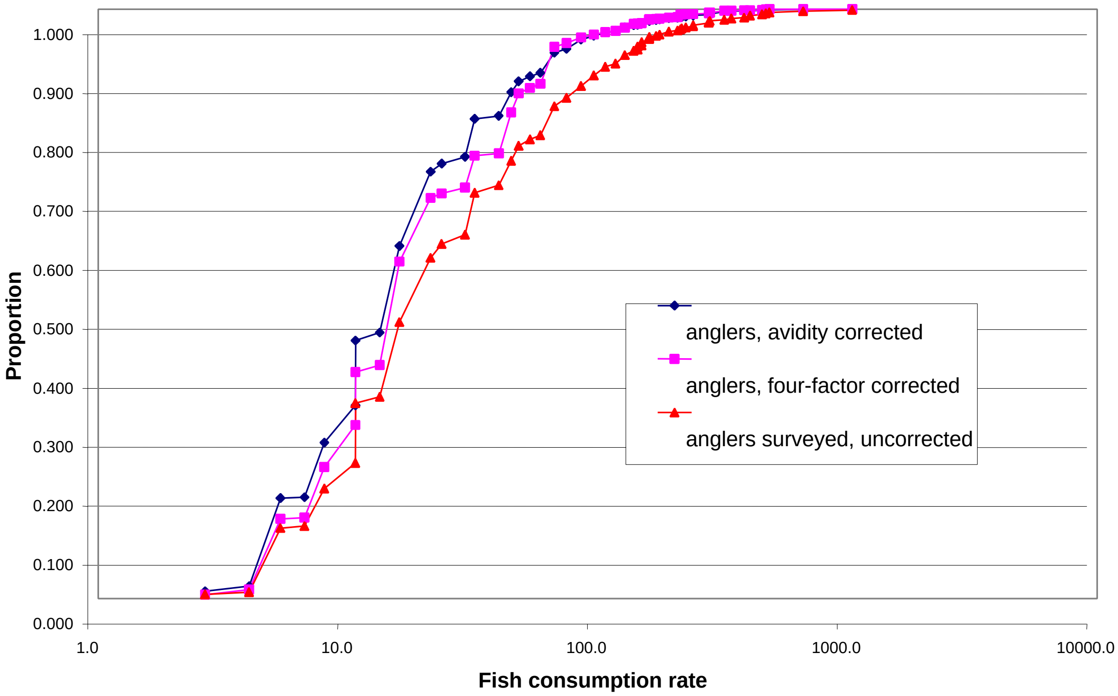

Figure 1. Empirical Cumulative Distributions for Anglers Who Caught Fish -- Horizontal Scaled by Logarithm Of Fish Consumption

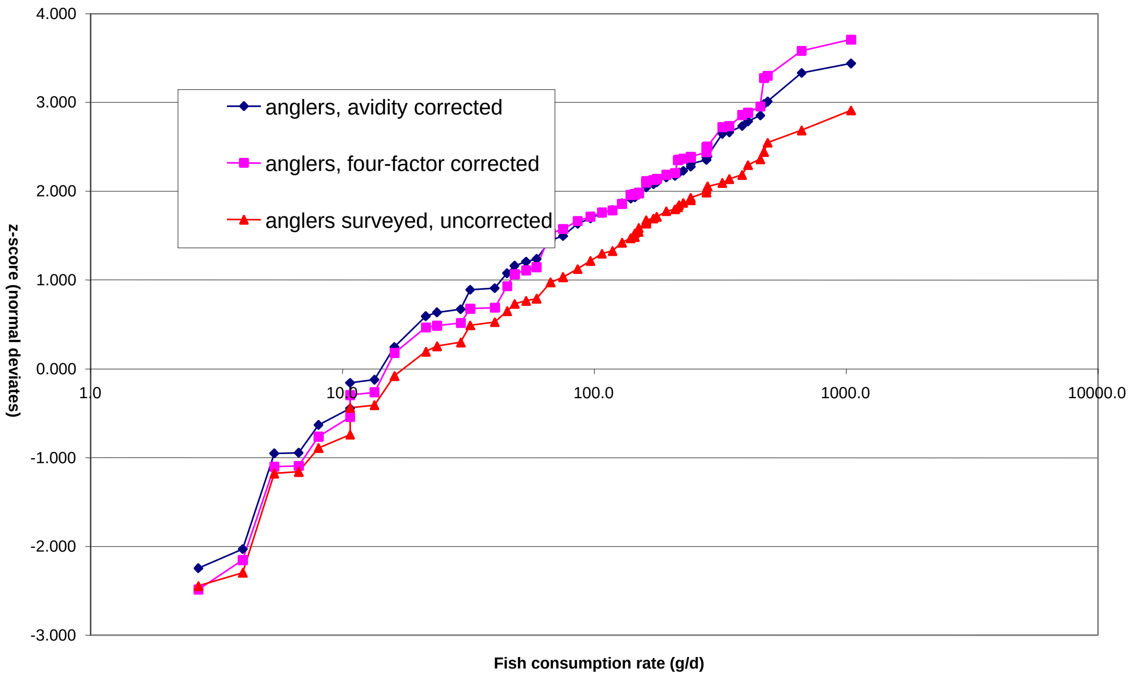

Figure 2. Empirical Cumulative Distributions For Anglers Who Caught Fish -- Horizontal Scaled By Logarithm Of Fish Consumption; Vertical Scaled By Z-Score

9.6 Recommendations

9.6.1 List of "Hot Spots" Chemicals for Which Evaluation of the Fish Pathway Is Recommended

The Air Toxics "Hot Spots" program does not evaluate all chemicals by multipathway analysis. Rather, as described in Appendix E, we have chosen to evaluate those semi-volatile compounds that may be deposited over time. In addition, if the chemical has a long half-life, the multipathway analysis becomes more important. Table 9.2 lists compounds on the Air Toxics "Hot Spots" list for which we propose to require multipathway exposure analyses in the Air Toxics "Hot Spots" program.

Table 9.2 Substances Recommended for Fish Pathway Analysis.

4,4'-methylene dianiline
creosotes
diethylhexylphthalate
hexachlorocyclohexanes
hexachlorobenzene
PAHs
PCBs
pentachlorophenol
cadmium & compounds
chromium VI & compounds
inorganic arsenic & compounds
lead & compounds
mercury & inorganic compounds
mercury & organic compounds
dioxins and furans

9.6.2 Point Estimates of Fish Consumption for Individual Cancer and Noncancer Risk Estimates for Those Who Consume Fisher-Caught Fish.

For the AB-2588 program, OEHHA is recommending that an average value of 0.48 g/kg-day and a high-end estimate of 1.35 g/kg-day be used as point estimate default values of noncommercial fish ingestion rate for the 9-, 30- and 70-year exposure scenarios (Tables 9.3). These values are the mean and 95th percentile, respectively, from our empirical distribution of fish consumption based on the Santa Monica Bay data. There were no data available to ascertain noncommercial fish consumption rates of children. We therefore assumed that noncommercial fish consumption rate would be proportional to body weight. Table 9.4 presents the point estimates in g/day for informational purposes. These can be obtained by multiplying the point estimates in g/kg-day by the time-weighted average body weights of 18 kg for 0-9 year olds and 63 kg for 0-70 year olds. The values in Table 9.3 are used to calculate individual cancer risk and noncancer chronic risk to those who eat noncommercial (fisher-caught) fish. The risks should be presented using the high-end estimate in Tier 1 and 2 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.

Table 9.3 Default values for Fisher –Caught Fish consumption (g/kg-day)[a]

	9-, 30- and 70-Year Exposure Scenario
Average	0.48
High-End	1.35

[a] Values obtained by dividing the mean and 95th percentile estimates by 63 kg, the time-weighted average body weight for 0 to 70 years. Since no data are available on fisher-caught fish consumption in children, the assumption is made that the fish consumption would be proportional to body weight. Thus these estimates normalized to body weight would apply to the 9-year exposure scenario where children specific values are used.

Table 9.4 Default Values for Fisher Caught Fish Consumption (g/day)*

	9-Year Exposure Scenario (children)[a]	30- and 70-Year Exposure Scenario
Average	8.7	30.5
High End	24.3	85.2

[*] Since the 9-year exposure scenario represents children, we have chosen to multiply the grams/kg-day by the ratio of the time-weighted average body weight of 18 kg for 0-9 year olds for the 9-year scenario, and of 63 kg for 0-70 years for the 30- and 70-year scenarios.

9.6.3 Stochastic Approach to Risk Assessment

OEHHA is recommending the avidity-bias corrected distribution derived from the SCCWRP and MBC (1994) data for use in Tier 3 and 4 risk assessments (Tables 9.5). A lognormal parametric model can be used for this distribution with a mean and standard deviation of 0.48 and 0.71 g/kg-day, respectively. The $\mu \pm \sigma$ is equal to exp (-1.31 ± 1.08). The lognormal parametric model is derived by dividing the fish consumption distribution parametric model parameters in (g/day) by 63 kg so that the units are g/kg-day. This distribution is recommended for the 9-, 30- and 70-year exposure duration scenarios.

The SCCWRP and MBC (1994) study is subject to avidity bias because it is designed as an intercept survey, and thus over-samples frequent fishers. This is mitigated to some extent by the fact that the survey was conducted over a year with multiple visits to the same site. However, we corrected the distribution for avidity bias as noted in Section 9.4.2. in order to obtain unbiased estimates for the total angler population (that is infrequent as well as frequent fishers) in the Santa Monica Bay study. In addition, we corrected for three other biases, which were small, related to sampling frequency of a specific site, proportion of successful interviews, and weekend versus weekday sampling. We also provide a distribution normalized to time-weighted average body weights for ease of use in assessing dose and risk (Table 9.5). This was obtained by dividing through the distribution in g/day by 63 kg, the time-weighted average body weight over a 70-year lifetime. The 9-year exposure scenario is meant to cover the first 9 years of life. However, fish consumption data are not available for children. Assuming that fish consumption is proportional to body weight for both children and adults, the distribution in Table 9.5, which is normalized to body weight, can also be used for the 9-year exposure duration scenario.

Table 9.5 Empirical Distribution for Fisher-Caught Fish Consumption Expressed in g/kg-day for Use in 9-, 30-, and 70-Year Exposure Scenarios.

Mean	SD	p05	p10	p20	P25	p30	p40	p50	p60	p70	p75	P80	p90	p95	σ±μ
0.48	0.71	0.07	0.08	0.12	0.13	0.17	0.21	0.24	0.27	0.47	0.51	0.69	0.99	1.35	Exp (-1.31± 1.08)

Table 9.6 Comparison of Parametric Model and Empirical Distribution Moments and Percentiles *

	Moments and Percentiles (Gm/day)	
	Empirical Distribution	**Lognormal Parametric Model**
Mean	30.5	28.6
Std Dev	45.0	33.1
Skewness	5.72	4.04
Kurtosis	58.1	31.7
$\mu \pm \sigma$		$\exp(2.93 \pm 0.92)$
%TILES		
Sample Min	2.7	
5	4.4	4.16
10	5.0	5.80
20	7.7	8.75
25	8.5	10.1
30	10.9	11.6
40	13.5	15.0
50	15.0	19.2
60	17.5	24.6
70	29.6	31.8
75	32.1	36.5
80	43.3	42.7
90	62.4	64.2
95	85.2	89.0
Sample Max	1045	

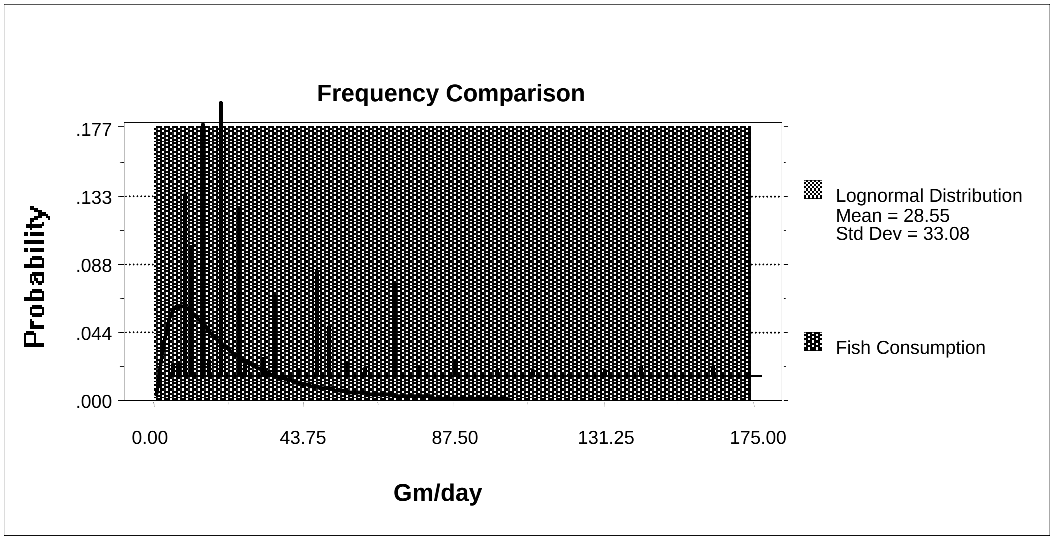

Figure 9-3. Probability Distribution of Fish Consumption and Parametric Lognormal Model.

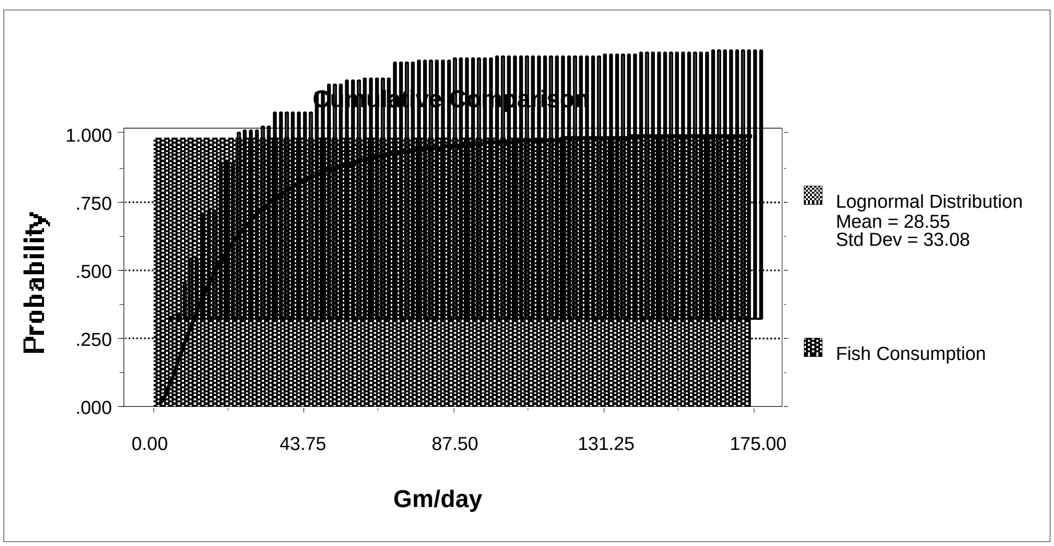

Figure 9-4. Cumulative Probability Distribution of Fish Consumption and Parametric Lognormal Model.

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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). Many of the studies that OEHHA used to generate the distributions and point estimates collected body weight data on the subjects in the study. The consumption rate for each subject 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 the studies, such as the one used to determine fish consumption rate, did not collect body weight information on the subjects. Therefore a review of the body weight literature was conducted and appropriate body weight defaults were selected for our purposes. The published literature on body weight is mainly based on data gathered in the first National Health and Nutrition Examination Survey conducted between 1970 and 1974, and more recently in the second National Health and Nutrition Examination Survey (NHANES II).

10.2 Empirical Distributions

10.2.1 NHANES II (U.S.EPA, 1997)

NHANES II was conducted on a nationwide sample of about 28,000 persons, aged 6 months to 74 years, from the civilian, non-institutionalized population of the United States. The sample was selected so that certain ‘at risk’ subgroups (low income, preschool children, elderly) were over sampled. 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 survey began in 1976 and was completed in 1980. The mean body weights of adults and children and their standard errors are given in Table 10.1. The average value of 71.8 kg for adults is the basis for the human default value of 70 kg.

10.2.2 Report of the Task Group on Reference Man (ICRP, 1975)

This task group of the International Commission on Radiological Protection (ICRP) reviewed and compiled extensive data on anatomical measurements, elemental composition, and physiological values for the human body. Weight (W), length (L), and surface area (SA) during prenatal life are presented as means +/- standard deviation (SD) as a function of gestational age. The data are based on 13,327 cases. 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. In addition to charts showing mean body weight ± one SD from 0 to 12 years and from 0 to 56 years by sex, the following defaults were recommended:

Newborn male:	mean = 3.5 kg; SD = ± 0.59 kg;
Newborn female:	mean = 3.4 kg; SD = ± 0.59 kg;
Adult male:	mean = 71.7 kg; SD = ± 10 kg;
Adult female:	mean = 56.7 kg; SD = ± 8.6 kg.

Tabular data relating height in cm to body weight in kg for 8 age groups 18-79 years are given for the 25th, 50th and 75th percentiles. These data are summarized in Table 10.2 for the reference total body heights of 170 cm for males and 160 cm for females.

10.2.3 NCHS (Hamill et al. 1979)

The National Center for Health Statistics (NCHS) prepared percentile curves for assessing the physical growth of children ages 0 to 36 months. Smoothed percentile curves were derived for body weight, length, and head circumference. Separate sets were produced for male and female children. The data used were from the Fels Research Institute, Yellow Springs, Ohio. Body weight percentiles of 5th, 10th, 25th, 50th, 75th, 90th, and 95th are given for ages of 0 (birth), 1, 3, 6, 9, 12, 18, 24, 30, and 36 months for each sex. The data were smoothed by cubic spline approximation.

10.3 Modeled Distributions

10.3.1 Brainard and Burmaster, 1992

These authors examined data on height and weight of adults from NHANES II and fit bivariate distributions to the tabulated values for men and women separately. The survey tabulated the height and weight of 5916 men and 6588 women aged 18-74. After statistically adjusting the raw data to reflect the whole U.S. population aged 18-74 for age structure, sex, and race the U.S. Public Health Service published results for an estimated 67,552 men and 74,167 women. Defining the variables height (Ht) in inches and weight (Wt) in pounds the authors observed that the marginal histograms for Ht were symmetrical and for Wt were positively skewed. Consequently they defined and analyzed the additional variable lnWt for each sex. For men straight lines were fit to cumulative values and z-scores for lnWt and Ht with R^2 values of 0.999. For weight (lb), the estimated values of $\mu \pm \sigma$ for men are exp (5.13 ± 0.17). For women the visual fit of the line to lnWt was not as good, but adequate. The estimated values (lb) of $\mu \pm \sigma$ are exp(4.96 ± 0.20). The body weight arithmetic mean (lb) and standard deviation for men and women are 171 ± 29.4 and 145 ± 29.4. The body weight mean and standard deviation in kg for men and women are 77.9 ± 13.3 and 66.1 ± 13.6, respectively. The conversion from $\mu \pm \sigma$ to arithmetic mean and standard deviation is done using the following formulas (Burmaster and Hull, 1997).

$$\text{Amean} = \exp(\mu + 0.5 * \sigma^2)$$

$$\text{AStdDev} = \exp(\mu) * \sqrt{\exp(\sigma^2) * [\exp(\sigma^2) - 1]}$$

10.3.2 Finley et al., 1994

These authors summarize body weight distributions analyzed by Brainard and Burmaster and present a combined standard distribution for equal numbers of adult men and women of 71.0 ± 15.9 kg. The 50th and 95th percentiles of the combined distribution are 70 and 101 kg, respectively. The distributions for adult males and females are given as 78.7 ± 13.5 kg and 65.4 ± 15.3 kg, respectively. Finley et al. also present annual age group weight distributions for children 18 years of age and under (Table 10.3). These distributions are considered by the authors to reflect almost entirely interpersonal variation due to the large sample sizes and consistent methodology used in the NHANES II survey.

10.3.3 Burmaster et al. 1977

In this paper, Burmaster et al. 1997 fit normal and lognormal distributions to the male and female child data sets from the NHANES II Survey. The authors concluded that the lognormal distributions consistently fit the points better than did normal distributions.

Table 10.1 Body Weight of Adults and Children from NHANES II (kg)[a]

Age Group, yr	Male		Female		Male & Female
	Mean	Std Dev	Mean	Std Dev	Mean
Adults (Years)					
18<25	73.8	12.7	60.6	11.9	67.2
25<35	78.7	13.7	64.2	15.0	71.5
35<45	80.9	13.4	67.1	15.2	74.0
45<55	80.9	13.6	68.0	15.3	74.5
55<65	78.8	12.8	67.9	14.7	73.4
65<75	74.8	12.8	66.6	13.8	70.7
18<75	78.1	13.5	65.4	14.6	71.8
Children					
6-11 months	9.4	1.3	8.8	1.2	9.1
1 year	11.8	1.9	10.8	1.4	11.3
2 year	13.6	1.7	13.0	1.5	13.3
3 year	15.7	2.0	14.9	2.1	15.3
4 year	17.8	2.5	17.0	2.4	17.4
5 year	19.8	3.0	19.6	3.3	19.7
6 year	23.0	4.0	22.1	4.0	22.6
7 year	25.1	3.9	24.7	5.0	24.9
8 year	28.2	6.2	27.9	5.7	28.1
9 year	31.1	6.3	31.9	8.4	31.5
10 year	36.4	7.7	36.1	8.0	36.3
11 year	40.3	10.1	41.8	10.9	41.1
12 year	44.2	10.1	46.4	10.1	45.3
13 year	49.9	12.3	50.9	11.8	50.4
14 year	57.1	11.0	54.8	11.1	56.0
15 year	61.0	11.0	55.1	9.8	58.1
16 year	67.1	12.4	58.1	10.1	62.6
17 year	66.7	11.5	59.6	11.4	63.2
18 year	71.1	12.7	59.0	11.1	65.1
19 year	71.7	11.6	60.2	11.0	66.0

[a] From U.S. EPA, 1997

Table 10.2 Median and Quartile Human Body Weights by Age; United States, 1960-2[a]

Age Group, yr	**25%**	**50%**	**75%**
Males			
18-24	63	68	76
25-34	67	74	85
35-44	68	74	81
45-54	68	75	85
55-64	67	76	85
65-74	64	72	78
75-79	66	83	88
18-79	66	73	82
Females			
18-24	51	55	60
25-34	52	58	66
35-44	57	63	73
45-54	57	64	73
55-64	61	68	82
65-74	60	65	74
75-79	55	66	71
18-79	56	62	72

[a] Weights in kg for reference heights of 170 cm male, 160 cm female
(Adapted from ICRP, 1975)

Table 10.3 Summary of Distribution Factors for Body Weight by Age[a]

Age, yr	**Arithmetic Mean, kg**	**SD, kg**
0.5-1	9.4	1.2
1-2	11.8	1.4
2-3	13.6	1.6
3-4	15.7	1.7
4-5	17.8	2.3
5-6	20.1	2.8
6-7	23.1	3.5
7-8	25.1	3.8
8-9	28.4	5.2
9-10	31.3	5.0
10-11	37.0	7.5
11-12	41.3	10.5
12-13	44.9	10.0
13-14	49.5	10.5
14-15	56.6	10.3
15-16	60.5	9.7
16-17	67.7	11.6
17-18	67.0	11.5

[a] Adapted from Finley et al. (1994).

10.4 Recommendations

10.4.1 Point Estimate Approach

The point estimates for body weight in kg for 9, 30 and 70 years are calculated by taking the time weighted average of the mean body weights for ages 0.5 through 9, and ages 0.5 through 70 as presented in Table 10.1. In the interest of simplicity males and females are averaged. 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. For the 30-year exposure scenario, the body weight for the 70-year scenario can be used in the interest of simplicity. The use of the time-weighted average approach allows for a more accurate calculation of dose from ages 0-9 and ages 0-70 because an estimate of the change in body weight as an individual grows is factored in.

Table 10.4 Point Estimates for Body Weight (kg)

	Ages 0-9	Age 0-70
Body weight	18	63

10.4.2 Distributions for Stochastic Approach

OEHHA is not recommending 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. The available data in the literature may be adequate to generate approximate ages 0-9 and ages 0-70 body weight distributions if such distributions are needed.

10.5 References

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11. Exposure Duration

11.1 Introduction

Currently an assumption of lifetime exposure duration (70 years) for the calculation of cancer risk is incorporated into the cancer unit risk factor and oral cancer potency factors. Thus, when risk is calculated by multiplying modeled or measured concentrations in air by the unit risk factor, the risk is generally considered a "lifetime" risk. A cancer risk of 5×10^{-5} means that in a population exposed for 70 years, 50 people per million exposed would theoretically develop cancer over that 70-year period.

The point estimate risk assessment approach (Tier 1 and 2) can be used with more than one estimate of chronic exposure duration to give multiple point estimates of cancer risk. For stochastic risk assessment (Tier 3 and 4), there are two possible approaches to incorporating duration of exposure. The first would 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.

In site-specific risk assessment, the risk manager wants an estimate of risk from a specific facility. Estimates of lifetime risk are often criticized as overly protective since most individuals will not be exposed to that facility's emissions for 70 years; there is interest in assessing risks from shorter durations of exposure. In order to accommodate adjustment for less-than-70 year exposure scenarios, the lifetime average daily dose is calculated and used to represent the daily dose over 70 years.

11.2 Dose Algorithm and Duration of Exposure

The following equation for inhalation dose can accommodate different exposure durations:

$$\text{DOSE} = (\text{Cair} \times \text{BR} \times \text{ED} \times \text{EF} \times 1 \times 10^{-6}) / [\text{AT}]$$

Where:

DOSE =	Inhalation dose [(mg/kg body weight)/day]
Cair =	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
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 or worker exposures of eight hours per day, 5 d/week) can be factored into the equation using the EF term.

11.3 Available Studies for Evaluating Residency Time

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 home owners 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, home owners, farm, urban and rural populations, and large geographic regions such as the West. However, no attempt was made in this study to examine the effect of socio-economic status. Many facilities in the Air Toxics "Hot Spots" program are located in areas surrounded by low socioeconomic status populations. 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.

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 11.1. Although the published methodology can be used to determine mobility for different income groups, the published tables are for the entire U.S. population. Also, 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 11.1).

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 home owners 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.

Table 11.1 Summary of Studies of United States Residency Times

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)

Table 11.2 Summary of Regulatory Recommendations for Residency Times

Reference	***Recommendation***
CAPCOA, 1993	70 years (point estimate)
U.S. EPA, 1997	9 years for central tendency; 30 years for high-end
U.S. EPA, 1989	9 years for average, 30 years for high-end

11.4 Discussion

Exposure duration is a variate in the Air Toxics “Hot Spots” program stochastic risk assessment guidelines for which consideration of the purposes that the information will be used is important. Public notification provisions of the Air Toxics “Hot Spots” program require that a facility notify the surrounding community if the risks from exposure to emissions is deemed significant by the district. Thus, one of the important uses for the risk assessment information is for public notification. The individual or household that receives a notification letter has little uncertainty as to the length of time that they have lived at their current address. If a range of risks is calculated for fixed lengths of residency, an individual would have a better idea of what his or her individual range of risks might be as they could compare the 9-, 30-, and 70-year risks with the length of time they have resided at their residence.

The other important user of the risk assessment information is the risk manager. The risk manager may wish to compare a range of risks for fixed reference periods of time when prioritizing or comparing facilities.

11.4.1 Problems with Less-than-Lifetime Risk Estimates

An assumption which appears to be implicit in the use of less than a lifetime exposure duration is that, when people move away from the source of exposure, they escape risk. This assumption may be erroneous for several reasons. In some cases they may be moving to another location within the zone of impact of the facility being evaluated. The person may also be moving out of the zone of impact of one facility and into the zone of impact of another facility. The U.S. Census data do not provide adequate information to determine whether a surveyed individual has moved next door or to another property removed from the zone of impact of a specific facility. The U.S. Census Bureau statistics on socioeconomic status and mobility show that homeowners in low income areas are likely to have less mobility than those with more resources (Bureau of the Census, 1993). Low income, inner city homeowners may constitute a sensitive subpopulation which has much longer residency times than predicted by Israeli and Nelson (1992), Johnson and Capel (1992), and U.S. EPA's analysis of the Bureau of the Census data.

When the results of a cancer risk estimate based on a 70-year exposure duration is below a significant risk level, the risk manager can be assured that the facility does not likely pose cancer risks above the defined risk level to any individual residing in the zone of impact of the facility in question within the limits of present knowledge. Risk estimates based on exposure durations of 9 or 30 years do not provide the same level of assurance because they exclude those who reside in the zone of impact for longer periods of time.

Another aspect of cumulative risk is the additive risks from all facilities impacting a given area. At the present time, the risk assessment process itself does not address cumulative risk. Only considering short-term durations of exposure in evaluating risk would increase the impact of ignoring cumulative risks of simultaneous or sequential exposures to multiple facility emissions.

11.5 Recommendations

OEHHA is recommending that point estimate and stochastic risk estimates be conducted for 70-year exposure durations. This will ensure that a person residing in the vicinity of a facility for a lifetime will be included in the evaluation of risks posed by that facility. In addition, the assessor may want to present risk estimates for 9-year and 30-year exposure scenarios using the duration-appropriate point estimates and distributions recommended in the previous chapters. The 9-year scenario point estimates and distributions in the previous chapters reflect children's exposures from age 0 to 9. The 9- and 30-year estimates are the figures that U.S. EPA (1989;

1997) has recommended for the central tendency and high-end estimates, respectively, of residency time. The U.S. EPA’s estimates may not apply to all populations. However, the 9- and 30-year estimates appear to fall into a range of possible estimates that will provide useful information to the risk manager and the notified community.

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