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ROCKY MOUNTAIN ARSENAL

FINAL
INTEGRATED ENDANGERMENT ASSESSMENT/ RISK CHARACTERIZATION
VERSION 4.2

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Appendix B,
Sections B.3 and B.4

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APPENDIX B
(SECTION B.3)

HUMAN HEALTH RISK CHARACTERIZATION PARAMETERS

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Centigrade
°F	degrees Fahrenheit
°K	degrees Kelvin
$ABS_{critical}$	absorption from critical toxicity study
ABS_{pure}	absorption of pure compound
ABS_{soil}	absorption from soil
Army	U.S. Army
atm	atmospheres of pressure
atm-m^3/mol	atmospheres of pressure cubic meter per mole
ATSDR	Agency for Toxic Substance and Disease Registry
BDL	below detection limit
BR	breathing rates
BW	body weight
CAS#	Chemical Abstract Service Registry Number
cm^2	square centimeters
cm^2/mole	square centimeters per mole
cm^2s	centimeters per second
cm^3/mole	cubic centimeters per mole
CMP	Comprehensive Monitoring Program
COCs	contaminants of concern/chemicals of concern
CPFs	cancer potency factor
CSS	concentration of suspended soil particles
D	Depth
DBCP	dibromochloropropane
DCPD	Dicyclopentadiene
DDE	dichlorodiphenyldichloroethene
DDT	dichlorodiphenyl trichloroethane
DINIT	breathing rates
D:	molecular diffusivity
DT	dose-response
DW	(annual) exposure frequency
EA	Endangerment Assessment
EBASCO	Ebasco Environmental Services, Inc.
EPA	U.S. Environmental Protection Agency
FR	respiratory deposition
g	grams
g/cm^3	grams per cubic centimeter
GI	gastrointestinal
GSD	geometric standard deviation

HCCPD	hexachlorocyclopentadiene
HHEA	Human Health Exposure Assessment
HHRC	Human Health Risk Characterization
hr	hour
hrs/day	hours per day
ICRP	International Commission on Radiological Protection
IRIS	Integrated Risk Information System
Kd	distribution coefficients
kg	Kilograms
K_H	Henry's Law constant
K_{oc}	soil water partition coefficients
K_{ow}	n-octanol-water partitioning coefficient
L	length
m	meters
m^2	meter squared
m^3/hr	cubic meters per hour
mg	milligrams
mg/cm^2	milligrams per centimeter
μ	microns
μg	micrograms
$\mu g/m^3$	micrograms per cubic meter
MLE	most-likely estimate
mol/m^3	moles per cubic meter
MRI	Midwest Research Institute
MSE	mean square error
MTRX	soil matrix
NPS	National Park Services
NSGA	National Sporting Goods Association
NTIS	National Technological Information System
OSWER	Office of Solid Waste and Emergency Response
Parties	EPA and State
PCBs	polychlorinated biphenyls
PDF	probability density function
PM-10	soil particulate concentrations less than 10μ in size
PPLV	preliminary pollutant limit value
PSCo	Public Service Company of Colorado
Qa	ventilation rate
RAF	relative absorption factor
RAGS	Risk Assessment Guidance for Superfund
RB	breathing rates in an enclosed basement

RD	respitatory deposition
RI	Remedial Investigation
RfDs	Reference dose(s)
RMA	Rocky Mountain Arsenal
RME	reasonable maximum exposure
SC	soil covering
SCS	Soil Conservation Service
SE	standard error
SEM	standard error of the mean
Shell	Shell Oil Company
SK	(standardized) skewness coefficient
TAC	time for basement air exchange
TDV	time-dependent variables
TE	exposure duration
TM	(daily) exposure time
TSP	total suspended particulates
TWA	time-weighted average
VAR	basement volume to air ratio
V_p	Vapor Pressure
W	width

B.3.0 HUMAN HEALTH RISK CHARACTERIZATION PARAMETERS

The parameters used in the preliminary pollutant limit value (PPLV) equations were either fixed at specific values or were allowed to vary. Parameters that were allowed to vary were assigned probability distributions. The approach for the assignment of fixed values or probabilistic distributions for each risk characterization parameter is provided in this appendix section.

Where possible, data specific to Rocky Mountain Arsenal (RMA) were incorporated in parameter development. When RMA-specific data were unavailable, Denver-specific, regional, or national information was included. The data were collected in an unbiased manner from all known sources in the published literature. However, an unbiased search of the literature does not guarantee that the data represent an unbiased sample from the population of parameter values being characterized. Accordingly, every effort was made to locate the most pertinent data, provide statistically and scientifically valid interpretation of these data, and correct any inadequacies or potential sources of bias reflected in the data's applicability to RMA.

The assignment of a specific distribution to a parameter cannot be characterized as a precise representation of the uncertainty attributable to that parameter. Limited information was available for a number of parameters and best professional judgment was often incorporated in the development of the distributions.

The parameters described in Sections B.3.1 to B.3.10 are indicated below:

- Soil ingestion rates (probabilistic): Section B.3.1
- Skin surface area (fixed) and soil covering (probabilistic): Section B.3.2
- Relative absorption factor (probabilistic): Section B.3.3
- Breathing rates (fixed) and respiratory deposition (fixed): Section B.3.4
- Dust loading factor (probabilistic): Section B.3.5
- Body weight (fixed): Section B.3.6
- Time-dependent variables (probabilistic): Section B.3.7
- Basement parameters (fixed and probabilistic): Section B.3.8

- Chemical-specific parameters (fixed and probabilistic) Section B.3.9
- Soil characteristics (fixed and probabilistic): Section B.3.10

Toxicity parameters used in the PPLV equations are not described in this section because they are described in detail in the Human Health Exposure Assessment (HHEA) report (EBASCO 1990a). Toxicity parameters are listed in Appendix B.1.

In the remainder of this section, the following general aspects of the exposure analysis are discussed:

- Rationale for the distributional approach
- Importance analysis
- General approach used to develop the probabilistic distributions
- General statistical methods for characterizing activity-based distributions for intake rates for the biological worker

Rationale for Distributional Approach

In general, the exposure parameters are inherently variable due to known or hypothesized dependence on other factors (e.g., environmental conditions, human behavior) and the effect of random or unknown factors. Because of this variability, the most accurate characterization of parameters is obtained by representing each parameter through its entire distribution rather than a single, fixed value. The incorporation of probabilistic distributions into the risk assessment greatly enhances the accuracy and effective interpretation of the resulting PPLVs and risks. The only way to determine the variability of a mathematical function of parameters is to characterize the variability of all the influential parameters.

Throughout the development of the human health risk characterization (HHRC) parameters, the available information on parameters was considered substantial enough to warrant the estimation of distributions. For each probabilistic exposure parameter, the uncertainty was not considered

great enough to resort to the high degree of bias and loss of interpretability implied by fixed values.

The assignment of a conservative, fixed value for a given parameter creates three problems: the empirical data are not utilized, the fixed value itself introduces subjectivity, and the interpretability of the PPLVs is reduced. These problems, discussed below, arise only if a few parameters are fixed at conservative values, and worsen as the number of fixed parameters increases.

The first problem in assigning a fixed conservative value to a variable parameter is that the available empirical data are either ignored or not carefully compiled and analyzed; therefore, no assessment is made as to what realistic values there are for the parameter. If empirical data are available, though scarce, a distribution can be estimated and used as a starting point for further analysis or best professional judgment. In this manner the estimated distribution based on these data conveys the current knowledge about the parameter. Conversely, if a default fixed value is assigned, this knowledge may not be developed.

The second problem in assigning a fixed value is that it implies that no uncertainty exists even though it is indeed a highly subjective choice. It is difficult to ensure that a chosen, fixed value is both conservative and reasonably likely to occur. Conversely, the multiple values sampled from a distribution includes both typical and extreme parameter values with a frequency that reflects the estimated likelihood of such parameter values arising at RMA.

The third problem in assigning a fixed value is that the PPLV distribution predicted by the model becomes biased and unreliable. Furthermore, the direction and degree of uncertainty cannot be known, which reduces the interpretability of the uncertainty analysis results. When many parameters are fixed at conservative values, the degree of conservativeness in the PPLV distribution is compounded substantially. The worst case in one parameter is matched with the

worst case in every other fixed parameter, resulting in a highly improbable worst-case scenario. For the PPLV model, if each parameter were to be fixed at a given percentile (e.g., 95 percent), then the percentile of the resulting PPLV would be unknown, but would be higher than the percentiles for each parameter (e.g., higher than 95 percent). Conversely, when distributions are assigned, these parameters are assumed to be independent; therefore, the uncertainty analysis calculates each PPLV based on a random sample selected from each parameter distribution.

Importance Analysis

In consideration of the number of parameters contained in the direct PPLV equations, the commitment to complete a quantitative uncertainty analysis for each, and the schedule limitations of the Endangerment Assessment (EA) for the on-post operable unit, the Organizations and State (OAS) agreed to streamline the uncertainty evaluations by reducing the number of parameters for which probabilistic distributions would be developed. An importance analysis was therefore used to determine which direct exposure parameters should be fixed or probabilistic. An importance analysis was not undertaken for the indirect PPLVs since cumulative indirect PPLVs were determined on a site-by-site basis. The U.S. Army (Army) evaluated the issue of assigning parameters in these direct PPLV equations as either fixed or probabilistic.

The results of the importance analysis are summarized in Tables B.3-1 and B.3-2. These results were presented and discussed with the OAS at the Endangerment Assessment meeting on October 31, 1990. The importance analysis was conducted by evaluating the percent change in the reasonable maximum exposure (RME) PPLV for the industrial worker and recreational visitor as a result of a two-fold increase in the value of each parameter. A parameter was considered important if the change in the PPLV was greater than 20 percent. The RME parameter values from the HHEA report (EBASCO 1990a) were used as the basis for the "baseline" PPLVs from which percent change was determined. The RME parameter values were selected over the most-likely estimate (MLE) values because of the contribution of the OAS in their development.

During the importance analysis, four categories of parameters were developed: Category I includes parameters important for all contaminants of concern (COCs); Category II includes parameters important for the majority of COCs; Category III includes parameters not important for the majority for any of the COCs, but important for some COCs; and Category IV contains parameters not important for any of the COCs (Table B.3-3).

Distributions were developed for all parameters identified in the importance analysis, with the exception of the toxicity parameter (DT), the absorption parameters, body weight, skin surface area, respiratory deposition and breathing rate. It is recognized that DT is both variable and uncertain, but current risk assessment guidance (EPA 1989b) specified that this parameter be fixed at values derived from EPA. The absorption parameters were removed from the PPLV equations because of the introduction of the relative absorption factor (RAF), which is discussed in Appendix B.3.3. Distributions were developed for the RAF parameter.

Although the 1OAS agreed that the time-dependent variables (TDVs) (i.e., exposure time, exposure frequency, exposure duration) would be fixed variables, Shell Oil Company (Shell) subsequently developed TDV distributions and requested that the OAS review its evaluation. The OAS indicated a concern with the database and approach used by Shell in developing the TDV distributions and stated its preference to retain the original fixed values. The Army concluded that since the information was consistent with the goal of the quantitative uncertainty analysis and could be incorporated without impact to schedule (the original intent behind streamlining), the TDV distributions developed by Shell would be revised in coordination with the Army and incorporated in the risk characterization.

General Approach Used to Develop Exposure Parameter Distributions

In this section, the general approach used to develop the probabilistic distributions is presented. The approach includes the following eight main aspects, each of which is discussed below:

- Estimation of distributional descriptors

- Identification of the distribution family
- Evaluation of the skewness of the data
- Evaluation of outliers
- Consideration of the lack of central or skewed tendencies in the data
- Establishment of a conservative estimate of the distribution spread
- Truncation of negative values
- Evaluation of the independence of the parameters

Estimation of Distributional Descriptors

Estimators for distributional descriptors were selected based on the distribution family being fit. For example, a given data set might be fit with both a normal distribution using the arithmetic mean and standard deviation as estimators, as well as a lognormal distribution using the mean and standard deviation of the log-transformed data as estimators. In general, maximum likelihood estimators were used; however, many of the estimations pertaining to the TDV and refuge worker (and biological worker) parameters were based on a percentile regression method explained at the end of this section.

Identification of the Distribution Family

In general, the data were not adequate to ascertain the exact nature of the underlying distribution. The fit of a distribution to a given data set can be statistically assessed only if the number of data points, n, is moderate to large. In general, n was so small (e.g., less than 10) that the statistical power of goodness-of-fit tests was very weak, and often resulted in the acceptance of a distribution even if it was very different than the true distribution from which the data were sampled. The P-value produced by a goodness-of-fit test gives the probability of error if the hypothesized distribution is rejected. However, the relevance of the P-value depends on the power of the test to discriminate between different distributions, which in turn depends on n. If the number of data values (n) is small, a given data set of n data points could well have arisen from very different underlying distributions. In this instance, each distribution would have a

goodness-of-fit P-value of nearly 1.0, implying acceptance. Therefore, goodness-of-fit tests cannot be relied on with small data sets. The P-values presented in the parameter packets must be interpreted in light of the corresponding number of data values. In many cases the P-values were included for consistency and thoroughness, even though they provide little or no information.

For cases in which the number of data points was small, the shape of a distribution was based both on data (e.g., skewness) and on assumptions regarding the process underlying the variability and uncertainty of a given parameter. Most parameters were believed to vary smoothly in the tails of the distribution (i.e., extreme values were expected to be possible, but less likely than less extreme or intermediate values). As discussed above, the variation in a parameter is often in response to a smoothly varying environmental variable such as temperature (e.g., vapor pressure) or variation in human behavior (e.g., soil ingestion). In addition, measurement error often exhibits central or skewed tendencies, passing such tendencies on to the data values. In such cases, it was more reasonable to fit a smoothly varying distribution (e.g., normal or lognormal) than to fit a distribution with sharp changes in probability, such as those that occur at the boundaries of a uniform or loguniform distribution, even if the few data points available appear to be uniform in their location.

In general, unimodal distributions were assigned because multiple modes could not be differentiated in small data sets and did not appear in any of the larger data sets. It is acknowledged that the true distributions for some parameters may be multimodal due to such factors as combining two or more subpopulations. In other cases, the uncertainty about a unimodal or constant parameter may be multimodal due to the repeated application of several analytical techniques, each producing a distinct distribution. However, such effects were not detected during the distribution development for any parameter.

When at least 25 data points were available, the Kolmogorov-Smirnov goodness-of-fit test was the primary criteria used to select a distribution family. Only the following parametric distribution families were tested: normal, lognormal, triangular, and Weibull. The Weibull distribution was only tested for negatively skewed data sets. If chosen, the Weibull distribution, which was not available in the model code, was approximated with a negatively skewed triangular distribution.

For large data sets, a P-value greater than about 0.5 indicates a reasonably close fit, and a P-value close to 1.0 indicates a very close fit. However, when the sample size is very large (e.g., 500), the test is powerful enough to detect very small and insignificant differences between the true distribution (which may not be of a statistically defined family) and the parametric distribution being tested. Therefore, a low P-value for a given distribution does not necessarily imply that the distribution gives a poor approximation to the data. In such cases when the data set is very large, the amount of information contained in the data is so great, that it is reasonable to represent the parameter with an empirical distribution in which the cumulative distribution function follows the cumulative data exactly. However, empirical distributions involve specifying a large number of descriptors (e.g., 60 values describing 30 percent and the associated percentiles) instead of the two or three (e.g., mean and variance) required for the parametric distributions listed above. It was not feasible to allow the model user the flexibility to specify such a large number of distributional descriptors, so one of the distributions listed above was always fit to the data when sample size was large. As indicated through graphical and tabular comparisons, all large data sets were approximated reasonably well by one of the standard parametric distributions.

Evaluation of the Skewness of the Data

If the number of data points was reasonable (at least six), then the standardized skewness coefficient (SK) of the data was used to assess whether the underlying distribution would most likely be lognormal, normal, or negatively skewed. Skewness coefficients, which are distributed

normally for large samples, can be used to determine a significant departure from symmetry for a given data set. Distribution assignment based on skewness coefficients was as follows:

$SK > 2.0$	Lognormal (positive skewness)
$-1.7 < SK \leq 2.0$	Normal
$SK \leq -1.7$	Triangular (negative skewness)

Lognormality was also assumed, regardless of skewness, when the data range was sufficiently close to zero such that the fit to a normal distribution would imply a significant chance for negative parameter values, which are not meaningful for the HHRC parameters. In such a case, it is likely that the distribution is in fact positively skewed, with values bounded by zero on the left tail of the distribution and unbounded on the right.

For negatively skewed data, the Weibull distribution tended to provide the best (Kolmogorov-Smirnov criteria) and most reasonable fit to the data. The fitted Weibull distribution has a smoothly varying bell-shape and extends slightly beyond the minimum and maximum values, appropriately reflecting the likelihood of parameter values occurring outside the data range. However, this distribution was not available in the model code. In many cases the Weibull distribution can be effectively approximated by a triangular distribution that loses the bell shape and gradual tails but not the overall skewness. Therefore, a triangular distribution was used to approximate the Weibull distribution with the triangular minimum, maximum, and apex location chosen by visual observation.

Evaluation of Outliers

Data were screened for validity and recentness of analytical technique and appropriateness of experimental or environmental conditions (e.g., temperature, soil type) prior to distribution fitting. However, seemingly extreme values (i.e., those falling away from a main body of other values) may be present in a data set as a result of differing but valid analytical techniques or as a result

of environmental conditions. When extreme values could not be screened out based on the scientific review of data, these values were generally left in the data set to represent uncertainty or variance in the distribution.

Several statistical tests (Beckman and Cook 1983; Dixon 1953; Barnett and Lewis 1978) are available for testing outliers based purely on the statistical criteria of whether values have undue influence as a result of their extreme position. However, these tests look for outliers that deviate from an assumed underlying distribution family. When this distribution is known, as few as five data points can be used to detect one to several outliers (Dixon 1953). A small number of data points cannot, however, be used to establish a distribution family if it is not known or hypothesized based on other information. Given the uncertainties in the estimation process for a small number of data points, it was not reasonable to test for outliers since the stated significance of rejection for an outlier may be much higher (lower alpha) than the true significance, which is not known. For larger data sets, the rare extreme values were considered reasonable outcomes of larger sample sets. No extreme values (i.e., outliers) that could be used to characterize risk to human health were discarded based on statistical criteria throughout the parameter development process.

Consideration of the Lack of Central or Skewed Tendency in the Data

For some parameters, the data points indicated a lack of central or skewed tendency in the data, i.e., there was no observed concentration of points, either in the middle or toward one end of the data range. If the number of data points were reasonable (i.e., greater than six), this lack was considered indicative of an underlying distribution with a somewhat uniform or flat probability for values in the observed range. Such uniformity may arise from measurement error or variation in experimental techniques. In such a case, the data maximum and minimum do not represent the most extreme values possible for the parameter. A realistic uncertainty distribution should incorporate the uniform probability that the data are in the observed data range as well as the lower probability of values occurring slightly outside this range. A simple distribution that

accomplishes uniform probability is constructed by combining the uniform and triangular distributions. This distribution, called the uniform triangular, was chosen to approximate the distribution for some parameters and is described below.

A right-tailed, uniform-triangular distribution is constructed by attaching a triangular distribution to the upper endpoint of a uniform distribution that spans the data range. A two-tailed uniform-triangular distribution has a triangular distribution attached to the both endpoints and is used if it does not overlap onto zero and negative values. The endpoint(s) of the triangular portion is chosen such that one-sixth of the possible values of the distribution occur outside the range of the data. Thus, if a uniform-triangular distribution was used for a given chemical, it was assumed that the following are valid characteristics:

- There is a uniform probability of parameter values occurring within the data range.
- One-sixth of the possible values occur outside the data maximum (if right tailed) or outside both the maxima and minima (if two tailed), and the probability for these values decreases linearly as they get farther from the data endpoints.

The uniform-triangular distribution was also assigned to a parameter when the data set was small and exhibited an extremely wide spread relative to the proximity of the data to zero. Such cases occurred for some chemical-specific parameters for which the maximum data point was several orders of magnitude larger than the minimum data point, and was relatively very close to zero. A lognormal distribution fit to such a data set is extremely skewed (standard deviation and the log-transformed values are well over 1.5) because this distribution must predict the occurrence in a small data set of both the near-zero value and a value orders of magnitude larger. With no other information to substantiate lognormality, the fitting of such an extremely skewed lognormal distribution was clearly unwarranted, the parameter was instead fit with a right-tailed uniform triangular distribution. As indicated above, this distribution assumes the data minimum and maximum are equally likely values for the parameter and that there is a decreasing chance for values larger than this maximum.

Establishment of a Conservative Estimate of the Distribution Spread

If so few data points are available (fewer than six) that there is an unacceptably high degree of uncertainty regarding a parameter distribution, the distribution was adjusted to incorporate the added uncertainty indicated by best professional judgment. Two methods were used to fit conservative distributions depending on the skewness of the data. These methods were used in the assignment of distributions for some chemicals for the vapor pressure and Henry's Law constant parameters.

For a normal distribution, the upper 75th confidence limit on the standard deviation was used instead of the maximum likelihood estimate, to increase the spread of the distribution since the use of the confidence limit for the mean would have significantly biased the distribution estimate. Conversely, the use of the larger standard deviation does not bias the parameter distribution itself and merely assumes that uncertainty is spread equally in either direction from the mean. However, the increase in standard deviation does result in a more conservative estimate of the 5th percentile PPLV. In general, the 5th percentile PPLV decreases and the upper 95th percentile increases as the uncertainty in the parameters increases. The conventional Chi-square-based confidence interval estimation of the standard deviation is described below.

The sample standard deviation, S, is a random variable that has a Chi-square distribution when multiplied by (n-1)/sigma (sigma represents the population standard deviation). Based on this distribution and the observed value of S, the confidence interval for the true standard deviation can be calculated. S* is defined to be the upper 75th percentile confidence limit for the standard deviation and is calculated as shown in equation (1):

$$S^* = q \times S^0, \quad q = \frac{\sqrt{n-1}}{X^2_{(.75,n-1)}} \qquad (1)$$

where S^o is the observed sample standard deviation and X^2 is the critical value from a Chi-square distribution. The value of q is 3.08 when n equals 3 and decreases to 1 as n gets larger.

The benefits from using this approach include the effective interpretation of S* as a confidence limit and the appropriateness of S* increasing as n decreases so that the uncertainty about the true distribution is incorporated.

In estimating lognormal distributions, the confidence interval method was not applicable because an increase in the standard deviation and/or the mean alters the shape and skewness of the distribution, making the new distributional shape arbitrary (not based on data). Therefore, lognormal distributions were not adjusted for the uncertainty due to a small sample size.

Truncation of Negative Values

For cases in which normal distribution provided a much better fit to the data than the lognormal distribution (as indicated by goodness-of-fit tests on a large data set), but overlapped zero slightly, a truncated normal distribution was assigned to the parameter. The distribution was truncated during the Latin Hypercube sampling algorithm of the model code so that any negative value sampled was replaced with a positive value equal to the lowest positive percentile encountered by the search algorithm. The 5th, 10th, 15th, 20th, 25th, and 50th percentiles were searched. Truncated normal distributions were only assigned in several cases (e.g., the exposure frequency parameter for the refuge worker) and are noted in this appendix section.

Evaluation of the Independence of the Parameters

The analysis of variability and uncertainty in the PPLV distribution requires that any correlation between parameter distributions be incorporated. Potential correlations between parameters were investigated throughout the distribution development. The strong correlation between total porosity and soil density was incorporated into the Latin Hypercube sampling procedure as explained in the packet for this parameter. In addition, the dependence of water content on total

porosity was also incorporated into the sampling stage of the model. Although no data on correlation were available, the other parameters were judged to be independent of each other. A few examples of the lack of correlation are discussed here. Henry's Law constants and vapor pressure are both dependent on temperature; however, best professional judgment indicated that other factors (e.g., atmospheric pressure, interaction with the soil matrix and water) confounded and diminished the potential correlation due to temperature. Thus, it was reasoned that for both visitor and worker populations, the three parameters would either not be correlated or possibly only somewhat correlated but in an unknown direction (i.e., positive or negative). For example, the number of hours per day for a worker might be positively or negatively related (or unrelated) to the number of days per week, and the number of days per year would probably not be related to the number of years per lifetime. Discussions addressing the potential effects on the analyses of correlation assumptions are presented in the specific parameter development summaries.

In this appendix Statistical methodology is presented for each probabilistic parameter in a detailed manner to enable these results to be reproduced by a knowledgeable professional. All estimation methods applied were unbiased, except where it was felt that a conservative estimation (implying more protection) was required. These cases are noted in the discussion of individual parameters provided in the appendix section. The general methods used in estimating distributions are discussed below. In some cases (e.g., ingestion of soil by adults), distributional descriptors were assigned based on best professional judgment. For some chemicals, no data on a particular chemical-specific parameter (e.g., soil water partition coefficients [K_{oc}) were available, so distributions were extrapolated from chemicals with similar properties. All assumptions used to interpret the data or to develop distributions are explicitly presented.

General Statistical Methodology for Characterizing Activity-Based Distributions for Intake Rates for the Refuge Worker Population and the Biological Worker Subpopulation

A refuge worker's lifetime average daily intake of a contaminant depends not only on how much time that worker spends at the refuge, but also on the type and duration of activities performed by the worker. Activity-based distributions for intake rates were developed based on survey data

for both the refuge worker population and the biological worker subpopulation for the soil covering, dust loading factor, soil ingestion, and breathing rate exposure parameters. However, it should be noted that the PPLVs and risks are characterized for the biological worker only; the refuge worker distributions are presented for comparison purposes only. The general methods used for developing the refuge and biological worker activity-based distributions are described in this section.

The refuge worker survey data (discussed in Appendix Section B.2) provide information on the type and duration of activities performed by the refuge worker, including the biological worker. The data show that there is substantial variability among job categories and workers within categories in the type and duration of activities. This variability is evident in the distributions of the percentages of time spent performing indoor activities, middle exposure level activities, and higher exposure level activities.

A refuge worker's lifetime average daily intake of a contaminant and the corresponding PPLV equations depend on DW × TE × (time-weighted average intake rate) for the soil ingestion and dermal absorption pathways, and on TM × DW × TE × (time-weighted average intake rate) for the particulate and vapor inhalation pathways, where DW is the exposure frequency (days/year), TE is the exposure duration (years/lifetime), and TM is the exposure time (hours/workday).

The time-weighted average (TWA) intake rate depends on the percentages of the total time at RMA, (TM × DW × TE) or (DW × TE), spent in different types of activities. The TWA intake rate is shown in equation (2):

$$INTAKE_{TWA} = (P_{lower} \times INTAKE_{lower}) + (P_{middle} \times INTAKE_{middle}) + (P_{higher} \times INTAKE_{higher}) \quad (2)$$

where:

TWA	=	Time-weighted average
P_{lower}	=	Percentage of refuge worker time spent in lower exposure level activities
P_{middle}	=	Percentage of refuge worker time spent in middle exposure level activities
P_{higher}	=	Percentage of refuge worker time spent in higher exposure level activities
$INTAKE_{lower}$	=	Intake rate during lower exposure level activities
$INTAKE_{middle}$	=	Intake rate during middle exposure level activities
$INTAKE_{higher}$	=	Intake rate during higher exposure level activities

The general, two-step statistical methodology to characterize intake rates involves combining data on proportional allocations of refuge worker activity durations among different activity types with data on activity-specific intake parameters. The first step is the data-based derivation of the distribution for the proportional allocation of activity time among the different general types of activities (i.e., the derivation of the probability distribution for P_{lower}, P_{middle}, and P_{higher}). The second step is the combination of the probability distribution for P_{lower}, P_{middle}, and P_{higher} with the data on $INTAKE_{lower}$, $INTAKE_{middle}$, and $INTAKE_{higher}$. These steps are described below.

The Probability Distribution for the Proportional Allocation of Time Among Three General Types of Activities

A data-based estimate of the probability distribution of the proportional allocation of refuge worker activity time among the three general types of refuge worker activities can be derived from the survey data. Table B.3-4 presents the data on the percentage of the total hours per year spent in the three types of activities—indoors, middle exposure level, and higher exposure

level—for each individual refuge worker. The values in Table B.3-4 are indicated by the range of soil depth categories involved (i.e., 0 to 2 inches, 0 to 12 inches, and greater than 12 inches).

In general, soil exposures can be characterized for a specified range of depths, so the proportion of activity time that is allocated should reflect the risks associated with the depth ranges. The percentages of time spent in middle exposure level activities are summed over all three soil depth categories. Similarly, the percentages of time spent in higher exposure activities are summed over all three soil depths.

The percentages in Table B.3-4 are the particular values reported by the interviewees and do not usually sum to 100 percent. The data were therefore normalized to sum to 100 percent and converted to proportions by dividing the reported values by the sum of the reported values. This approach assumed that all reported values are equally likely to contain errors. The normalized proportions for the 33 refuge workers and 20 biological workers interviewed are listed in Table B.3-5.

The 33 refuge worker sample values (and the 20 biological worker values) of the three normalized proportions in Table B.3-5 provide a data-based approximation to the worker population distribution of P_{lower}, P_{middle}, and P_{higher}. For example, selecting a worker at random from Malheur, Minnesota Valley, and Crab Orchard and determining that worker's proportional allocation of time among the three classes of exposure activities—indoors, middle, and higher—is approximately the same as selecting one of the 33 refuge worker values (or one of the 20 biological worker values) of the triple (P_{lower}, P_{middle}, and P_{higher}) from Table B.3-5.

Randomly sampling the triples in Table B.3-5 is approximately equivalent to sampling the probability distribution of the proportional allocation of worker activity time among the three general types of worker activities. Hence, Table B.3-5 is a surrogate for the probability

distribution of the proportional allocation of worker activity time among the three general types of worker activities.

Estimation of Time-Weighted Intake Rates and Lifetime Average Daily Intake Rates

The TWA intake rate value reflects the proportion of time spent performing activities in each of the three possible general classes of activities as well as the potentially different intake parameter values associated with these three possible general classes of activities. P_{lower}, P_{middle}, P_{higher}, $INTAKE_{lower}$, $INTAKE_{middle}$, and $INTAKE_{higher}$ may vary by worker, so these variables have associated distributions.

The resulting distribution of $INTAKE_{TWA}$ was derived using the following Monte Carlo simulation technique:

1. Select a sample value of P_{lower}, P_{middle}, and P_{higher} from Table B.3-5.
2. Select sample values of $INTAKE_{lower}$, $INTAKE_{middle}$, and $INTAKE_{higher}$ from their respective probability distributions or constant values.
3. Calculate a sample value of

$$INTAKE_{TWA} = (P_{lower} \times INTAKE_{lower}) + (P_{middle} \times INTAKE_{middle}) + (P_{higher} \times INTAKE_{higher})$$

4. Repeat steps (1) through (3) until a large number of samples of $INTAKE_{TWA}$ are generated.
5. Estimate the probability distribution of the lifetime average value of the intake parameter from these Monte Carlo sample values. A refuge worker's lifetime average daily intake of a contaminant is estimated as shown in equation (3).

$$[(TM \times DW \times TE) \text{ OR } (DW \times TE)] \times [(P_{lower} \times INTAKE_{lower}) + (P_{middle} \times INTAKE_{middle}) + (P_{higher} \times INTAKE_{higher})] \quad (3)$$

The resultant probability distribution of the lifetime average value of the intake parameter can be used directly for parameters represented in terms of probability distributions. For parameters represented as constants, the constant can be selected from this data-based distribution of parameter intake values that incorporate activity types and durations.

6B.3.1 SOIL INGESTION RATE

Probabilistic distributions to characterize soil ingestion were developed for each of the potentially exposed populations at RMA. For adults, only limited soil ingestion data are available, and no information to correlate the data with the potential land uses under evaluation is available. Therefore, the distributions for adults are based on best professional judgment, empirical data, and EPA soil ingestion guidance (EPA 1989a). For children between the ages of 1 and 7, data from five soil ingestion studies were combined and a preliminary distribution was developed. To account for the uncertainties associated with this distribution, the median value from the preliminary distribution was combined, based on EPA guidance, with a 95th percentile of 200 milligrams per day (mg/day). A preliminary soil ingestion distribution was also developed for children less than 1 year old based on the results of one study of six children. However, due to uncertainties associated with this distribution, a judgment-based fixed value was chosen to represent the low soil exposure likely for this age group.

The development of the adult and child soil ingestion distributions, which are summarized in Table B.3-6, are described in detail in this appendix section including PPLV distributions and associated uncertainties.

B.3.1.1 Data Compilation

A comprehensive search of the general scientific literature to identify articles on soil ingestion rates for humans was conducted using the Medline computer database. Regulatory guidance documents, such as the EPA Exposure Factors Handbook (1989a), EPA Risk Assessment Guidance for Superfund (RAGS) (1989b), and Superfund Exposure Assessment Manual (1988), were also reviewed.

The literature search indicated that a number of methodological approaches have been used to estimate soil ingestion rates. In the past, soil ingestion rates were derived through both theoretical estimates and indirect empirical measurements. As a result, estimates of soil ingestion

have ranged from 20 mg/day (Dugan and Williams 1977) to 10,000 mg/day (Kimbrough et al. 1984). More recently, an experimental technique utilizing elemental tracers in soil has been developed, providing more accurate estimates of soil ingestion. The major premise behind the tracer method is that some naturally occurring elements (e.g., aluminum, silicon) present in soil are poorly absorbed across the gastrointestinal tract and can be measured in excrement as surrogate estimates of soil ingestion. The tracer method offers the most quantifiable approach available for estimating soil ingestion rates, so tracer studies alone were considered for the development of the child soil ingestion distribution.

Seven tracer studies were located in the literature, six of which were conducted on children. The child studies are the following: Calabrese et al. (1989); Stanek et al. (1991); Davis et al. (1990); van Wijnen et al. (1990); Clausing et al. (1987); and Binder et al. (1986). These studies are evaluated in Section B.3.1.2.2. With the exception of the Binder et al. (1986) study, data from these studies were used to develop the soil ingestion distribution for children.

The only available soil ingestion estimates for adults were reported by Calabrese et al. (1990). These estimates were developed by re-evaluation of validation data from a previous investigation in children (Calabrese et al. 1989). The 1989 study assessed soil ingestion over 3 weeks. The first week was used to establish background soil ingestion rates. For 3 days during the second week subjects received two doses of soil capsules each day, each at 50 milligrams (mg). For 3 days during the third week, subjects received two doses of soil capsules each day, each at 250 mg. The tracer quantities in ingested food and capsules were determined and then subtracted from the tracer excreted to obtain an estimate of background tracer (soil) ingested. The results of the re-evaluation (Calabrese et al. 1990) indicate that the following four metals provided the most reliable estimates—silicon, titanium, aluminum, and zirconium. The mean and median estimates, in mg/day, were 77 and 57, 5 and 1, 53 and 65, and 22 and -4.0, respectively.

The 1990 Calabrese et al. data for adults indicate a high frequency of negative values (one tracer had only three positive soil ingestion values). It is apparent from the frequency of negative values that a large degree of error is present. For this reason, combined with the low number of subjects and lack of information about their activities, this data set was not at first considered rigorous enough to characterize the entire adult soil ingestion distributions. At the April 1, 1992, Subcommittee meeting, however, the Army developed an adult soil ingestion distribution with a median of 33 mg/day based on the results of this soil ingestion study. This value, along with best professional judgment and input from the OAS, is used to develop some of the adult soil ingestion distributions, as described in Section B.3.1.3.

B.3.1.2 Development of Preliminary Soil Ingestion Distribution for Children

In this section, the development of the preliminary soil ingestion distribution for children is described in three parts. First, a description of the methods for treating negative soil ingestion estimates is presented. (Negative soil ingestion estimates can arise in mass balance studies when the amount of tracer ingestion through food and non-soil sources is not fully excreted during the time period of the study.) Second, the results of the six child soil ingestion studies are summarized, and the study-specific distributions are developed. Third, the study-specific distributions are combined to estimate a single preliminary soil ingestion distribution. The preliminary distribution is combined with the judgment-based values presented in Section B.3.1.3 to estimate the child soil ingestion distribution used in the HHRC analysis.

B.3.1.2.1 Treatment of Negative Soil Ingestion Estimates

Extreme negative and positive values may not always imply an inaccurate estimate of the median soil ingestion rate, the quantity typically reported from the studies. This is because the median is not sensitive to the values of extreme data points. However, the present analysis fits a lognormal distribution to the data, and when negative values occur in a potentially lognormal data set, the standard maximum likelihood estimators (the mean and standard deviation of the log-transformed data) cannot be used to estimate the distributional parameters. The arithmetic mean

and standard deviation (equations (1) and (2)) can be used to calculate the lognormal parameters (Gilbert 1987); however, these provide biased and variable estimates. Therefore, below detection limit methodology was applied by assuming a detection limit and using the Robust Method to estimate the lognormal distribution.

$$\hat{\mu}_y = \log(\bar{x}) - \sigma_y^2/2 \quad (1)$$

$$\hat{\sigma}_y = \sqrt{\log(SD^2/\bar{x}^2 + 1)} \quad (2)$$

where = $\bar{x}$ = arithmetic mean
SD = standard deviation
$\hat{\mu}_y$ = lognormal mean
$\hat{\sigma}_y$ = lognormal standard deviation

Assumption of Detection Limit

The designation of an appropriate detection limit is highly uncertain. Stanek and Calabrese (1991) developed detection limits based on a series of strong assumptions. It is uncertain whether their assumptions are appropriate for the data at hand. However, the concept of an inherent detection limit provides one method to reasonably treat negative soil ingestion data.

Negative soil ingestion estimates, and underestimates in general, can arise in mass balance studies when the amount of tracer ingested by an individual through food and other non-soil sources is not fully excreted during the time period of the study. Three of the child soil ingestion studies reviewed in this analysis (Calabrese et al. 1989; Stanek et al. 1991; Davis et al. 1990) are mass

balance studies. This discrepancy can result from the day-to-day variation in both the amount of tracer ingested through food and the transit time for food from ingestion to feces (Stanek and Calabrese 1991). The impact of this discrepancy can be seen by reviewing the simplified mass balance equation given by Stanek and Calabrese (1991):

$$I_{fo} + I_s = O_{fe} \quad (3)$$

where I_{fo} and I_s are the amounts of a tracer element from ingesting food and soil, respectively, and O_{fe} is the amount of the tracer element in feces. In this equation, it is assumed that I_{fo} and O_{fe} are known and that the equation is solved for I_s. Therefore, if I_{fo} exceeds O_{fe} (i.e., true soil ingestion is zero or very small), I_s is estimated to be negative in order for the mass balance equation to hold. If the tracer intake due to food is not fully excreted during the period of the study, even though the true soil ingestion is substantial, then I_s will be positive but still be an underestimate of the true soil ingestion. An overestimate of soil ingestion may also occur because the excretion of food source tracer amounts may exceed that ingested during the time period of the study.

Stanek and Calabrese (1991) suggest that the error resulting from discrepancies in mass balance of tracer amounts from food has a relatively large effect on soil ingestion estimates as the true soil ingestion decreases and as the concentration of the tracer in the soil decreases relative to the concentration in food. The second phenomenon is tracer specific, while the first implies a detection level of soil ingestion below which estimation is unreliable. Stanek and Calabrese (1991) document both phenomena in their analysis of the adult validation study of Calabrese et al. (1989). Stanek and Calabrese compared the estimated soil ingestion rates from this study to the actual soil ingestion rates (via soil capsules) to obtain the percentage recovery (i.e., 100 percent estimated soil ingestion/actual soil ingestion). The mean square error (MSE) in percentage recovery was defined as the average of the squared deviation in percentage recovery from 100 percent. The MSE was shown to increase as the tracer concentrations in the soil

decreased relative to concentrations in food, or as the amount of soil ingested decreased relative to the amount of food ingested. By assuming a fixed-tracer concentration in the soil (equal to that in the Calabrese adult study) and a fixed amount of food ingested (equal to the median amount for the adult study), the authors derive a model that can predict detection limits for soil ingestion. The detection limit is defined as the soil ingestion level where the standard error exceeds 20 percent. The standard error is defined as:

$$SE = \sqrt{\frac{MSE}{n}} \qquad (4)$$

where: n = Number of samples
SE = Standard error
MSE = Mean square error

In Figure 4 of Stanek and Calabrese (1991), a sample size of 100 corresponds to a detection limit of approximately 20 mg/day for aluminum and 30 mg/day for silicon, while a sample size of 50 corresponds to a detection limit of approximately 30 mg/day for aluminum and 50 mg/day for silicon.

Although the mass balance studies considered for the RMA soil ingestion distributions have sample sizes of 63 (Calabrese et al. 1989) and 101 (Davis et al. 1990), a single detection limit of 20 mg/day for both studies and all tracers was assumed. This detection limit corresponded to a sample size of 100 for the aluminum tracer, which had the lowest predicted detection limit given the sample size and tracers of the three studies. Although the predictive model implies that a higher detection limit may have provided a more accurate estimation of the distributions, this model has not been thoroughly tested for its general applicability and sensitivity to assumptions. The minimum predicted detection limit was chosen because it implies the least alteration of original data.

The value of the detection limit influences the resulting estimated distributions. In trial estimations applying the Robust Method to the Calabrese et al. (1989) data for children, an increase in the detection limit from 5 mg/day to 20 mg/day resulted in a slight increase in the estimated median from 25.8 mg/day to 30.0 mg/day (for the aluminum tracer). This introduces additional uncertainty into the estimation of the distributions because the most appropriate detection limit for the studies is not known.

In assuming a detection limit, positive soil ingestion values less than the limit were also assumed to be unreliable and classified as below detection. For example, it was assumed that two individuals with estimated ingestion rates of 5 and 15 mg/day could both have a true soil ingestion anywhere between 0 and 20 mg/day, with the second individual no more likely to have a high soil ingestion than the first. Thus the detection limit concept applied here is analogous to that of detection limits in chemical analyses.

Robust Method for Handling Below Detection Data

The Robust Method uses the values of the N_D data points above the detection limit and the number N_B (but not the values) of the data points below the detection limit (BDL) data to estimate a lognormal distribution. The BDL data are then filled in with estimates based on the N_B lowest expected order statistics of the estimated lognormal distribution. (The first expected order statistic is the most likely minimum data point to occur if a total of $N_D + N_B$ points are sampled from a given distribution. Likewise the nth expected order statistic is the most likely value of the nth lowest data point in a sample of size $N_D + N_B$.) This method is described in detail in Gilliom and Helsel (1986).

B.3.1.2.2 Interpretation of Results From Each Study

The data from the soil ingestion studies, summarized in Table B.3-7, are described below. The following notation for describing age classes was adopted in order to provide consistency between authors. This notation differs from that used by some authors, but the age classes are

described accurately. Whenever an integer (e.g., 5) is used to report an age class, the class contains all ages valued at that integer and below the next one. For example "age 5" includes individuals of age 5.0, 5.5, 5.9 , etc. When a range of ages is presented, the endpoints are not included within the class. For example "age 5–7" includes individuals of age 5.1 up to age 7.9, and ages >18 includes age 18.1 and older. The age class "infants" includes individuals less than 1 year old.

As described below, data for each individual were provided in the Clausing et al. (1987) and Calabrese et al. (1989) papers. The Davis et al. data were provided by the authors for 101 of the 104 subjects in the study. Three subjects were not included because of incomplete food sample data. The Stanek et al. data were supplied in graphical form from which numerical equivalents were digitized. Age-specific data from van Wijnen et al. (1990) could not be obtained, so the summary statistics provided in the paper were used. The Binder et al. (1986) study was reviewed but not incorporated into the child distribution due to uncertainties associated with the study methodology.

Calabrese et al. (1989)/Stanek et al. (1991) — Ages 1 to 4

Calabrese et al. conducted a mass balance study in which stool, urine, and duplicate food samples were collected from 64 children in Amherst, Massachusetts for 2 consecutive weeks (8 days total). The children ranged in age from 1 to 4 years. The study was conducted in the early to middle fall months of September and October, but climatic conditions were not reported. Using eight elemental tracers, soil ingestion rates were determined by measuring the tracer concentration in urine and feces and subtracting the contribution from non-soil sources (as determined from duplicate food samples). One limitation of this study is the use of a non-random population, middle and upper class subjects, which may have lower soil contact than subjects from lower socioeconomic status.

The authors stated that due to high intra-individual variability in this study, the median provides a better measure of central tendency than the mean. Data were lognormally distributed and positively skewed, with median estimates of soil ingestion ranging from 9 to 96 mg/day depending on the tracer selected (maximum estimates ranged from 1,391 to 11,695 mg/day). It was also reported that one child had a soil ingestion rate between 5 and 8 grams per day (g/day), but since the authors did not appear to be confident whether this was a display of pica behavior on the part of the subject or whether it was an analytical aberration, this child was not included in the summary statistics.

Stanek et al. (1991) re-evaluated the data of Calabrese et al. (1989) and presented age-specific soil ingestion estimates based on the tracers aluminum, silicon, titanium, and zirconium. The four other tracers analyzed by Calabrese et al. in the 1989 study (barium, manganese, vanadium, and yttrium) were excluded from re-evaluation by Stanek et al. because they had a higher estimated variance in recovery values, thereby reducing confidence in the estimates (Stanek et al. 1991).

Using the process shown in Figure B.3-1, age-specific data from Stanek et al. (1991) were examined. Only the data points for silicon and aluminum were digitized from the scatter plots, because there was a large degree of variability in the estimates given by titanium and zirconium. There were three titanium estimates that were less than -1,000 mg/day, and there were two zirconium estimates that were less than -500 mg/day. In contrast, there were no estimates of aluminum and silicon that were less than -100 mg/day. There were also extreme positive data for titanium (in the range 1,000 to more than 4,000 mg/day). These extreme positive values are not necessarily errors, but are questionable because they occur in both studies only for the titanium tracer, and the extreme negative errors observed for this tracer may reflect a variability that would cause extreme positive errors as well.

The tracer-specific estimates were grouped into single-year classes for the purpose of determining the appropriateness of pooling. For each age class, the data less than 20 mg/day were replaced with estimated values from the Robust Method of Gilliom and Helsel (1986). The lognormal distributions shown in Table B.3-8 were then fit to the single-year classes. Because pooling was deemed appropriate, the estimates for all ages were then pooled into one multiyear class (Table B.3-9). The data less than 20 mg/day from the multiyear class distribution were again replaced with Robust Method estimates and fit with the lognormal distribution indicated in Table B.3-9. The Robust Method data set does not differ substantially from the original data set, as can be seen in Figure B.3-2. The fit of the lognormal distribution to the multi-year class data is shown graphically in Figure B.3-3.

Davis et al. (1990)

Davis et al. used a mass balance approach to study soil ingestion in 104 volunteers aged 2 to 7 years old. These volunteers were randomly selected from three cities in southeastern Washington during the summer months. Children in diapers were excluded from this study. Eighty-eight percent of the children came from two-parent households with the majority of parents having professional careers. In addition, 87 percent of the children were white. Aluminum, silicon, and titanium were used as tracer elements. Duplicate food samples were analyzed to permit adjustment of soil ingestion estimates for nonsoil tracer contribution. Average and median daily soil ingestion estimates (in mg/day) reported by Davis et al. (1990) for a single age class of children aged 2 to 7 years old were 39 and 25, 82 and 59, and 246 and 81, respectively, for aluminum, silicon, and titanium. The data appear to be skewed in a lognormal fashion (personal communication with Paul White, February 4, 1991).

Following the process shown in Figure B.3-1, the aluminum and silicon tracers were used to develop distributions. The estimates based on titanium were discarded because large errors were suspected for this tracer. Three soil ingestion estimates from titanium the ranged from -1,000 to -6,000 mg/day and six estimates ranged from -500 to -1,000 mg/day. In contrast, there were

no aluminum and silicon estimates that were less than -500 mg/day. There were also extreme positive data for titanium (in the range of 1,000 to more than 6,000 mg/day). These extreme positive values are not necessarily errors, but are questionable because they occur in both studies only for the titanium tracer. Moreover, the extreme negative errors observed for this tracer may reflect a variability that would cause extreme positive errors as well.

The tracer-specific estimates were grouped into both single-year classes and multiyear classes. As shown in Figure B.3-2, the original negative values were replaced by positive values less than 20 mg/day using the Robust Method. The resulting single-year and multiyear class distributions are presented in Table B.3-8 and B.3-9 respectively. The fitted distribution for the combined age class was compared to the data as shown in Figure B.3-3.

Van Wijnen et al. (1990)

Using a "least tracer approach", van Wijnen et al. investigated soil ingestion rates using aluminum, titanium, and acid-insoluble residue as an elemental tracer in 385 children aged 1 to 4 years old in the Netherlands. The study was conducted in June/July and August/September. Reported analytical recoveries of aluminum and titanium in a soil/feces mixed sample was 94 percent and 97 percent, respectively. Children from four different environmental situations with different potential soil exposures were selected: inner city children with little potential for contact with soils, children living in houses with gardens, children staying at campgrounds with high potential for soil contact, and children staying at hospitals with no possible direct soil contact. The hospitalized subjects represent background exposures.

The soil ingestion distribution was defined based on the first-period data (June/July) for "nursery school" children. Results of the second period (August/September) of nursery school children were not included in the analysis because weather conditions during this period were such that a reduction in outdoor play was suspected. Weather was found to be significantly correlated with soil ingestion such that bad weather tended to coincide with low soil ingestion rates. Children

vacationing in campgrounds were not considered representative for exposures at the RMA since their soil ingestion would be expected to be greater due to longer duration and more intense contact with soil as well as possible lack of shower facilities. Additionally, camping is not a defined recreational activity at RMA. Consequently, data for children staying at campgrounds were not incorporated in the distribution development. Hospitalized children (ages 1 to 4) were used to obtain data for developing background tracer contributions.

The results of this study, presented for specific age groups, indicate that the amount of soil ingested by children under normal living conditions (i.e., day-care age children) is between 0 and 90 mg/day. Specific activities such as camping may lead to soil ingestion estimates as high as 300 mg/day. All distributions were described as lognormal by the authors. The geometric means and standard deviations were reported, allowing the lognormal descriptors to be calculated.

Van Wijnen et al. (1990) applied the least tracer method to obtain a single distribution for each age class prior to correction for non-soil sources. The least tracer method assigns to each subject the minimum soil ingestion estimate given by any of the tracers. This method quantifies the soil ingestion rate for each tracer based on the assumption that all of the tracer came from the soil and that it therefore represents an overestimate of the true soil ingestion. The authors then reason that the tracer, which overestimates the lowest ingestion rate for a given individual (i.e., the minimum of all tracer estimates), must provide the closest estimate of true soil ingestion.

The least tracer method approach has been criticized recently as having no biological foundation and as possibly underestimating soil ingestion rates (Calabrese et al. 1989). The authors question whether the food intake of hospitalized children is representative of the non-hospitalized subjects' food intake. Also, the soil ingestion estimates are likely to have artificially high variability due to the assumption of constant food ingestion among subjects.

Despite these uncertainties, the least tracer method distributions reported by van Wijnen et al., even after subtracting a correction term for non-soil sources (discussed below), imply the highest soil ingestion values of any study in this analysis. There is no reason, therefore, to suspect that the least tracer method underestimates soil ingestion in this case.

The least tracer method distributions were corrected for non-soil (i.e., background) sources by subtracting the lower and upper 95 percent confidence limits on the arithmetic mean soil ingestion (70 and 120 mg/day, respectively) of hospitalized children from the individual soil ingestion estimates for a given age class. The geometric mean of the corrected data was reported for age classes 1–2 and 3–4. The subtraction of a constant correction value from all individuals does not account for the variation in non-soil intake of each tracer and the potential correlation between total soil ingestion and non-soil tracer intake. In addition, it is questionable whether the food intake of hospitalized children is representative of the non-hospitalized subjects. Therefore, additional uncertainty is introduced by this correction. Nevertheless, values based on the subtraction of 70 mg/day because this rate represents a somewhat conservative estimate of the true mean contribution by non-soil sources.

Only uncorrected distributions (Table B.3-8) were reported for the single-year age classes and used to investigate the appropriateness of pooling. The lack of correction for non-soil sources is not expected to interfere with the investigation of age-related trends because each of the distributions would be similarly affected by the correction of non-soil tracer sources.

In developing the multiyear age class distribution, the geometric means reported for the corrected data for age classes 1–2 and 3–4 (88 mg/day and 62 mg/day), respectively, were used. The geometric standard deviations for the corrected data were not reported. Therefore, the geometric standard deviation (0.8065) reported for the uncorrected data from all age classes was used as an estimate of the geometric standard deviation of the corrected populations. Since the geometric standard deviation controls the skewness of the distribution, the use of the geometric standard

deviations from the uncorrected data implies that the uncorrected and corrected data have the same degree of skewness. This assumption is reasonable given that no information on the skewness of corrected populations is available. To obtain a distribution for the 1–4 age class, 300 points were drawn from each of the 2–year class distributions and combined to represent a simulated population of equal portions of the age classes 1–2 and 3–4. The combined data were then fit with a lognormal distribution (Table B.3-9).

The authors reported a range of 0 to 30 mg/day for corrected soil ingestion estimates for children less than 1 year old. This range was not considered appropriate because the non-soil intake of tracers, which is in large part dependent on quantity of food, cannot be assumed to be equal for infants and children aged 1 to 4 years old. Therefore a multiplicative, rather than additive, correction factor was applied. The correction factor was derived by comparing the uncorrected geometric means reported for the single-year classes age 1 and age 2 (average geometric mean = 161.5 mg/day) to the corrected geometric mean reported for combined ages 1–2 (88). The corrected geometric mean is approximately half the value of the uncorrected geometric mean. (For the 1987 Clausing et al. study, the correction factor was approximately 0.6.) The geometric mean reported for children less than 1 year old was adjusted downward by a factor of 0.5 and used with the original geometric standard deviation (Table B.3-9). The assumption of a constant fractional reduction between uncorrected and corrected geometric means for infants and older children has not been verified in any current studies. However, this assumption is more realistic than the authors' (Clausing et al. 1987) assumption that a constant quantity of tracer is ingested through food and other non-soil substances regardless of age.

Clausing et al. (1987)

Clausing et al. used a least tracer approach to examine soil ingestion in 18 nursery school children aged 2 to 4 years old in the Netherlands. Titanium, aluminum, and acid-insoluble residue were used as elemental tracers. Analytical recoveries reported for aluminum and titanium in a soil/feces sample were 94 percent and 89 percent, respectively. The authors collected

duplicate food samples from six hospitalized children and assumed that the amounts/concentrations of tracers were the same as those in nursery school children. These tracers were then subtracted from fecal tracer totals of nursery school children. The average soil ingestion for the nursery school children was 105 mg/day (geometric mean of 90 mg/day) with a population standard deviation of 67. Hospitalized children had an average soil ingestion of 49 mg/day (standard deviation of 22 (statistically significant difference - $P < .04$)). Assuming that the hospitalized children represent background exposures, the average soil ingestion rate corrected for background is 56 mg/day.

Estimates obtained from the least tracer method were not used in the analysis because of concerns over the validity of the least tracer method. Also discarded were the estimates obtained from titanium because there was a potential for large over- and underestimates. The estimates for silicon and aluminum were then averaged for each individual. For 11 individuals, one of the tracer estimates was missing, so the other tracer estimate was assigned to an individual. None of the tracer specific estimates was negative or less than 20 mg/day, so robust estimation was not required.

The age of each individual was not reported, so a multiage class distribution was fit (Table B.3-9). Nursery school children and hospitalized children were fit with separate distributions based on the reported data. Because the non-soil tracer intake of the nursery school children was not measured, the correction for non-soil sources introduces a high amount of uncertainty. The authors suggest that the arithmetic mean of the hospitalized group be subtracted from the arithmetic mean of the nursery group. However, the arithmetic mean is a highly unstable descriptor for the lognormal distribution since its value may vary widely for the same underlying population. For this reason, the geometric mean for hospitalized children (51.50 mg/day) was subtracted from the geometric mean for nursery school children (123.8 mg/day). The geometric standard deviation for the corrected distribution was assumed equal to that of the

uncorrected data. Both the uncorrected and corrected distributions were compared to the data, as shown in Figure B.3-3.

Binder et al. (1986)

Binder et al. collected diapers for 3 days from 59 non-toilet-trained children in East Helena, Montana. The children ranged in age from 1 to 3 years old. Urine and stools were analyzed for aluminum, silicons and titanium. In addition, yard soil samples were obtained and similarly analyzed for elemental tracers. Soil ingestion was then determined by comparing the tracer concentration in feces with the soil tracer concentrations. Correction for food and other non-food sources was not conducted, so the following results are likely to be an overestimation of soil ingestion. Based on these analyses, Binder et al. reported the arithmetic mean of soil ingestion was 121 mg/day, 184 mg/day, and 1,834 mg/day, respectively, for aluminum, silicon and titanium. Aluminum and silicon appear to provide more realistic estimates of actual soil ingestion than titanium. The data were skewed lognormally (the log-transformed data appeared to be normally distributed).

A major limitation of the Binder et al. study was the lack of quantitative measurement of tracer intake from food and other non-soil sources. Another limitation was the assumption used that fecal excretion was 15 g/day for all subjects to compensate for sample loss. The lack of correction for non-soil tracer contributions in this study may result in a significant overestimation of actual soil ingestion rates. The use of a mass balance approach that considers non-soil sources would result in lower soil ingestion estimates by a factor of 2 to 6 depending on the specific tracer (Calabrese et al. 1989). However, since it is not known what the contribution of non-soil sources was in the study, the results of Binder et al. were not incorporated into the distribution development for soil ingestion.

B.3.1.2.3 Combination of Study-Specific Distributions for Children

It is important that as many independent studies as possible be integrated into the final estimated distributions since the methods of estimation are still being refined and the measurement error appears to be large, and also since the measurement error of each study may be biased so that one study may provide higher soil ingestion estimates purely due to its particular methodology. It was assumed that bias would be reduced if the studies were combined. Because multiple distributions can be integrated in different ways, the methods used and key assumptions are stated explicitly. Some methods involve use of best professional judgment and introduce a possible bias into the results. Other methods for integrating multiple distributions are based on simple objective assumptions. In either case, the uncertainty as to how close the estimated distributions approximate the true variability is increased. However, the distributions are expected to provide a better characterization of the parameter variability than if the parameter were to be fixed.

Distributions specific to single-year age classes were investigated for those years with data (ages less than 1 year, 1 to 7 years, and adults). Although these distributions are based on small sample sizes and are therefore uncertain, they provide the only means of assessing potential differences in soil ingestion due to age. Pooling data for children aged 1 through 7 is expected to reduce the uncertainty regarding the true soil ingestion distributions. The improvement in the accuracy of estimation due to an increase the number of data points is expected to outweigh the slight loss in accuracy due to reduced age specificity.

To combine the distributions, the age- and study-specific distributions were first compared visually to assess differences in distribution shape and location (Figure B.3-4). The distributions for ages 1 to 7 appear to be similar and to not show a consistent relationship with age. The distributions derived from the Davis et al. (1990) data are very similar for ages 2 to 7. The distributions derived from Stanek et al. (1991) and van Wijnen et al. (1990) indicate similarity for ages 2 to 4 and 2 to 7, respectively; however, both sets of distributions indicate a substantial difference for 1-year-old children. The distribution for 1-year-old children derived from van

Wijnen et al. implies a much higher mean soil ingestion (see Table B.3-8) and a lower frequency of soil ingestion values below 200 compared to the other distributions. The distribution for 1-year-old children derived from Stanek et al. indicates the opposite tendency, with this distribution having a lower mean and a substantially higher frequency of low soil ingestion values. Figure B.3-5 shows the relationship between mean or median soil ingestion and age for each study. The derived distributions from the Davis et al. study do not indicate a consistent trend with age, while those of the Stanek et al. and van Wijnen et al. study indicate trends for children aged 1 to 3 that run in opposite directions.

The distribution for infants (i.e., children less than 1 year old) given in the van Wijnen et al. (1990) study indicates a distinctly lower mean, median, and skewness than the remaining distributions derived from van Wijnen et al. (1990). This result is reasonable given that infants are expected to be more closely watched by adults than older children. Therefore, this age class was assigned a preliminary distribution based on the reported single-year distribution (N=7) and a correction factor for non-soil sources of 0.5. However, a judgment-based soil ingestion rate was used to characterize the infant population as described in Section B.3.1.3.

The distribution for the 1- to 7-year-old age class was based on results of four studies: Davis et al. (1990), Stanek et al. (1991), van Wijnen et al. (1990), and Clausing et al. (1987) (see Table B.3-8). Study-specific distributions were developed (Figure B.3-6) using the individual methods described above. The two distributions derived from mass balance studies have lower means and medians than those derived from the two least tracer method studies, and are thought to provide more accurate estimates of soil ingestion than the least tracer method studies. However, the discrepancy between the distributions may in part be due to factors affecting the sampled population. Distributions from different studies may not describe the same subpopulation since geographic location, weather, and socioeconomic factors may affect normal (i.e., those not related to pica) soil ingestion rates. The subpopulations are assumed to be equally important (i.e., representative of equal numbers of people). In order to include the widest range

of subpopulations and the factors affecting them, the four studies are given equal weight regardless of the assumed accuracy of experimental procedure or the number of subjects. (Although this did not occur, exception would have been made had there been one study with such a low sample size that results would have been highly questionable.)

The studies were combined under the assumption of equal weight by applying the following Monte Carlo approach. In this approach, 300 points were drawn from each of the study-specific distributions and combined into a set of 1,200 points that were then fit with a lognormal distribution. The combined simulated data set represents an overall population of soil ingestion values comprised of equal portions of the four subpopulations. The combined simulated data set was fit with a lognormal distribution of 53 mg/day (median) and 274 mg/day (95th percentile).

B.3.1.3 Final Soil Ingestion Distributions

The soil ingestion distributions assigned for each age class and land-use scenario are presented in Table B.3-6. Based on the observation that soil ingestion data was positively skewed in a consistent manner, all soil ingestion distributions were assumed to be lognormal. Development of these distributions is described below.

Age-specific distributions developed from the data for the ingestion of soil in children were not made specific to a land-use scenario due to the lack of specific data regarding activity. Therefore, since it was considered inappropriate to separate distributions for children in the regulated/casual and recreational populations, the soil ingestion studies for children, which presumably considered a variety of play activities, were used as a basis for the development of soil ingestion distributions for children under all open space land-use scenarios.

B.3.1.3.1 Regulated/Casual, Recreational — Infants (< 1 year old)

Infants were assumed to have negligible soil ingestion. A fixed value of 1.0 mg/day was assigned to this parameter to avoid a "divide by 0" error in the PPLV calculations. Although a preliminary soil ingestion distribution was developed for this age group, the data were uncertain and the sample size was low. Therefore, the fixed value was chosen based on best professional judgment.

B.3.1.3.2 Regulated/Casual, Recreational — Ages 1 to 7

Soil ingestion distributions for children aged 1 to 7 were developed as follows. The distribution type (lognormal) and median were based on the median of the preliminary soil ingestion distribution as developed in Section B.3.1.2. The median soil ingestion of 53 mg/day was based on an equal weighing of the results of four soil ingestion studies, Davis et al. (1990), Calabrese et al. (1989), van Wijnen et al. (1990), and Clausing et al. (1987). The distribution was further defined by a 95th percentile of 200 mg/day consistent with EPA guidance.

B.3.1.3.3 Regulated/Casual, Recreational — Ages 8 to Adult

Since no data were available for children aged 8 to 17, and since data on adult soil ingestion were considered highly uncertain, soil ingestion rates for these age classes were assumed to be less than those for young children. Accordingly, the 95th percentile of the soil ingestion distribution was assigned the value of 100 mg/day consistent with EPA guidance. The distribution was further defined by assigning the 50th percentile a value of 26.5 mg/day, which is half that of that for age class 1 to 7.

B.3.1.3.4 Industrial Worker

The soil ingestion distribution for industrial workers was assigned a 95th percentile of 50 mg/day consistent with EPA guidance. The distribution was further defined by assigning a value of 13 mg/day to the 50th percentile.

B.3.1.3.5 Commercial Worker

The soil ingestion distribution for the commercial worker was assigned a 50th percentile of 10 mg/day and 95th percentile of 33 mg/day. The assignment of both percentiles was based on best professional judgment.

B.3.1.3.6 Biological Worker

Available data (Shell Chemical 1991) indicate that exposure to three soil depth categories during the course of a working day may be pertinent to an individual within this subpopulation. Therefore, all three soil exposure distributions, described below, are combined into a single representative biological worker soil ingestion distribution using a Monte Carlo simulation.

Low Exposure Category

The low exposure category applies to normal background soil ingestion and also reflects exposures in indoor and outdoor environments where there is minimal soil contact. Paustenbach (1987) conducted an extensive review of the literature and suggested adult daily soil intakes are in the range of 0 to 10 mg/day. These values are lower than the median soil ingestion value of 33 mg/day based on the Calabrese et al. (1990) adult study. However, since the Calabrese et al. study included individuals who worked outside of the home, a value of 33 mg/day was considered an appropriate RME value for total daily exposure in this category. A median value of 10 mg/day was assumed for this category based on the high end of the range proposed by Paustenbach. Therefore, for the low soil exposure category, a lognormal distribution with a median of 10 mg/day and 95th percentile of 33 mg/day is proposed.

Medium Exposure Category

The medium exposure category applies to those individuals performing outdoor activities involving some contact with surface soils. Current EPA guidance for soil ingestion under an industrial scenario is 50 mg/day (EPA 1991a). This value is proposed as the RME (95th percentile) for the medium exposure category. The proposed median of the distribution for

adults is 33 mg/day and is based on the median of the adult soil ingestion distribution developed from the Calabrese et al. 1990 study. Therefore, for the medium soil exposure category, a lognormal distribution with a median of 33 mg/day and 95th percentile of 50 mg/day is proposed.

High Exposure Category

The high soil exposure category applies to workers exposed to soil through intrusive activities. Current EPA guidance (EPA 1991a) indicates a theoretical (i.e., not based on data) RME ingestion rate of 480 mg/day for those individuals performing construction and landscaping-type activities, but stresses the short-term, weather-dependent nature of this type of work. Exposures at this rate would only be expected for short periods of time.

In consideration of the potential for higher soil exposures associated with certain activities, and the absence of data to support the value of 480 mg/day suggested in the Office of Solid Waste and Emergency Response (OSWER) Directive, an alternative ingestion rate was considered. Based on the assumption that a biological worker will exhibit greater personal hygiene than a toddler or young child, the distribution derived for these children should be sufficiently protective of a worker engaged in invasive activities. The child soil ingestion rate, which was developed based on empirical data, suggests a lognormal distribution with an upper 95th percentile (RME) concentration of 273 mg/day and a median concentration of 53 mg/day.

As explained in Appendix B.3.0, the TWA average soil ingestion experienced by a given biological/maintenance worker is defined as follows:

$$SI_{TWA} = P_{lower} * SI_{lower} + P_{middle} * SI_{middle} + P_{higher} * SI_{higher} \quad (5)$$

where:

P_k = Proportion of time spent by the worker in activity class k

SI_k = Soil ingestion value associated with class k

SI_{lower} = Low exposure: net SI

SI_{middle} = Medium exposure: net SI

SI_{higher} = High exposure: net SI

Because P_k and SI_k vary by individual, these variables have associated probability distributions. The values for P_{lower}, P_{middle}, and P_{higher} were sampled from the 20 individuals identified for the biological/maintenance worker subpopulation. The resulting distribution of SI_{TWA} was simulated by repeatedly sampling from the component distributions and calculating SI_{TWA} until a large number of SI_{TWA} values were obtained. The simulated data for the biological worker were fit with a lognormal distribution having a mean of 34 mg/day and a 95th percentile of 85 mg/day. However, based on discussions at the April 1, 1992 EA Technical Subcommittee meeting, the biological worker distribution was anticipated to have a median soil ingestion rate of 33 mg/day and a 95th percentile of 106 mg/day. Since these most recent values have been presented to the OAS, the distribution reflects these assigned values rather than those based directly on the simulation. The resulting biological worker soil ingestion distribution used in the risk characterization has a mean of 40.26 mg/day and a standard deviation of 36.05 mg/day.

In comparison, the soil ingestion distribution for the refuge worker was also developed using the same simulation methodology and activity-specific distributions as the biological worker subpopulation. However, a correction for non-RMA soil ingestion was also applied. The non-RMA median and 95th percentile soil ingestion rates were assumed to be 50 percent of the "Low Exposure Category" distribution median and 95th percentile, respectively. This results in a non-RMA ingestion median and 95th percentile of 5 mg/day and 16.5 mg/day, respectively. The non-RMA median and 95th percentile values were subtracted from the corresponding values of the distribution for each soil exposure category. The data for the refuge worker were fit to a lognormal distribution with a mean of 25.27 mg/day, a standard deviation of 23.78 mg/day (log mean of 29.12 and log standard deviation of 0.7964), and a 95th percentile of 68.2 mg/day. This

refuge worker distribution is provided for comparison to the biological worker. The refuge worker scenario was not used in the estimation of PPLVs or risks.

B.3.1.3.7 Uncertainty in Soil Ingestion Distributions

An unknown degree of uncertainty is introduced by a number of variable factors when the results of the studies described in this appendix section are used to predict soil ingestion rates for the potentially exposed populations at RMA. This uncertainty could result in either over- or underestimating risks. Some of the factors introducing uncertainty include the following:

- Variability in soil types and environmental conditions in the studies compared with the soils and conditions present at RMA. Some soil ingestion studies were conducted in the eastern United States, which is less arid then Denver. Dustier climates could increase the degree of soil ingestion.

- Different socioeconomic status of study subjects compared with the potentially exposed populations. Children of lower socioeconomic status could have higher soil ingestion intake rates.

- Different activity levels of study subjects compared with the potentially exposed populations. The experimental population was supervised; estimates of soil ingestion for unsupervised play could be higher.

- Variable tracer-recovery efficiencies in the studies. Low tracer recovery could lead to underestimates of soil ingestion.

- Measurement error from recovery and analysis of the tracer in excrement as well as in soil and non-soil sources. This error is reflected in the highly variable results from different tracers and was assumed to be partially mitigated by averaging these results rather than relying on a single tracer.

- Error in the data resulting from mass balance calculations due to relatively short duration of the studies.

B.3.2 SKIN SURFACE AREA AND SOIL COVERING

Skin surface area and soil covering are parameters used in the PPLV equations to evaluate dermal contact with soil. Skin surface area is a fixed parameter, while soil covering is probabilistic. These parameters are defined and described in this appendix section.

B.3.2.1 Skin Surface Area (Fixed)

The exposed skin surface areas for each potential future RMA population are shown in Table B.3-10. The data and methods used to identify these values are described below.

B.3.2.1.1 Data Compilation

A recent EPA document, Guidance for Dermal Exposure Assessments (1991b), presents mean skin surface areas (total area and body parts) for male and female adults in the 5th through 95th percentiles. Based on several studies in the literature recommending skin surface area estimates for various exposed body parts, EPA determined that 10 to 25 percent of an individual's skin surface area may potentially be exposed to soil (1991b). Considering the upper end of this range, EPA recommends a default skin surface area value of 5,000 square centimeters (cm^2) for adults and 2,500 cm^2 for children. However, because these default estimates do not consider seasonality or other factors related to the exposed skin surface area for a given population (i.e., amount of clothing worn), they were not adopted for use. Instead, values specifically determined in consideration of the exposed populations at RMA and as adapted from EPA (1985b) were considered.

Time-weighted estimates of skin surface area were derived by considering the amount of clothing likely to be worn by each exposed population as well as season and temperature. Specifically, the TWA surface area was determined for exposed body parts by considering the clothing worn by each exposed population for three seasons of the year and the percentage of time spent wearing this clothing during each season. Seasons were defined as summer (May through September), spring/fall (March, April, October, November), and winter (December through

February) based on daily maximum temperatures above 70 degrees Fahrenheit (°F), above 50°F, and below 50°F, respectively. The time-weighted factor for these seasons (i.e., percentage of time that body parts are exposed each season) are 41.6, 33, and 25 percent for summer, spring/fall, and winter, respectively.

Age-specific 50th percentile skin surface area estimates for applicable body parts were obtained from the statistical distributions presented in EPA (1985b). Skin surface areas were developed for 19 age groups ranging from less than 1 year to less than 18 years and adults over 18 years. However, specific body-part surface area estimates were not available in EPA (1985b) for the age classes less than 1 to less than 18 years. Therefore, surface area estimates for specific body parts in these age groups were instead estimated from total body surface area and the percentage of total body surface area for each body part. These data are reproduced from EPA (1985b) in Table B.3-11. Estimated surface areas for specific body parts assumed to be exposed to soil are presented in Table B.3-12. Data presented in these tables represent an average of the 50th percentile of skin surface areas for both males and females.

It was noted that data in EPA (1985b) were lacking for several age groups. Data gaps were filled either by averaging the nearest bounding values or by analyzing the linear regression. Empirical surface-area data in EPA (1985b) indicate that the relationship between surface area and age is not completely linear, though subportions of the curve are nearly linear. Therefore, some missing surface-area data for an age group were predicted by analyzing the linear regression in data from nearby age groups. For example, data for ages to less than 1 year and 1 to less than 2 years were missing; therefore, data were obtained by regressing the data available from the 2- to 5-year-old age groups. Linear regression, however, was not considered appropriate for head surface area for ages 9 years through adult because the variability was such that no trend could be detected. It was, therefore, considered more reasonable to compute an average head surface area across all the age groups in question and to assign this average head surface area to each age group. Data derived by either technique are summarized in Table B.3-12.

Data distinguishing surface areas for a forearm from an entire arm were not available for children or female adults. For population groups where forearms are exposed, therefore, it was assumed that the surface area of the forearm is equivalent to 50 percent of the total area of the arm based on data from adult males (EPA 1985b). During the summer season it was assumed that individuals in regulated/casual or recreational visitor populations would wear short-sleeve shirts. Accordingly, an additional 10 percent of the total surface area of arms was added to represent a portion of the upper arms exposed while wearing short-sleeve shirts. A similar assumption was made in deriving the surface area of legs exposed while wearing short pants (i.e., exposed area is equivalent to 60 percent of the total surface area of the leg).

B.3.2.1.2 Computation of Time-Weighted Average Surface Area

Using the surface area estimates for specific body parts (Table B.3-12), and the extent of clothing coverage defined for each population by season, an average exposed surface area was determined for each season. The total exposed skin surface area for each season was then multiplied by the factors that represent the percentage of each year spent on RMA during each season, and summed for each population in order to derive the TWA. Mathematically, the time-weighted surface area estimates were computed as follows:

$$SA_{TWA} = (SA_S)(SF) + (SA_{SF})(SFF) + (SA_W)(WF) \quad (1)$$

where:

SA_{TWA}	=	Total time-weighted surface area estimate for a given population in square meters
SA_S	=	Surface area estimate for summer in square meters
SF	=	Time-weighted factor for summer (5 months/12 months = 41.6 percent)
SA_{SF}	=	Surface area estimate for spring/fall in square meters
SFF	=	Time-weighted factor for spring/fall (4 months/12 months = 33.3 percent)
SA_w	=	Surface area estimate for winter in square meters
WF	=	Time-weighted factor for winter (3 months/12 months = 25 percent)

Time-weighted average skin surface area estimates considering seasonal variation were developed for each exposed population. These estimates are summarized in Table B.3-10 and are discussed below.

Regulated/Casual and Recreational Visitors

In the summer, the regulated/casual or recreational visitor could reasonably be expected to wear short pants, short-sleeve shirts, and shoes. Such dress would leave the forearms, a small portion of the upper arms, hands, neck, head, lower legs, and partial thighs exposed. A similar scenario exists in the spring/fall, except individuals are considered more likely to wear long pants due to cooler temperatures. This corresponds to exposure of the head, neck, forearms, and small portion of the upper arms, and hands. During the winter, heavy dress, including gloves and scarves, may be worn, so the head alone would be exposed. The TWA surface area of these body parts for each age group was averaged for male and female adults and children.

Commercial Worker

In the summer, the commercial worker could reasonably be expected to wear long pants, shoes, socks, and short-sleeve shirts, so only the hands and forearms are assumed to be exposed to indoor dusts. In the spring/fall and winter, only the hands are expected to be exposed since longer shirt sleeves would be worn due to the cooler temperatures. The sum of the TWA surface area of these body parts averaged for adult men and women is 0.155 per square meter (m^2).

Industrial Worker and Biological Worker

Similar to the commercial worker, the industrial and the biological worker could reasonably be expected to wear short-sleeve shirts (summer), long pants, shoes, and socks. However, since exposure can be more intensive for these workers, whose time is spent outdoors, than for commercial workers, the head, neck, forearms and a portion of upper arms, and hands were considered in determining surface area estimates for the summer and spring/fall. In the winter,

only the head and neck were assumed to be exposed. The sum of the TWA surface area estimates of these body parts averaged for adult men and women is 0.327/m^2.

B.3.2.2 Soil Covering (Probabilistic)

The amount of contaminated soil in contact with exposed skin is a key parameter in assessing dermal exposure to environmental chemicals. Soil covering is defined as the mass of soil adhering to skin per unit of surface area. It is influenced by several factors including age, type of activity (i.e., those that increase potential contact with soil), and soil type.

Distributions for the soil covering parameter for each population are presented in Table B.3-13 and Figures B.3-7 and B.3-8. This section summarizes the results of a review of the literature for the soil covering parameter, and describes the development of age-specific probabilistic distributions appropriate to each of the six potentially exposed populations/subpopulations projected to frequent RMA under future land-use scenarios.

B.3.2.2.1 Data Compilation

A comprehensive literature search was conducted to locate data on the soil covering parameter. Additionally, several EPA documents were also reviewed for data on soil covering estimates including RAGS (1989b), Exposure Factors Handbook (1989a), Interim Guidance for Dermal Exposure Assessments (1991b, 1992), Superfund Exposure Assessment Manual (1988), and Dermal Exposure Assessment (1992), and Review of Dermal Absorption (1984).

The literature search revealed a total of four studies that provided empirically derived soil covering estimates. In addition, two qualitative analyses by Hawley (1985) and Sedman (1989) that provided soil covering estimates for adults and children, respectively, were reviewed. Additional studies quantifying soil covering for children and adults are discussed below. The soil covering values extracted from these studies are summarized in Table B.3-14.

After a comprehensive search of the literature, two studies were found that determined skin soil covering values in children. In the first study, Lepow et al. (1975) observed randomly selected children exposed to lead-contaminated dust and dirt during the summer while playing outside. The weight of soil adhering to exposed skin (22 hand samples) was determined by removing adhered dirt with an adhesive tape with a surface area of 21.5 cm^2. The mean weight of dirt was determined to equal 11 mg and was converted by Sedman (1989) to a soil covering estimate of 0.51 mg/cm^2. In the second study Roels et al. (1980) determined the amount of soil adhering to the hands of 9- to 14-year-old children using lead as a tracer element. Soil was removed from the hands by pouring diluted nitric acid over the palm of children's dominant hand, and the sample was then analyzed for total lead content. Sedman (1989) compared the mean weights of lead for boys at four school locations, as reported in Roels et al. (1980), to the reported lead concentrations in the soil to obtain a mean soil weight of 159 mg. Sedman (1989) assumed 60 percent (185 cm^2) of the surface area of the hand was sampled by Roels et al. (1980) to obtain a mean soil covering of 0.9 mg/cm^2.

In another study using slightly older children, Que Hee et al. (1985) determined soil adherence to the palm of adolescents (aged 14) using soil with particle sizes ranging from 44 to 833 microns (μ). Soil adherence was determined by applying 5 grams of each soil size, shaking the hands to remove any non-adhered soil and then measuring the difference in soil weight before and after application. An average of 32 mg of soil adhered to the hands. Sedman (1989), assuming that the average surface area of the palm of a small adult was 160 cm^2, calculated a resultant soil covering value of 0.2 mg/cm^2. Soil covering values are summarized in Table B.3-14 for each size fraction and age group.

Driver et al. (1989) measured the soil adherence in adult males of unknown age exposed to varying soil types and particle sizes. Soil adherence was measured by immersing one hand in a preweighed mixture of several soil types for a period of 30 seconds. Excess soil was removed and the weight of soil adhering was determined by the difference in soil sample weights

measured before and after soil application. In general, it was found that adherence values decreased as particle size increased (Table B.3-14). Driver et al. also investigated the influence of organic matter content of soil on soil adherence. However, these results were not found to be significant.

In an assessment of health risks from exposure to contaminated soils, Hawley (1985) estimated soil covering values for adults under the following three exposure scenarios: exposure in ordinary living space, exposure in attic crawl spaces and other areas that are rarely cleaned, and exposure outdoors while engaged in yard work for 8 hours a day, 2 days per week for 5 months. For the first exposure scenario, Hawley assumed the surface area of an adult hand (910 cm^2) was exposed. The weight of dust adherence was estimated based on data on the average dustfall occurring inside of a house (Table B.3-14). For the latter two exposure scenarios, Hawley assumed both the hands and forearms were exposed (surface area of 1,700 cm^2) and a 50 μm layer of dust covered the skin surface area. The weight of the dust (indoors) and soil (outdoors) adhering to the skin was adjusted for the difference in the density of dust and soil.

Harger (1979), as reported in EPA (1988), determined a kaolin adherence value of 2.77 milligrams per square centimeter (mg/cm^2) by a similar method employed by Que Hee et al. (1985). Also reported in this study is an adherence value of 1.45 mg/cm^2 for commercial potting soil on human skin. The 2.77 mg/cm^2 kaolin soil adherence value is reported in EPA (1988) as an upper-bound value. These two values are rejected by EPA in recent dermal exposure assessment guidance (1992) due to the lack of details regarding experimental procedures and the informality of the study. For example, only one experimental subject was used and the soil types (e.g., kaolin) were not appropriate to RMA. Moreover, there was a general lack of study details that could have permitted a more meaningful statistical interpretation. Accordingly, the data from the Harger study were not included in the distribution development for the soil covering parameter.

In a review of the data discussed above, it is apparent that all of the studies have inherent uncertainties. These data uncertainties are recognized in recent EPA guidance (1992), as are the difficulties in the selecting a "default" value. However, from the range of soil covering values identified above (0.2 to 1.5 mg/cm^2), a central soil adherence value of 1.0 mg/cm^2 is recommended by EPA (1992). Additionally, EPA considers 1.0 mg/cm^2 to be a conservative value because the reported soil covering estimates are based on soil covering values derived from intense hand exposure to soils. Exposures of other body parts to soil during common activities would be expected to be less intense than for hands only.

Empirical evidence suggests that soil covering may depend on behavioral patterns, which vary between individuals and with age, as well as on soil characteristics such as particle size and organic matter content. Age was the key factor in matching soil covering estimates from literature values to a particular population/subpopulation at RMA. Soil covering data specific to the age classes evaluated at RMA were generally not available, however. For example, the age groups represented in the soil covering studies reviewed include children (age 4), adolescents (age 11 through 14), and adults (age not specified). For those age groups not represented in the literature, values for soil covering were extrapolated directly from the projected activities of the population and the available soil covering data. For example, participants in organized team sports would incur higher skin soil covering as compared to an individual who is walking. Soil covering estimates were assigned to populations using best professional judgment based on the relevance of the activity of the population at RMA to that of the activity summarized in the study.

Only two of the studies reviewed, Driver et al. (1989) and Que Hee et al. (1985), investigated the influence of particle size on skin soil covering. Driver et al. (1989) reported statistically significant increases in adherence with decreasing particle size, while Que Hee et al. (1985) found relatively little change over particle size. Due to the variability between the results of the two studies addressing particle size, it was not possible to correlate the relationship between soil

covering and particle size quantitatively. No data were found that determined the influence of specific soil types on soil adherence values.

Specific soil covering estimates for each exposed RMA population and the criteria used to select appropriate studies are discussed further below.

B.3.2.2.2 Distribution Development

Most of the studies obtained in the literature review were not directly applicable to the land-use scenarios or age groups of interest at RMA, so the estimation of distributions required subjective interpretation of the available studies. As a result, there is an increase in the uncertainties regarding the estimated distributions. Professional judgment was used to group age classes and assign soil covering studies considered to be relevant.

Assignment of Qualitative Soil Covering Ratings to Exposed Populations

The methodology depicted in Figure B.3-9 was followed to estimate distributions for the soil covering parameter. First, mean soil covering values were extracted from the literature and any studies directly applicable to the populations of concern identified. Second, the sources of variability were identified for all populations. Based on the expected sources of variation, as well as the results of directly applicable studies, the populations were assigned a qualitative soil covering rating (e.g., "low", "medium", "low to high") according to their expected exposure to soil. The most applicable study for each population was then selected considering two factors: the match of key study elements to the population at RMA and the maintenance of the relative soil covering ratings for each population. Each study was then reviewed to extract variance estimates, which in some cases involved converting to units of soil covering (e.g., from units of lead amount on hand). In some cases, judgment-based estimates of the variance were included. The estimation of variance for some data adds an element of uncertainty to the soil covering parameter that cannot be readily quantified.

The qualitative soil covering ratings, assigned studies, and associated distributions for each population are shown in Table B.3-13. The rationale for assigning the qualitative ratings is discussed below, as is the assignment of studies and distributions to the populations. The assigned distributions are shown in Figures B.3-7 and B.3-8.

Children less than 1 year old were expected to have very minimal contact with the soil due to close parental supervision. Therefore, for both the regulated/casual and recreational visitor populations, infants were assigned a "very low" soil covering rating.

Toddlers are expected to engage in similar play whether they are regulated/casual or recreational visitors to the RMA. Toddler play activities were assumed to result in a "medium" skin soil covering.

The behavior of children/adolescents in the recreational scenario is expected to include sports such as soccer, baseball, and football, each of which involve an increased contact with soil over the hiking and picnicking activities defined for children/adolescents in the regulated/casual visitor population. Accordingly, ratings of "high" and "low" were assigned for children/adolescents in the recreational and regulated/casual visitor populations, respectively.

Adult exposure to soils is expected to be lowest in the commercial land-use scenario since the individual would be indoors most of the day. Accordingly, adult commercial workers received a "very low" soil covering rating. The regulated/casual visitor is expected to have a "low" exposure via the soil and dust generated during picnicking and hiking (walking) activities. The recreational visitor is expected to have a somewhat higher level of soil exposure due to sports and other rigorous activities. The adult recreational visitor population was assigned a soil covering rating of "medium" rather than "high" as assigned to younger recreational age groups as a result of the lower propensity for soil contact assumed for adult recreational visitors. A soil covering rating of "medium to high" was assigned to the adult industrial worker under the

assumption that the individual may be working for extended periods in direct contact with the soil (i.e., excavation activities), or working with soil-covered equipment and in warehouses that may accumulate significant amounts of soil and dust. The biological worker subpopulation was assumed to have a range of high and low soil exposures, depending on the frequency of various activities. Observational activities (e.g., taking surveys) would be expected to result in low contact with soil, while setting traps and collecting wildlife (e.g., burrowing animals) could result in very high soil contact rates. The activities observed in the Refuge Worker Survey (Appendix Section B.2) are incorporated into the estimation of the soil covering distribution for the biological worker subpopulation. This group was assigned a soil covering rating of "medium to high."

Assignment of Studies and Distributions to Correspond with Exposed Populations

Soil covering distributions for each of the potentially exposed populations are presented in the following sections. The distributions for the regulated/casual and recreational visitors are presented for various age groups.

Soil covering distributions were determined for each exposed population by assigning one or more of the literature studies considered to be representative of a population. Except where noted, the distribution for the study was then used to represent the exposed population. Distributions for the soil covering parameter for each population are presented in Table B.3-13.

Distribution types were not reported in the soil covering studies; therefore, normality was assumed unless the implied frequency of negative soil covering values was significantly high. For a distribution having a standard deviation as large or larger than the mean, a lognormal distribution is more reasonable than a normal distribution because the values are likely to be positively skewed.

Infants: Regulated/Casual and Recreational Visitors

None of the available soil covering studies was considered representative of children less than 1 year old under close parental supervision. Therefore, a normal distribution with mean 0.02 mg/cm^2 and standard deviation of 0.006 was assigned based on best professional judgment.

Toddlers: Regulated/Casual and Recreational

As discussed above, Lepow et al. (1975) gathered patch samples of soil lead from the hands of 22 children with a mean age of 4 years during the course of outdoor play in several different areas. The authors reported a mean soil weight of 11 mg adhering to the 21.5 cm^2 patch samples, from which Sedman (1989) calculated the mean soil covering as 11 mg/21.5 cm^2 = 0.51 mg/cm^2. Lepow et al. also reported the confidence interval about the mean lead amount. This reported confidence interval was used to solve for the sample standard deviation in units of lead amount; this value was then converted to units of soil weight using the mean lead concentration of lead in the soil. The sample standard deviation was then converted from units of soil weight to soil covering following the Sedman calculation. This conversion results in a standard deviation of 0.83 mg/cm^2. This standard deviation reflects not only behavioral variation between individuals and over time but probable variation due to different soil types as well. Because of the proximity of the data range to 0.0, a skewed distribution was considered most appropriate. Accordingly, a lognormal distribution having the same mean and standard deviation as those converted from the values reported by Lepow et al. (1975) was assigned. This distribution was considered most representative for toddlers at play as both regulated/casual and recreational visitors.

Children/Adolescents and Adults: Regulated/Casual Visitor

Que Hee et al. (1985) conducted a soil application experiment on a "small adult" (age unclear) that examined variation in soil covering due not to behavior, but to different particle sizes. The variation due to different size fractions was assumed to approximate the variation due to soil type, although most soils, including those at RMA, are a mix of particle sizes. The mean and

standard deviation of soil weight reported for the six sieved soils were converted to a mean and standard deviation of 0.20 mg/cm^2 and 0.10 mg/cm^2, respectively, for soil covering. The proximity of the data range of 0.0 imply that a skewed distribution was appropriate, so a lognormal distribution with the above-referenced mean and standard deviation was assigned. The mean soil covering in the Que Hee et al. (1985) study is relatively low compared to other empirical studies. The experimental procedure probably did not allow for more than a very superficial exposure to soil (i.e., there was no chance for the soil to be ground into cracks in the skin and between skin and fingernails.) This degree of exposure was considered most representative of the activities (hiking and occasional handling of soil) that are defined for the child through adult age groups of the regulated/casual visitor. The study was considered representative for adults as well as children/adolescents due to the lack of behavioral specificity.

Children/Adolescent: Recreational Visitor

Roels et al. (1980) conducted a field study of lead occurring on the hands of children and adolescents aged 9 to 14 during the course of play. The number of children sampled was not reported. The Roels et al. (1980) study reported mean weight of lead on hands for each of four schools located at varying distances from a lead smelter operation, as well as lead concentrations in the soils of the playgrounds. Sedman (1989) converted this data to a mean soil covering for all schools using the following conversion formula and assuming that an average adolescent hand is 185 cm^2 in area:

$$SC\ (mg/cm^2) = LW\ (\mu g) / LC\ (\mu g/g) * 1{,}000\ (mg/g) / 185\ (cm^2) \qquad (1)$$

where:

SC = Soil covering

LW = Lead weight

LC = Lead concentration

Sedman (1989) obtained a mean of 0.86 mg/cm^2 over all schools and a variance of 0.282 mg/cm^2 as described below.

Although the variation of soil covering for the entire sample of children is not reported, the two components of this variation, between school and within school, can be derived from information reported in the paper. The total variance of soil covering is the sum of the between-school variance and within-school variance. The between-school variance may reflect different soil types, playground equipment, and amounts of soil on the playground. The between-school standard deviation of soil covering, calculated directly from the four means, is 0.116 mg/cm^2.

The within-school variation represents the effect of different individual activities and is reported only in the form of a graph showing error bars about the mean for each school. The error bars were not defined in the paper. However, error bars are most commonly used to represent one standard deviation, so this interpretation was assumed. The numerical value for the error bars was visually estimated from the graph and converted to soil covering standard deviations of 0.241 (urban), 0.237 (rural), 0.058 (2.5 kilometer from smelter), and 0.106 milligrams per kilometer (mg/km) (less than 1 kilometer from smelter). The scale of the graph allowed a visual resolution of an interval of approximately 5 micrograms (μg) lead weight, which corresponds to a soil covering interval of about 0.12 mg/cm^2 for the urban school data and 0.0053 mg/cm^2 for the school less than 1 kilometer from the smelter. It is expected that the actual numeric values differ from those estimated by less than these intervals of resolution. The four estimates of the within-school standard deviation were pooled based on their associated degrees freedom (number of subjects – 1) to obtain the within-school standard deviation of 0.166.

The mean (0.86 mg/cm^2) and total standard deviation (0.116 + 0.166 = 0.282 mg/cm^2) imply that the distribution may be symmetrical, so a normal distribution having this mean and standard deviation was assigned. The variation observed in the data includes variation between individuals

and over time, and may also include variation due to soil type, so the study was used to represent children/adolescents at play for the recreational visitor population.

Adult: Recreational Visitor

Driver et al. (1989) conducted a soil application experiment on adults that examined variation due to particle size and organic fraction of soil. The data primarily reflects variation in soil covering due to soil composition (particle size and organic content). The mean and standard deviation of the soil covering values reported for 13 soils were 0.57 mg/cm^2 and 0.22 mg/cm^2, respectively. Again, the proximity of the data range to 0.0 implied that a skewed distribution was appropriate, so a lognormal distribution with the above-listed mean and standard deviation was assigned. This study was chosen to represent the adult recreational visitor because the mean and variation were slightly higher and more reflective of higher soil contact rates for recreational activities than those reported by Que Hee et al. (1985) and used as the basis for the adult regulated/casual visitor soil covering. The reason for the higher values is unknown, but likely reflects experimental procedure. The variation of the assigned distribution may understate the true variation due to the lack of a behavioral component.

Commercial Worker

Hawley (1985) estimated soil covering for an indoor living space using a theoretical model and empirical data on dust levels, as well as soil content in dust, in houses of an urban area. This estimate — 0.56 mg/cm^2 — was considered the best estimate available for soil covering for adults in a commercial (i.e., indoor) setting. In addition, since the Hawley value was used as mean soil covering, a judgment-based estimate of the standard deviation was assigned. This variability was intended to include the effects of differing behavior and differing indoor environments, and was assumed to be relatively small. An assumed coefficient of variation (standard deviation/mean) of 0.25 was assumed, resulting in an assigned standard deviation of .014.

Industrial Worker

Hawley (1985) presents theoretical estimates of soil covering for an adult working in a garden and in an attic with a relatively high dust level. However, since this soil covering value (3.5 mg/cm^2) is greater than the EPA-recommended (1992) default value of 1.0 and is not based on data, the value was not used to characterize the soil covering distribution for the industrial worker. Instead, a judgment-based distribution was assigned to reflect the conservative default value of 1.0 recommended in EPA (1992). For the purposes of estimating a distribution, the value of 1.0 was taken as a 95th percentile value. An assumption was required regarding the shape and spread of the distribution, both of which are related to the standard deviation of the log-transformed values (S_y). The industrial worker population was, therefore, assumed to have a value for S_y equal to that estimated for the biological worker subpopulation (0.47 mg/cm^2) discussed below. A lognormal distribution having a 95th percentile of 1.0 and a S_y of 0.47 was used to characterize soil covering for this population. This distribution has a log mean of -0.77 and log standard deviation of 0.47, as shown in Table B.3-13.

Biological Worker

Unlike other populations, data were available on the time spent by biological workers indoors, outdoors, and in soil-intrusive activities. The soil contact in each of these activity classes differs, so the TWA soil covering for biological workers depends on the time spent in these activities. To develop the distributions, following Monte Carlo simulation was used.

The lifetime TWA soil covering value for a given worker is defined as follows:

$$SC_{TWA} = P_{indoor} * SC_{indoor} + P_{outdoor} * SC_{outdoor} + P_{soil\ intrusive} * SC_{soil\ intrusive} \quad (2)$$

where:

SC_k = Soil covering value for activity class k

P_k = Fraction of time spent in activity class k

The distribution of SC_{TWA} was simulated by repeatedly sampling a value from each of the distributions for SC_{indoor}, $SC_{outdoor}$, and $SC_{soil\ intrusive}$ and multiplying these by the corresponding P_k sampled from the data on time allocations. The values for P_{indoor}, $P_{outdoor}$, and $P_{soil\ intrusive}$ were sampled from the 20 individuals identified for this subpopulation.

The soil covering distributions for the biological worker were assigned to the three exposure activity classes as described below.

Indoor Exposure Class

No data were available for the indoor exposure class; therefore, the theoretical estimate derived by Hawley (1985) was used. No attempt was made by Hawley to estimate the variance and uncertainty about this value. Nonetheless, best professional judgment indicates that the variance would be very small relative to that in other exposure classes due to the uniformity of office conditions, so the soil covering distribution for this class was simply fixed at the Hawley estimate of 0.056.

Medium Outdoor Exposure Class

The experimental studies of Que Hee et al. (1985) and Driver et al. (1989) provided for direct hand contact with soil, but did not include the prolonged and rigorous contact that would occur with high exposure activities such as digging and some types of habitat remediation. Therefore, these studies were expected to be representative of medium outdoor soil exposure activities. The Que Hee et al. (1985) soil covering values are substantially lower than those reported by Driver et al. (1989), a difference that is likely to reflect the different soil application techniques, hand sifting of soil (in the case of Que Hee et al.), and hand immersion in soil (in the case of Driver et al.) This variation in type of soil contact is appropriate for the medium exposure class and at least partially accounts for the variation in activities in this class. To incorporate the variation observed in these two studies, distributions were fit individually to the data for each study and then combined under the assumption of equal weight. The combination of distributions involved

fitting a distribution to a data set created by drawing an equal number of samples from each of the two component distributions and combining them into one distribution.

The Que Hee et al. data reflects variation due only to different soil composition (e.g., particle size) and differently sized hands, and does not reflect variation due to differing activities. The mean and standard deviation of soil weight reported for the six sieved soils were converted to a mean and standard deviation for soil covering of 0.20 mg/cm^2 and 0.104 mg/cm^2, respectively. The proximity of the data range to 0.0 imply that a skewed distribution was appropriate, so a lognormal distribution with the above-referenced mean and standard deviation was assigned.

The Driver et al. data also primarily reflect variation in soil covering due to soil composition (i.e., particle size and organic content). The mean and standard deviation of the soil covering values reported for 13 soils were 0.567 mg/cm^2 and 0.224 mg/cm^2, respectively. Again, the proximity of the data range to 0.0 imply that a skewed distribution was appropriate, so a lognormal distribution with the above-referenced mean and standard deviation was assigned.

High Outdoor Exposure Class

The playground measurements of Roels et al. (1980) imply soil covering values for boys (mean of 0.86 mg/cm^2), which are substantially higher than for girls (mean of 0.48 mg/cm^2). If only boys are considered, the Roels et al. (1980) measurements imply mean soil covering values that are substantially higher than values implied by the studies of Lepow et al. (1975) (playground sample, ages 2 to 6 years), Que Hee et al. (1985), and Driver et al. (1989, unsieved results). The distribution fit to the Roels et al. data for boys (derived below) implies a 95th percentile soil covering value of 1.38 mg/cm^2. This same distribution implies that 26 percent of the soil covering values are larger than 1.0. Because the Roels et al. playground sample reflects an opportunity for subjects to have a more prolonged exposure to soil and did result in relatively high soil covering values, this study (boys only) was considered to be representative of soil covering for the high outdoor exposure class of refuge workers.

The Roels et al. study reported mean weight of lead on hands for each of four schools of varying distance from a lead smelter operation, as well as lead concentrations in the soils of the schools. Sedman (1989) converted these data to a mean soil covering for all schools using the following conversion formula and assuming that the surface area of an average adolescent hand is 185 cm^2:

$$SC(mg/cm^2) = LW(\mu g) / LC(\mu g/g) * 1000(mg/g) / 185(cm^2) \quad (3)$$

where:

SC = Soil covering
LW = Lead weight
LC = Lead concentration

This calculation was followed to obtain a mean of 0.86 mg/cm^2 over all schools and a variance of 0.282 mg/cm^2 as described below.

Although the variation of soil covering for the entire sample of children is not reported, the two components of this variation, between school and within school, can be derived from information reported in the paper. The total variance of soil covering is the sum of the between-school variance and the within-school variance. The between-school variance may reflect different soil types, playground equipment, and amounts of soil on the playground. The between-school standard deviation of soil covering, calculated directly from the four means, is 0.116 mg/cm^2.

The within-school variation represents the effect of different individual activities and is reported only in the form of a graph showing error bars about the mean for each school. The error bars were not defined in the paper. However, error bars are most commonly used to represent one standard deviation, so this interpretation was assumed. The numerical value for the error bars was visually estimated from the graph and converted to soil covering standard deviations of 0.241 (urban), 0.237 (rural), 0.058 (2.5 kilometers from the smelter) and 0.106 mg/cm^2 (less than

1 kilometer from the smelter). The scale of the graph allowed a visual resolution of an interval of approximately 5 μg lead weight, which corresponds to a soil covering interval of about 0.12 mg/cm^2 for the urban school data and 0.0053 mg/cm^2 for the school less than 1 kilometer from the smelter. It is expected that the actual numeric values differ from those estimated by less than these intervals of resolution. The four estimates of the within–school standard deviation were pooled based on their associated degrees freedom (number of subjects - 1) to obtain the within-school standard variation of 0.166 mg/cm^2.

The mean (0.86 mg/cm^2) and total standard deviation (0.116 + 0.166 = 0.282 mg/cm^2) imply that the distribution may be symmetrical, so a normal distribution with this mean and standard deviation was assigned.

The soil covering distributions for the three activity classes are summarized below.

Activity Specific-SC		Distribution Type	Source
SC_{indoor}	(low soil exposure—office setting)	Fixed	Hawley (1985)
$SC_{outdoor}$	(medium soil exposure)	Combined: Normal Lognormal	Que Hee et al. (1985) Driver et al. (1989)
$SC_{soil\ intrusive}$	(high soil exposure—outdoor)	Lognormal	Roels et al. (1980)

The simulation resulted in 10,000 samples of SC_{TWA} as calculated in the above-referenced equation. These values for the biological worker were fit with a normal distribution with a mean of 0.41 mg/cm^2 and standard deviation of 0.20 mg/cm^2 (log of soil covering has a mean of -1.0 and a standard deviation of 0.47 as shown in Table B.3-13).

In comparison, the soil cover distribution for the refuge worker was developed using the same simulation methodology and activity distributions as described above. The distribution providing the best fit was a lognormal distribution with a mean of 0.3176 mg/cm^2 a standard deviation of 0.1908 (log mean of -1.301 and a standard deviation of 0.5515) and a 95th percentile of 0.6744 mg/cm^2.

B.3.3 RELATIVE ABSORPTION FACTOR

B.3.3.1 Background

In addition to the role that chemical/physical properties can play in influencing contaminant absorption in organisms, chemical absorption is also influenced by the type of environmental medium or matrix (e.g., soil, water, air) in which a contaminant is incorporated. For example, soil-bound contaminants are generally more poorly absorbed across skin than might otherwise occur across other media due to tight binding of the contaminant to soil constituents (e.g., organic carbon matter). Therefore, the influence of a soil matrix on the potential bioavailability from oral and dermal exposure routes was investigated for the 27 COCs. In this evaluation, bioavailability was incorporated into a term referred to as the RAF, which is the ratio of chemical absorption in soil to chemical absorption in the medium used in the toxicity study. RAFs were used to derive the reference dose or slope factors.

The following sections briefly review the mechanisms relating to contaminant absorption as well as those factors that influence bioavailability of soil-bound contaminants from both dermal and oral exposure routes.

B.3.3.1.1 Mechanisms of Dermal Absorption

The human skin is generally not readily permeable to many environmental chemicals due to its complex, multilayered structure (Klaassen 1986). Despite this rather effective barrier, a large number of chemicals remain that may be absorbed in sufficient quantities to produce toxic effects. Contaminants are absorbed through skin directly through the epidermal cells, through sweat or sebaceous glands, or through hair follicles (Klaassen 1986). Most chemicals, however, pass directly through the epidermal cells at a rate and to an extent that is limited by the outermost layer (the stratum corneum) due to its composition of keratin and dead cells (Klaassen 1986). Compounds are transported or diffuse through skin via two different molecular mechanisms—intracellular and transcellular processes—depending on their physiochemical properties such as lipid solubility and molecular weight (Marzulli et al. 1965). Absorption of

chemicals across skin is known to vary among species and by chemical. Bartek et al. (1972) have determined that skin permeability decreases for many chemicals according to species as follows: rabbit > pig and rat > human.

Absorption of a soil-bound chemical across the skin is a more complicated, two-fold process. First, the chemical must desorb (detach) from the soil to be in a form available for absorption. Second, the chemical must cross the skin barrier and be absorbed systemically. Therefore, depending on the strength of the soil-chemical bond, absorption is in most cases lower for soil-bound contaminants than for pure compounds.

B.3.3.1.2 Mechanisms of Oral Absorption

The gastrointestinal (GI) tract is a primary route of exposure to environmental contaminants. In contrast to skin, many environmental toxicants in water, food, and soil are ingested and subsequently absorbed from the GI tract, which is readily permeable to many chemicals because it is designed to facilitate the absorption of nutrients from food. As such, the absorption rate from the GI tract is typically much greater than that from skin. Most contaminants are absorbed through simple diffusion, with lipid-soluble compounds more rapidly and extensively absorbed than nonlipid-soluble compounds. Toxicants may also be metabolized to other compounds in the GI tract by acidic conditions, resident microflora, and enzymes, thereby altering absorption and toxicity (Klaassen 1986). Absorption of a soil-bound contaminant across the GI tract is also a two-fold process of desorption from soil and systemic absorption (Klaassen 1986).

B.3.3.1.3 Factors Influencing Bioavailability From Soil

A number of soil- and chemical-specific factors influence the rate and extent of contaminant absorption from soil. Soil-specific factors include, but may not be limited to, soil organic content, cation exchange capacity, temperature, moisture, and particle size. Chemical-specific factors influencing soil binding include, but are not limited to, chemical structure, solubility, polarity, and vapor pressure. Additionally, exposure-related factors such as animal test species,

dose applied, and the duration of exposure can also influence absorption estimates as determined from laboratory studies.

The route of exposure can also exert a number of influences on the absorption of a contaminant. Skin-specific factors that may influence absorption of a contaminant include species, site of application, degree of hydration, temperature, and condition of the skin (EPA 1991b). As with dermal absorption, many factors also influence GI absorption of a soil-bound contaminant including GI motility, presystemic elimination, and presence of other chemicals (e.g. cadmium, copper, calcium), and age (Klaassen 1986).

Although all of these factors are expected to influence absorption of a soil-bound contaminant through the oral and dermal exposure pathways, adjustment for these factors in the specific studies evaluated was not attempted. When varying dose levels and soil types were used in a given study to determine a percent-absorption value, an average of these percent-absorption values was computed for the study.

In the HHEA report (EBASCO 1990a), contaminant bioavailability (dermal pathway only) was defined as the product of the percent absorption of pure compound and a soil matrix correction factor (i.e., a ratio calculated as the contaminant dose in liver from administration in a soil matrix divided by the contaminated dose in the liver found after administration of pure compound). Consistent with the approach adopted by EPA Region 1, bioavailability (the percent of contaminant absorption in soil) has been incorporated into the term RAF (EPA 1989c). RAF is computationally defined as the fraction of the contaminant absorbed from soil divided by the fraction absorbed from the medium used in determining a critical toxicity value.

RAF is used to compute PPLVs for the soil ingestion and soil dermal contact pathways only. The dermal RAF term is intended to address the following estimation tasks: (1) conversion of both administered doses in the oral critical toxicity study and dermal intakes to absorbed

quantities, (2) the differential contaminant absorption between oral and dermal pathways (since an oral DT value is used), and (3) the decreased bioavailability of soil-bound contaminants. The oral RAF term addresses the following estimation tasks: (1) conversion of orally administered DT values and intakes to absorbed quantities; and (2) the decreased bioavailability of soil-bound contaminants. The following sections discuss the literature sources consulted during data compilation as well as the derivation of RAFs for each COC.

B.3.3.2 Data Sources

A number of EPA references were reviewed in defining input values for RAF distributions including RAGS (1989b), Exposure Factors Handbook (1989a), Superfund Exposure Assessment Manual (1988), Review of Dermal Absorption (1984), and Interim Guidance on Dermal Exposure Assessment (1991b). Other data sources examining site-specific soil absorption were also reviewed including Oral Bioavailability of RMA Contaminants of Concern: Results of a Literature Survey (Shell Oil Company 1991) and Oral Bioavailability of Soil-Associated Aldrin/Dieldrin (Midwest Research Institute 1991). Additional information was also sought in toxicological profiles prepared by the Agency for Toxic Substances and Disease Registry (ATSDR), EPA's (1993) Integrated Risk Information System (IRIS), and a comprehensive search of the general scientific literature; specific reference sources are cited in Tables B.3-15 and B.3-17.

B.3.3.3 Data Review and Compilation

In developing chemical-specific RAFs, data were compiled separately to define the terms for the numerator and denominator of the RAF term. In compiling data for RAF determinations, only empirically derived data were considered. Articles were deemed relevant if, based on professional judgment, the percent absorption values reasonably represented a total percent absorption from either soil or the medium of the critical toxicity study.

B.3.3.3.1 Consideration of Excretion Pathways in Determining Percent Absorption

Critical excretion pathways, which vary among contaminants, were considered in evaluating the suitability of a study for inclusion in the RAF evaluations. For example, aldrin/dieldrin are known to be excreted primarily in the feces. The approaches used in determining and interpreting the percent absorption of an administered compound are described below.

Several absorption values were obtained from the literature for solvents, including benzene and toluene, that address administration of radiolabeled chemicals and subsequent measurement of radioactivity in the primary excretion pathway. For the solvents, urinary excretion and expired air were considered to be the primary excretion pathways. In some of these solvent studies, expired radioactivity was found to be unmetabolized (in this case not absorbed), so radioactivity in the urine was considered the best reasonable estimate of absorbed dose. Percent absorption values for aldrin/dieldrin were derived differently in the Midwest Research Institute study (1991). In this case, percent absorption was derived by determining the difference between percent of the parent compound recovered in the feces and the quantity administered. Studies judged not to adequately represent total percent absorption were not included in determining contaminant absorption from soil.

B.3.3.3.2 Consideration of Experimental Conditions in Determining Percent Absorption

During the evaluation, the relevance of the experimental medium to the medium under evaluation was also considered. For example, studies that determined percent absorption from ingestion of vegetables (such as radishes or wheat) grown in contaminated soil were not considered in the evaluation of absorption from soil. In determining absorption from the critical toxicity study, only values of absorption from similar experimental media were considered from surrogate studies. None of the critical toxicity studies reported the absorbed fraction. Animal species for surrogate absorption studies were selected to represent those of the critical toxicity study to the extent possible based on available data.

B.3.3.3.3 Absorption of Contaminant From Soil

Oral Exposure Route

Very little information was located regarding the percent of oral absorption from a soil matrix. Oral soil absorption values were located for the following COCs: aldrin, arsenic, benzene, dieldrin, mercury, and toluene (Table B.3-15). No information was obtained for the remaining COCs from the literature reviewed. As discussed above, methods for determining percent absorption differed depending on the types of data reported in the studies.

Due to the anticipated paucity of data for dermal and oral soil absorption for specific COCs, chemicals were grouped based on considerations of similar physical/chemical characteristics and/or structural similarities in order to extrapolate the soil absorption data. The rationale for these chemical groupings is detailed below.

Data on dermal and oral absorption from soil were generally extrapolated from chemicals within defined groups sharing similar soil-binding potential. Soil-binding potential was determined from (K_{oc} since K_{oc} is considered a reasonably good predictor of the tendency of an organic contaminant to bind to the organic fraction of soil (soil at RMA has low organic content). Chemicals were initially grouped into four categories as follows: Group A (log K_{oc} >5), Group B (3 < log K_{oc} <5), Group C (log K <3), Group D (no K_{oc} data). The chemical groupings used for data extrapolation purposes are summarized in Table B.3-16.

The K_{oc} database, which served as a basis for the original groupings, has since been updated. After re-evaluating the updated K_{oc} data, the distinctions between groupings A and B based on K_{oc} alone could not be justified given the uncertainties in the K_{oc} data for chemicals within both groups. Therefore, former Groups A and B were combined to form a single Group (A), and other group designations were shifted accordingly. The new Group A consists of aldrin, chlordane, dichlorodiphenyldichloroethene (DDE), dichlorodiphenyltrichloroethane (DDT), dicyclopentadiene, dieldrin, endrin, hexacholorocyclopentadiene, and isodrin. The new Group B

contains all other chemicals except the metals (new Group C). A discussion on the re-evaluation of K_{oc} values for each of the COCs is presented in Attachment B.3-1.

Oral soil absorption values were not extrapolated among metal soil constituents because their valence state required individual consideration. Empirical oral soil absorption data were located for only three metals: arsenic, lead, and mercury. These values were assumed to be the minimum oral RAFs as indicated in Table B.3-17; the maximum oral RAF was assumed to be 1.0 (100 percent). Due to the lack of specific data on the oral absorption of metals from soil for the remaining metal COCs, the oral RAF ratio was conservatively assumed to be 1.0. Although it is recognized that 100 percent absorption from soil is not likely for some metals, this assumption was adopted in light of the data deficiencies. The potential overconservatism of this assumption for some metals is discussed in the qualitative uncertainty evaluations of the report.

Dermal Exposure Route

A comprehensive search of the literature yielded very little data on the extent of dermal absorption of soil-bound contaminants. Dermal soil absorption data were located for benzene, chlordane, DDT, DDE, and toluene (Table B.3-15). These values were determined in differing animal species including the rat, Rhesus monkey, and human. No corrections were attempted to address species differences in absorption. Evaluation of dermal absorption studies was conducted in the same manner as described above for oral absorption.

Recent guidance on dermal exposure assessment (EPA 1992) indicates that data for dermal absorption of pure compound be considered as a surrogate estimate of soil dermal absorption when soil dermal absorption data are lacking. Pure compound absorption was considered only for aldrin and dieldrin, since other chemical sin Groups A and B had actual or extrapolated soil absorption values. In reviewing available data for dermal absorption of pure compound, only human data were considered if available. However, due to the extremely lipophilic nature of the Group A chemicals, absorption of pure compound was not considered a realistic estimator of

absorption potential from a soil matrix. Therefore, a soil matrix correction factor was multiplied by the chemical-specific pure compound absorption estimates for aldrin/dieldrin in the manner described below.

Information from DDT, a lipophilic chemical assumed to be related to the other Group A chemicals based on soil-partitioning properties, indicates that soil matrix correction factors range from approximately 0.06 (human skin; *in vitro* study by Wester et al., 1990) to approximately 0.17 (monkey skin; *in vivo* study by Wester et al., 1990). Data from a study by Poiger and Schlatter (1980) on the soil absorption of another lipophilic compound indicates a soil matrix correction factor of approximately 0.13. However, in light of the structural dissimilarities between DDT and tetrachlorodibenzo-p-dioxin, as well as the dissimilarities between DDT and the other chemicals in Group A, the range of soil matrix values from the cited studies—0.06 to 0.17—was considered to be uncertain, in particular the upper-bound value. Therefore, the upper bound of this soil matrix range was increased for use in determining the range of soil absorption for Group A chemicals (aldrin/dieldrin). The upper bound of the selected soil matrix range was established at 0.5 based on professional judgment (not empirically based). supporting information on the studies used as a basis for the pure compound absorption estimates for aldrin and dieldrin is provided in Attachment B.3-2.

Information on dermal absorption of metals from soil was generally lacking, although some recently published abstracts indicate that the degree of absorption is very low to negligible. Because so little information was available for characterizing absorption from soil, and since it is known that metals are generally poorly absorbed from the dermal pathway, it was not considered reasonable to fix the RAF values for these contaminants at a value of 1.0. Accordingly, RAF values are not developed here, and the dermal exposure from these contaminants is assessed qualitatively in the report.

Absorption of Contaminants from Critical Toxicity Study

The denominator of the RAF represents the absorption of contaminants in the critical toxicity study used to determine reference doses (RfDs) and cancer potency factors (CPFs) (slope factors). As stated in Section B.2 above, chemical-specific IRIS files and studies cited in IRIS were obtained and reviewed for absorption estimates appropriate to either RfDs or CPFs. No absorption estimates were obtained from these sources for any of the COCs. Available ATSDR profiles were also reviewed, but they provided only a limited number of absorption values. Therefore, surrogate absorption studies were sought from a computerized chemical-specific literature search that matched the medium, route of administration, and species with those used in the critical toxicity studies. In a several instances, a precise match was not possible and best professional judgment was used to evaluate the appropriateness of extrapolating the absorption data. Only three absorption estimates were obtained from surrogate studies to support the RfD values, and only four to support the CPF values; these values are summarized in Table B.3-18. Different absorption estimates were possible for CPFs or RfDs due to the use of different toxicity studies (and, therefore, different experimental media and animal species) by the EPA in defining the toxicity values for carcinogenic and noncarcinogenic endpoints. Supporting information regarding specific media and individual species from both the critical toxicity study and the surrogate studies is presented in Attachment B.3-2.

Percent-absorption values from the media of the critical toxicity studies were not found for metals.

B.3.3.4 General Considerations in the Development of RAF Distributions

Several problems arise in trying to statistically fit distributions to numerator and denominator data and to the RAF quotient itself. A significant factor in attempting to fit distributions to the RAF is the strength of the correlation between the RAF components (i.e., the numerator and denominator). Because of the difficulties in firmly establishing the correlation between the RAF components and the vastly different statistical results implied by low vs. high correlations, the

distributions assigned rely heavily on best professional judgment. Accordingly, these distributions should be viewed as one of several possible interpretations of the data.

The potential correlation between RAF components and the assumptions made in analyzing the data are discussed below.

B.3.3.4.1 Potential Correlation Between ABS_{soil} and $ABS_{critical}$

RAF varies due to factors affecting its numerator—absorption from soil (ABS_{soil})—and its denominator—absorption from critical toxicity study ($ABS_{critical}$). Because factors such as species, site of application, and dosage affect both the numerator and denominator, the two variables are correlated to some extent. For example, ABS_{soil} and $ABS_{critical}$ should be measured on the same species with similar dosages and site of application, etc., such that the RAF is a true function of the difference due to the soil vehicle. Statistically speaking, the variability due to experimental procedure should ideally be factored out, so that each pair of ABS_{soil} and $ABS_{critical}$ values constitute a single independent measurement of the RAF. The RAF created by each pair would then be fit with a distribution.

In reality, values for ABS_{soil} and $ABS_{critical}$ are measured independently and under unmatched experimental conditions. Assuming correlation between numerator and denominator, however, the two sets of independently measured data are still theoretically correlated in that low ABS_{soil} values tend to be matched with low $ABS_{critical}$ values. For example, consider the following data sets: ABS_{soil} {20, 30, 40} and $ABS_{critical}$ {20, 30, 45}. The true RAF distribution may be more likely to have a range of {20/20 to 40/45}, a positive correlation, than a range of {20/40 to 40/20}, which would imply a negative correlation. Positive correlation implies a range for RAF of {0.89 to 1.0}, while a negative correlation implies a range for RAF of {0.50 to 2.0}, a very different answer.

The correlation between ABS_{soil} and $ABS_{critical}$ is reduced by factors affecting only one or the other of these variables (e.g., soil characteristics affect the ABS_{soil} measurements only). However, it is still important to acknowledge the potential correlation so that artificial results are not deemed statistically credible.

B.3.3.4.2 Extrapolation of ABS_{soil} Within Chemical Groupings

The soil-bonding characteristics of a group are believed to have a significant effect on ABS_{soil}; therefore, chemicals within a group are assumed to have relatively similar ABS_{soil} values. It was considered more reasonable to extrapolate ABS_{soil} values from other chemicals lacking data within the same group rather than to ignore their similar characteristics (i.e., the basis for the groupings assigned) and assign an RAF value of 1.0. Where data were available for ABS_{soil} for more than one member of a chemical group, extrapolation based on all group data was performed only for those contaminants lacking specific ABS_{soil} values. Extrapolated mean RAFs for chemicals without data were calculated by averaging the mean ABS_{soil} estimates for chemicals for which data were available.

B.3.3.4.3 Extrapolation of $ABS_{critical}$

$ABS_{critical}$ was not extrapolated within the defined groups since absorption values may be from experimental media unique to the critical toxicity studies. The $ABS_{critical}$ data obtained for a given chemical reflects as closely as possible the absorption that can be expected, based on the conditions of exposure (i.e., medium, experimental model) in the critical toxicity study.

B.3.3.4.4 Use of ABS_{pure} and Soil Matrix for Dermal Pathway

No data on ABS_{soil} for the dermal pathway were available for aldrin or dieldrin; however, pure compound data were available. Therefore, data on absorption of pure compound (ABS_{pure}) were multiplied by a range of soil matrix (MTRX) values to obtain a range of surrogate estimates of ABS_{soil} (see discussion on Section B.3.3.3.3, as well as Figures B.3-10 and B.3-13).

B.3.3.4.5 Mean of RAF

Attachment B.3-3 presents equations (1) and (2), which demonstrate the relationships between the mean and variance of the RAF ratio as well as the means and variances of the numerator and denominator components. The quotient of the means was used to estimate the mean of the quotient even though the two are not generally equivalent. The exact degree of underestimation or overestimation is indeterminable, but is expected to be small based on the following reasoning. Equation (1) implies that the mean of the quotient is roughly equal to the quotient of the means only if the last two terms in equation (1) cancel each other out (approximately) or if they are relatively small. The second to last term depends on the correlation between the numerator and denominator. If the correlation is positive, which is likely, then ignoring this term will cause the ratio of the means to overestimate the mean of the ratios. Given that a large degree of uncertainty implies that a somewhat conservative estimate is appropriate, this overestimation is preferable to an underestimation of the mean RAF. However the last term, if ignored, will lead to a potential for underestimation. Both terms are expected to be small (on the order of 0.1 or 0.2) and to cancel each other out to some unknown extent. If correlation is on the order of 0.1 or larger, which is very likely, then the mean RAF is expected to be estimated with a positive bias, as explained in Attachment B.3-3 of this appendix.

B.3.3.4.6 Variance of RAF

Attachment B.3-3 indicates that the variance of RAF is not only dependent on the correlation between the numerator and denominator but also on the ratio of the means taken to a power of 2. Because of the importance of other terms in the equation, the variance of ABS_{soil} does not give usable information regarding the variance of the RAF. It is not valid to use the range of the numerator divided by a single denominator value to estimate the range of plausible RAF values. Unfortunately, the range observed in the ABS_{soil} data is not necessarily indicative of the range in RAF because there is a potential correlation and because the ABS_{soil} data often do not come from the same chemicals as the $ABS_{critical}$ data. In addition, the range of a data set increases as the number of data points (and certainty) increases. It is inappropriate for the range

of uncertainty to increase when the actual uncertainty has decreased. Therefore, the range of ABS_{soil} is not a consistent and reliable estimator of the range of RAF. The range of RAF was estimated based on professional judgment as described in Figure B.3-12 (see Section B.3.3.5 below).

B.3.3.4.7 Uniform Uncertainty

There is substantial uncertainty about the estimation of the RAF distribution due to the small number of data, the correlation between components, the extrapolation of ABS_{soil} values within a group, and the unknown degree of bias of the estimation method used. It is reasonable to model this uncertainty with a uniform distribution because, within a given range of values, there is no reason to expect one value to be more likely than another. Although the uniform triangular distribution allows a more sophisticated view, where probability decreases linearly in the tails surrounding a uniform distribution, such elaborate treatment does not seem justified due to the difficulty that would be encountered in defining the mode (peak) of a triangular distribution from the available data. The simple uniform distribution adequately estimates the level of uncertainty reflected in the data.

For the oral pathway and Group B chemicals in the dermal pathway, a range of ±0.2 was added to the mean when an estimate of mean RAF was available to obtain a lower and upper bound for the uniform distribution. The value of ±0.2 was chosen because it represents a range of uncertainty that is 40 percent of the absolute range of RAF (0 to 1). Although the choice of 40 percent is subjective, it is important that some range be applied. For cases in which the mean RAF is close to 0 or 1, the 40-percent range is clearly not appropriate, so the rule was modified. The upper bound for RAF was not allowed to exceed 1.0. The lower bound for RAF was set at the mean RAF if the mean RAF was less than or equal to 0.2, indicating that a lower bound could not be estimated in this case. For Group A chemicals in the dermal pathway, a range of ±0.02 was added to the mean RAF to obtain lower and upper bounds for the uniform distribution.

B.3.3.4.8 Factors Influencing Dermal Absorption

Several factors influence the rate and amount of percutaneous absorption of a compound that comes into contact with the skin. The physical/chemical characteristics of the compound (e.g., its volatility, partition coefficient, lipophilicity, and solubility) are important determinants. When possible, these factors were taken into consideration in assigning chemical groups and, ultimately, in deriving dermal RAFs. The vehicle in which a substance is applied also influences dermal absorption. For example, organic lipids such as benzene penetrate skin at a different rate when applied neat than when applied in an aqueous or solvent solution.

Dermal absorption is also influenced by other factors such as the anatomical site of application, the magnitude of the applied concentration and the surface area exposed, the duration of exposure, occlusion (or covering of the skin), washing, and the condition of the skin. These factors could not be addressed in the quantitative risk assessment due to lack of specific information, but are discussed briefly below.

Site of Application or Exposure

For many compounds, the extent of absorption depends on the anatomical site of application (Feldmann and Maibach 1974). This observation has been attributed to differences in the thickness of the outer layer of the skin (or stratum corneum). For example, the pure compound data used to derive dermal RAFs for aldrin and dieldrin were taken from a study in which chemicals were applied to the ventral forearm. However, the authors acknowledged that other studies have shown that the face, forehead, scalp, and neck absorb 2 to 6 times more than the forearm (Feldmann and Maibach 1974).

Effect of Applied Concentration, Surface Area, and Duration of Contact

Higher chemical concentrations, larger surface areas, and longer durations of skin contact time enhance the potential for increased systemic availability. The frequency of application in a single

day, as well as multiple applications on a continual daily basis, have also been shown to affect percutaneous absorption (Feldmann and Maibach 1974; Wester and Maibach 1985).

Occlusion

Occlusion is a covering of the applied dose, either intentionally as with bandaging, or unintentionally as having clothing over a pesticide on skin. Occlusion, especially with clothing, restricts evaporation and promotes hydration of the skin. Both of these factors may contribute to increased absorption of topically applied substances (Feldmann and Maibach 1974; Wester and Maibach 1985).

Skin Decontamination

Pesticides are often highly fat soluble and can therefore quickly enter the fatty layer of the dermis where they could not be washed away easily. The dermal fat could then act as a reservoir for continued slow absorption of the pesticide. For example, several studies indicate that pesticides persist on the skin even after washing for two minutes with soap and water, and that the percent of absorbed chemical can continue to increase even after washing (Wester and Maibach 1985).

Skin Condition

Any skin condition that compromises the capability of the skin to serve as a permeability barrier (e.g., injury, rashes, dermatitis) that also result in increased percutaneous absorption in affected individuals. The barrier layer of the skin can also be affected by exposure to the chemical penetrant itself, especially at high concentrations, In general, the age of the exposed individual has not been shown to be a major factor influencing dermal absorption (Feldmann and Maibach 1974).

B.3.3.5 Development of Chemical-Specific RAF Distributions

The schemes used in assigning RAF distributions or fixed values for each COC are summarized in Figure B.3-10 through Figure B.3-12. These schemes describe the interpretation of different cases in which some or all of the RAF components (including ABS_{pure} and MTRX) are available. In general, the data for each component were used to compute a mean estimate. The use of the term "mean" indicates that the central tendency of the data was estimated even if only one data point was used. The means of the components were then combined (quotient) to obtain a reasonable estimate of the mean RAF as discussed above. However, in no cases were the data adequate to estimate the variance or spread of the resulting RAF parameter. Therefore, a variance was incorporated based on best professional judgment since it would not be accurate to infer a zero variance for the RAF. If one of the components was missing, a mean RAF could not be estimated, although an estimate of an upper or lower bound for the RAF based on toxicological considerations was possible for some chemicals as discussed below.

The steps used to estimate means for ABS_{soil} and $ABS_{critical}$ are outlined in Figure B.3-10. The logic flow used to translate these mean values into estimates of the upper and lower bounds for the RAF are outlined in Figures B.3-11 and B.3-12 for the oral and dermal pathways, respectively. The uncertainty distribution for RAF was assumed to be uniform between these bounds.

As indicated in Figure B.3-10, the mean ABS_{soil} was estimated if at least one data point exists for a chemical group. The mean of all chemical-specific means in a group was extrapolated to all chemicals in that group with available data. For chemicals with available data, the mean of the chemical-specific data only was used. The value for mean $ABS_{critical}$ was estimated on a chemical-specific basis and was not extrapolated to other chemicals in the defined groups. If no ABS critical data were identified for a given chemical, then no estimate of mean $ABS_{critical}$ was made.

As a surrogate estimate of dermal ABS_{soil}, the mean ABS_{pure} values estimated for aldrin and dieldrin, 1.0 and 2.0, respectively, were then multiplied by a range of soil matrix values (0.06 as minimum and 0.5 as maximum) to develop a range for ABS_{soil} for these chemicals (see Table B.3-19 and Figure B.3-13).

The steps in developing the RAF distribution for the oral pathway are shown in Figure B.3-11. If no value for mean ABS_{soil} was available (as was the case for some metals), no information regarding the RAF could be derived; therefore, the RAF was fixed at 1.0. If the mean ABS_{soil}, but not the mean $ABS_{critical}$, was available for the oral pathway or Group B dermal pathway chemicals, the lower bound for RAF was estimated by assuming the highest possible value for $ABS_{critical}$ (100 percent). For Group A dermal pathway chemicals, the lower bound for RAF was estimated by assuming the highest possible value for $ABS_{critical}$ (100 percent) and then subtracting 0.02 from the mean $ABS_{soil}/ABS_{critical}$ quotient. The upper bound for RAF was estimated to be 1.0 by assuming that $ABS_{critical}$ was equivalent to ABS_{soil}. This range for RAF is thought to reasonably represent the uncertainty due to a lack of data on $ABS_{critical}$. If both the mean ABS_{soil} and mean $ABS_{critical}$ were available, the mean RAF was estimated as the ratio of these two values. However, there is likely to be considerable uncertainty regarding the mean RAF, so the specification of a range about this mean is appropriate. As discussed above, the range was assumed to be 40 percent (0.4) of the absolute range of the RAF parameter, so a variance of $\pm$ 0.2 was added to the mean RAF to determine the upper and lower bounds for the uniform distribution. The judgment range was not subtracted from the mean if the mean was less than or equal to 0.2. Instead, the mean RAF was used as the lower bound because no other lower bound could be estimated. The upper bound was never allowed to exceed 1.0.

As discussed previously, RAF distributions for the dermal pathway were not developed for metals. For the remaining COCs, the steps used to develop the RAF distribution for the dermal pathway are similar to those described above, except for the added consideration of mean ABS_{pure} (Figure B.3-12).

The RAF distributions resulting from the approaches discussed above are presented in Tables B.3-17 and B.3-19.

B.3.3.6. Summary

A comprehensive literature survey was conducted to identify studies that could be used as a basis for quantifying the two components of the RAF: contaminant absorption from soil and contaminant absorption from the critical toxicity study. RAF values were developed based on available data for both oral and dermal pathways. Data were generally available for quantifying contaminant absorption of organic COCs from soil for the oral route, either directly or through extrapolation. Fewer data were available for soil absorption for the dermal pathway, so studies based on absorption of pure compound multiplied by a soil matrix factor were considered as soil absorption estimates for aldrin and dieldrin. Information on contaminant absorption from the media of the critical toxicity study were generally not available, although some values from surrogate studies were identified for specific organic COCs. In consideration of the lack of soil absorption and critical toxicity study values, best professional judgment was used to estimate absorptions in order to facilitate calculation of reasonable RAF values (see Appendix Section B.4).

B.3.4 BREATHING RATES AND RESPIRATORY DEPOSITION

B.3.4.1 Breathing Rates (Fixed)

TWA breathing rates were computed as fixed parameters for each of the five potentially exposed populations based on projected activities and appropriate ventilation rates for time spent daily at RMA. Because the exposure scenarios for each exposed population differ, breathing rates also differ. TWA breathing rates are also expected to vary between age groups for the regulated/casual and recreational visitor populations, which include children as well as adults. Therefore, age-specific TWA breathing rates were calculated for these exposed populations (Table B.3-20).

In the HHEA report (EBASCO 1990a), breathing rates for different populations were identified by different abbreviations. Consistent with the HHEA report, these designations have been retained; however, all corresponding breathing rates have been converted to units of cubic meters per hour (m^3/hr) to streamline calculations in the model. For the regulated/casual and recreational visitors, breathing rates are abbreviated as BR. For the commercial and industrial workers, breathing rates are abbreviated as DINH. For commercial and industrial workers, breathing rates in an enclosed basement are referred to as RB.

The process of compiling data, identifying of population-specific activity levels, and calculating TWA breathing rates is discussed below.

B.3.4.1.1 Data Compilation

Data on age-specific breathing rates for various levels of activity (i.e., high, medium, and low) were obtained from an EPA document, Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments (1985b). The EPA Exposure Factors Handbook (1989a) was also reviewed. For exposure scenarios in which activity patterns are known, however, the Exposure Factors Handbook recommends using the breathing rates presented in the former publication. The activity patterns of the potentially exposed populations are described in

the HHEA report (EBASCO 1990a) and summarized in Appendix Section B.2, so the EPA (1985b) data were used.

Breathing rates were derived from EPA (1985b) data by calculating an arithmetic mean of male and female ventilation rates for each age group (Table B.3-21). Breathing rates for age groups lacking data points were derived through linear regression of the bordering values. In some instances, ventilation data for females were lacking, so ventilation rates for males were used instead.

B.3.4.1.2 Population-Specific Activity Levels

The HHEA report (EBASCO 1990a) contains activity descriptions that were used to define the types of ventilation rates appropriate to each population's TWA breathing rate. The activity descriptions (e.g., resting, light work) help to determine the percentage of time assumed at these ventilation rates and are defined below for each population to demonstrate how TWA breathing rates were calculated. The activity levels vary across age groups, particularly in the younger age classes. Reasonable assumptions as to the level of activity (and the appropriate ventilation rate) were made for each age class. This information is summarized in Table B.3-22.

Regulated/Casual Visitor

It was assumed that infants (aged 0 to less than 1 year) spend 50 percent of their time at rest and 50 percent of their time at light activity levels. All other age groups within the regulated/casual visitor population are assumed to spend 50 percent of their time at a light activity level and 50 percent of their time at a moderate activity level.

Recreational Visitor

The same assumptions for calculating breathing rates for infants in the regulated/casual visitor population were applied to the recreational visitor. For children aged 1 to 4 years, a 50 percent light to moderate level of activity was assigned since their participation in recreational activities

was assumed to be at a lower level. For all other age classes, the projected ventilation rates for biking, jogging/running, and outdoor games were assumed to vary from moderate to very heavy. Ventilation rates specific to recreational jogging/running (i.e., very heavy) are reported for adults only in EPA (1985b). Therefore, the projected very heavy ventilation rates for children were derived by using linear regression analysis.

Commercial Worker

Commercial workers are assumed to spend 88 percent of their 8-hour (hr) workday (i.e., 7 hrs) at a light ventilation rate and 12 percent (i.e., 1 hour) at a moderate ventilation rate. For working days in excess of 8 hrs, the same proportions of time at specific ventilation rates was assumed.

Industrial Worker

Within each of the job types possible for an industrial worker, activity level and hours per activity are expected to vary. Since only one single breathing rate value is used to represent all industrial workers, activity levels throughout an 8-hr workday (for all potential job types) were assigned as follows: 25 percent to light, 50 percent to moderate, and 25 percent to heavy. These activity levels were used to calculate a total breathing rate for the industrial worker. For working days in excess of 8 hrs, the same proportions of time at specific ventilation rates were assumed.

Biological Worker

The types of activities of the biological worker are defined in terms of their potential to incur soil exposures (e.g., low, medium, and high). Accordingly, light activity ventilation rates were assigned to "low" soil exposure level activities. However, medium and high soil exposure level activities did not correlate with moderate and high ventilation rates. For example, driving a tractor is a higher exposure level activity, but not a heavy breathing rate activity. Therefore, "medium" soil exposure level activities are assumed to be 50 percent light and 50 percent moderate activities. Similarly, the "high" soil exposure level activities are assumed to be 50 percent moderate activities and 50 percent heavy activities.

B.3.4.1.3 Calculation of Time-Weighted Average Breathing Rates for Exposed Populations (Except Biological Worker)

To determine an estimated breathing rate for each designated activity (i.e., high, moderate, low ventilation rate) and exposed population, a TWA breathing rate considering the time spent at each activity was computed. The number of hours estimated for participation in each activity as well as the projected level of each activity for each exposed population is summarized in Table B.3-22. Using data presented in Tables B.3-21 and B.3-22, TWA BRs were calculated for all populations (except biological worker) using the following equation:

$$\text{TWA-BR} = [(BR_1)(hr_{BR\ 1}) + (BR_2)(hr_{BR\ 2}) + (BR_3)(hr_{BR\ 3})] \,/\, \text{Total Hours of Exposure} \quad (1)$$

Where $hr_{BR\ X}$ represents the number of hours spent performing various activities at different BR values.

The TWA rates for the regulated/casual and recreational visitors by age group are presented in Tables B.3-23 and B.3-24. A similar approach was used to calculate a TWA breathing rate for industrial and commercial (Table B.3-20).

B.3.4.1.4 Calculation of Time-Weighted Average Breathing Rates for the Biological Worker

The development of the breathing rate probability distribution for the biological worker and final fixed value uses the general statistical methodology described for this subpopulation in Appendix B.1. This methodology includes characterizing the distribution of the proportional allocation of time among the three general types of refuge worker activities. This proportional allocation is a triple (P_{indoor}, P_{middle}, and P_{higher}). The three values in this triple are the percentages of time (P_k) that workers are engaged in activities of exposure class k (where k = lower, middle, or higher).

For biological workers a similar TWA breathing rate was computed as follows:

$$\text{TWA-BR} = (P_{lower})(BR_{lower}) + (P_{middle})(BR_{middle}) + (P_{high})(BR_{high}) \quad (2)$$

where P_k is the proportion of time spent by an individual in activity class k, and BR_k is the ventilation rate associated with class k, as defined below:

BR_{lower} = Breathing rate for light activity level

BR_{middle} = 0.5 * (Breathing rate for light activity level) +
0.5 * (Breathing rate for moderate activity level)

BR_{higher} = 0.5 * (Breathing rate for moderate activity level) +
0.5 * (Breathing rate for heavy activity level)

The breathing rates recommended by EPA in the Exposure Factors Handbook (1989a) for light, moderate, and heavy activity levels are used to derive the breathing rates associated with the activities performed by the biological worker. The breathing rates are 0.66 cubic meters per hour (m^3/hour) for light, 2.0 m^3/hr for moderate, and 3.8 m^3/hr for heavy. Following the examples in the handbook, the breathing rates for the different types of refuge worker activities are calculated as time-weighted averages of the breathing rates for the different breathing-rate activity types provided by EPA.

Because there is a probability distribution representing the amount of time spent in each of the biological worker soil-activity levels (P_k), the TWA breathing rate was simulated by repeatedly sampling the P_k distribution and calculating TWA breathing rate until a large number of TWA breathing rate values were obtained. These values form the following distributions:

Percentage	BR-TWA (m^3/hr)
1.0	0.72
2.5	0.72
5.0	0.72
7.5	0.73
10.0	0.73
25.0	0.80
50.0	1.14
75.0	1.47
90.0	1.96
92.5	2.07
95.0	2.12
97.5	2.45
99.0	2.45

The 95th percentile of this distribution (2.1 m^3/hr) was selected as the fixed breathing rate value for the biological worker (Table B.3-20).

B.3.4.2 Respiratory Deposition (Fixed)

The respiratory deposition parameter has been identified as a fixed parameter with a value of 85 percent. The data used to develop this estimate and the quantification of total respiratory deposition is described in this section.

The parameter FR is defined as the fraction of particulate matter retained in the lung from which contaminant absorption could occur. FR can be further defined as the amount of material present in the lung at any time that may be influenced by clearance and translocation mechanisms (Brain and Valberg 1979). A closely related term, respiratory deposition (RD), refers to the collection of inhaled particles by the respiratory tract and to the initial regional pattern of distribution of these particles throughout the respiratory tract (Raabe 1984). It appears, however, that total and regional deposition in the respiratory tract are more critical parameters for the assessment of the toxicity of inhaled contaminants than simply the total amount of contaminant retained (Menzel and Amdur 1986). The term FR, as used in the HHEA report (EBASCO 1990a), actually

characterized deposition in the respiratory system rather than retention. Recognizing that the terms retention and deposition characterize different physical processes, "respiratory deposition" is a more accurate term than "retention" in the risk characterization, although the terminology (FR) itself has not changed for purposes of consistency. For the purposes of this discussion, RD is considered synonymous with FR.

B.3.4.2.1 Data Compilation

EPA guidance on particulate matter (1982) and the general literature served as the basis for assigning a value to the respiratory parameter. Key factors influencing respiratory deposition are discussed below, as are the specific studies that examine the value selected for this parameter.

The human respiratory tract includes the nose, mouth, nasal pharynx, oral pharynx, epiglottis, larynx, bronchi, bronchiolus, and small ducts and alveoli of the lungs. The above-mentioned areas of the respiratory tract may be divided into three distinct regions: extrathoracic, tracheobronchial, and pulmonary (EPA 1982). The alveolar region or pulmonary region of the respiratory tract is the largest and most blood-enriched region; hence, it is the primary site of exchange of gases and toxicants (i.e., absorption) with capillary blood. It also appears to be the most sensitive region to toxicants.

Respiratory tract deposition may be defined in two basic ways—total deposition and regional deposition. The sum total of the deposition within the three respiratory tract regions comprise total deposition. Theoretically, total deposition can range between 0 and 100 percent, but is rarely 100 percent due to suspended particulates that are exhaled (Snipes 1989). The regional site of deposition of inhaled particles within the respiratory tract affects the severity of tissue damage, the degree of absorption of systemic toxicants, and the clearance mechanism available to remove the toxicant (Menzel and Amdur 1986). A number of factors influence the extent of total and regional deposition in the respiratory tract including particle characteristics such as particle size, shape, mass density and electric charge; respiratory conditions such as tidal volume,

breathing frequency, and the mode of breathing (nose versus mouth); and airway geometry (Xu and Yu 1986).

Although multiple factors influence deposition, the extent and site of respiratory deposition appears to be more influenced by particle-size distribution than other factors. Particulate matter smaller than 10 μ in aerodynamic diameter are considered respirable (Alpaugh 1989). Since data on the distribution of PM-10 (particulate matter 10 μ and less in diameter) from ambient monitoring data at RMA were not available, a search of the literature for Denver-specific data was conducted. The best available source of data located was an EPA document, Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982). In this document, EPA reports particulate matter concentrations were measured from ambient air monitoring stations in several cities throughout the United States, including Denver, using dichotomous samplers. Mass samples in the 0 to 2.5 μ particle size range (defined as the fine fraction) and in the 2.5 to 15 μ size range (defined as the coarse fraction) were obtained. From the Denver-specific data, it was determined that 42 percent of the sample mass consisted of particles less than 2.5 μ, while particles between 2.5 and 15 μ comprised 58 percent of the sample mass. Using this information and the total respiratory deposition efficiency for particles less than 15 μ, an estimate was developed for the total respiratory deposition at RMA as described below.

B.3.4.2.2 Quantification of Total Respiratory Deposition

Particulates

Total respiratory deposition is determined experimentally by comparing the difference between the total amount of material inhaled and the amount that is exhaled. However, a number of models exist that predict total and regional deposition. The model most widely used to calculate total and regional deposition versus particle size was developed by the International Commission on Radiological Protection Task Group (ICRP) (Raabe 1984). The models developed by ICRP (Morrow et al. 1966) were intended to estimate exposure to inhaled radiation particles, but may be applied to other types of particulates as well. The results of their research are shown

graphically for nose breathing in Figure B.3-14. As shown in Figure B.3-14, total and regional deposition varies considerably over particle sizes ranging from 0.01 to 100.0 μ in aerodynamic diameter. Total deposition is biphasic, reaching 100 percent for particle sizes greater than 10 μ and approximately 93 percent for particles at 0.01 μ. Minimum deposition occurs for particles with a diameter between 0.3 and 1.0 μ.

The effect of mouth breathing on total respiratory deposition was also considered. Raabe (1984) and EPA (1982) presented data demonstrating that mouth breathing shifts the deposition curve upward, resulting in lower respiratory deposition for particle sizes 0.6 to 10 μ for mouth breathing. Based on lower total respiratory deposition for mouth breathing, it was considered appropriate to utilize data on percent deposition from nasal breathing.

Total respiratory deposition for particles less than 15 μ was quantified through extrapolation from the EPA particle fractionation data and the ICRP particle deposition model. Specifically, the fraction of deposition for particles less than 2.5 μ and for particles between 2.5 and 15 μ was calculated. To accomplish this, the curve depicting total respiratory deposition in Figure B.3-14 was segregated into 0.25-μ increments and the percent of total deposition was recorded for each increment below 2.5 μ (see Table B.3-25). Because Figure B.3-14 represents a lognormal graph, resolution of 0.25-μ increments for particulates greater than 2.5 μ was not possible. Therefore, for particulates ranging from 2.5 to 15 μ, the data was instead segregated into 1.0 μ increments (Figure B.3-14) and the percent of total deposition recorded (Table B.3-25).

The arithmetic average of respiratory deposition for particles less than 2.5 μ and for those between 2.5 μ and 15 μ was then calculated. The arithmetic averages of the percent respiratory deposition for particles less than 2.5 μ and between 2.5 μ and 15 μ were 64 and 99 percent, respectively. These average respiratory depositions were then multiplied by respective percent sample mass as presented in EPA (1982) (i.e., 42 and 58 percent) and summed according to the following equation to obtain a specific RD fraction approximating conditions in the Denver area:

$$RD = (\text{percent dep.} < 2.5\ \mu)\ (\text{percent mass} < 2.5\ \mu) + \quad (3)$$
$$(\text{percent dep. } 2.5 \text{ to } 15\ \mu)\ (\text{percent mass } 2.5 \text{ to } 15\ \mu)]$$

This approach yields what should be considered RME for total respiratory deposition of 85 percent. Particle-size fractionation data for RMA were not available that would permit some quantification of an actual MLE or RME. Since the maximum possible value for deposition is 100 percent, the 85 percent value is considered an RME value. Clearly, this value is somewhere between the lowest possible value (23 percent) and the highest possible value (100 percent). No additional particulate matter data from the Denver area were located that could provide more definitive information on particle-size fractionation data than that which was described above to calculate respiratory deposition.

Organic Vapors

Inhalation of organic vapors is generally not subject to complex physical processes like deposition, retention, and clearance. It can, therefore, be reasonably assumed that total respiratory deposition of organic vapors would be 100 percent. Organic chemicals that are not highly water soluble or that do not readily react with respiratory airways can reach the deep alveolar region of the lung. For highly water soluble and highly reactive compounds, pulmonary deposition is reduced, while deposition in the upper respiratory target increases due to electrophillic interaction with liquids in the mucous lining of the respiratory tract. Assuming that no upper respiratory tract scavaging occurs, respiratory deposition for organic vapors is fixed at a value of 100 percent.

B.3.5 DUST LOADING FACTOR (PROBABILISTIC)

The dust loading factor (CSS) is used in the PPLV soil particulate inhalation pathway equations. CSS is the concentration of suspended soil particles to which individuals at RMA may be exposed. RMA-specific measures of soil particulate concentrations less than 10 μ in size (PM-10) were used as the source of data for defining this parameter. CSS varies with ambient environmental conditions as well as with the activities of a given individual.

Distributions of respirable soil particulate concentrations (<10 μ) were estimated for each exposed population or subpopulation defined for RMA (Table B.3-26 and Figure B.3-15). The compilation of data and development of the distributions are described below.

B.3.5.1 Data Compilation

The ambient CSS generally varies according to wind direction, wind speed, soil moisture, temperature, and snow cover. Man-made sources of dust loading such as vehicular traffic, earth-moving activities, and open burning can also contribute to the ambient CSS. For example, on certain days, Denver city smog may contribute significantly to RMA concentrations. Because it is difficult to determine accurately what portion of this particulate matter is not related to RMA, all ambient CSS data have been conservatively assumed to have their origin in on-post soil.

Three sources of data were considered in developing population-specific CSS distributions. The first source of data, ambient outdoor dust loading, was characterized using 3 years (1988 to 1990) of daily (every sixth day) PM-10 monitoring data collected from 11 locations around RMA as part of the Comprehensive Monitoring Program (CMP). All PM-10 data from the CMP (RLSA 1990) were included as data points to develop a distribution for this parameter. Other monitoring programs such as the Basin F air monitoring system and the RIFS2 air monitoring stations have also monitored PM-10 concentrations; however, these monitoring systems are concentrated in small areas and do not represent overall on-post conditions.

The second source of data was the refuge worker survey results on the proportion of time spent in different activities (Appendix Section B.2). The activity data and distribution development for the refuge worker population and the biological worker subpopulation are presented in detail in Appendix Section B.2. As discussed in Section 4.4.1, however, the quantitative risk evaluations address the more highly exposed subpopulation of the refuge worker population, the biological worker. Accordingly, the following sections highlight distribution development for this subpopulation rather than for the refuge working population.

The third data source was relevant literature used to characterize indoor dust loading levels for the biological and commercial workers. Hawley (1985) reviewed several studies that indicated a reasonably consistent extrapolation factor between dust loading indoors and outdoors. Roberts et al. (1974) measured total suspended particulates (TSP) inside and immediately outside of 100 homes, correlated the data (correlation coefficient, $R^2 = 0.85$), and concluded that indoor values were found to be 15 percent to 30 percent of the outdoor values. Schaefer et al. (1972) provided another indication of indoor/outdoor dust concentration correlation in which dust fall in milligrams per square meter per day was measured indoors and outdoors in 100 homes. Indoor dustfall was found to be 5 percent to 30 percent of outdoor values. For the purposes of developing a distribution to describe indoor dust loading, the range observed by Roberts et al. (1974) for indoor/outdoor TSP relationship (15 percent to 30 percent) was assumed.

B.3.5.2 Distribution Development

For the biological worker subpopulation, relevant data on activities were available on the time spent indoors, outdoors, and in soil-intrusive activities. This information permitted the development of time-weighted average distributions. For the remaining populations, the time-weighted average approach was not applied because data on time spent in different activity classes were either not available for these populations or were not relevant to projected future conditions at RMA.

B.3.5.2.1 Biological Worker

The biological worker at RMA will be exposed to CSS levels representative of both indoor and ambient outdoor environments based on various dust-generating activities. Although uncertainty exists regarding the spatial and temporal variation in dust concentrations, uncertainty about dust exposure is reduced through the incorporation of actual data regarding the proportion of time spent in activities.

An activity-based distribution was developed for the refuge worker population using the standard statistical methodology presented in Appendix B.3. For the purposes of the PPLV soil inhalation pathway, the CSS parameter is defined to be the time-weighted average dust loading experienced by individuals at RMA. The time-weighted average CSS for a given individual is defined as shown in equation (1).

$$CSS_{TWA} = P_{indoor} * CSS_{indoor} + P_{ambient\ outdoor} * CSS_{ambient\ outdoor} + P_{soil\ intrusive} * CSS_{soil\ intrusive} \quad (1)$$

where P_k is the proportion of time the individual spends in activity class k and CSS_k is the dust loading rate associated with class k. CSS_k varies for individuals participating in each activity type due to variation in activity and environmental conditions, so each CSS_k has an associated probability distribution developed below.

To develop the CSS probability distribution for ambient outdoor conditions at RMA, the CMP PM-10 data were used. The CMP PM-10 ranged in concentration from a minimum of 4 micrograms per cubic meter ($\mu g/m^3$) to a maximum of 168 $\mu g/m^3$. These data were fit with a lognormal distribution having a mean of 23.65 $\mu g/m^3$ and a standard deviation of 13.525 $\mu g/m^3$. (The log-transformed data are normally distributed with mean and standard deviation of 3.022 and 0.532, respectively.) The data and fitted lognormal distribution are shown in Figure B.3-16.

The CSS indoor distribution was assumed to be correlated to the outdoor distribution and reduced by an attenuation factor drawn randomly from a uniform distribution between 0.15 and 0.30 (i.e., 15 percent and 30 percent) as taken from Hawley (1985) and as discussed in Section B.3.5.1. A distribution for indoor CSS was obtained by repeatedly drawing a CSS value from the lognormal distribution for ambient outdoor air and multiplying this value by a attenuation factor drawn from the uniform distribution. The resulting simulated data was fit with a lognormal distribution with a mean of 5.464 $\mu g/m^3$ and standard deviation of 3.505 $\mu g/m^3$. (The log-transformed distribution has a mean of 1.526 and standard deviation of 0.5870.) This lognormal distribution is compared to the outdoor distribution in Figure B.3-16.

The correlation between the indoor and ambient outdoor CSS was incorporated into the simulation described above. For the biological worker subpopulation, which is exposed to both ambient outdoor and indoor air, simulated values of CSS_{indoor} were not drawn independently from the indoor CSS distribution described above. Instead, for each calculation of CSS_{TWA}, the sample representing the indoor distribution is equal to the sample drawn from the ambient outdoor distribution multiplied by a attenuation factor drawn from a uniform distribution with bounds of 0.15 and 0.30. Equation (2) restates the simulation formula for CSS_{TWA}. Note that CSS_{indoor} is substituted with its more explicit definition:

$$CSS_{TWA} = P_{indoor} * CSS_{ambient\ outdoor} * [\text{uniformly distributed attenuation factor}] + P_{ambient\ outdoor} * CSS_{ambient\ outdoor} + P_{soil\ intrusive} * CSS_{soil\ intrusive} \quad (2)$$

No dust loading data were available for soil intrusive activities on RMA. Therefore, CSS during soil-intrusive activities was represented by a fixed value equal to the maximum PM-10 value measured in the CMP program (168 $\mu g/m^3$).

The CSS_{TWA} distribution was simulated as follows. A set of P_k (for k = indoor, outdoors ambient, and soil intrusive), which sums to 1.0, was sampled from the 20 individual time allocations

identified for the biological worker in the refuge worker survey (Appendix Section B.2). These P_k were multiplied by a sample from the corresponding distribution of CSS according to the above-referenced time-weighted average formula. This process was repeated 10,000 times to obtain 10,000 values for CSS_{TWA}.

The biological worker dust loading distribution resulting from the time-weighted average simulation for time spent in the three activity categories (i.e., outdoor, indoor, and soil intrusive) was lognormal with a mean of 56.21 $\mu g/m^3$ and a standard deviation of 32.88 $\mu g/m^3$. (The log-transformed distribution has a mean of 3.882 and standard deviation of 0.5425.)

Using the same methods, the dust loading distribution for the refuge worker was developed for comparison to the biological worker distribution. The distribution providing the best fit was a lognormal distribution with a mean of 40.35 $\mu g/m^3$ and a standard deviation of 34.26 (log mean of 3.426 and log standard deviation of 0.7369). The 95th percentile of the fitted lognormal distribution is 103.3 $\mu g/m^3$.

B.3.5.2.2 Regulated/Casual Visitors, Recreational Visitors, Industrial Workers

Because data on activities that would enable development of activity-weighted distributions were not available for other RMA populations, the ambient outdoor PM-10 concentrations were instead used to assign distribution to the regulated/casual and recreational visitor, and industrial worker populations. This assignment is identical to applying the time-weighted average simulation with zero weight given to indoor and soil-intrusive activities as discussed above. These data were fit with a lognormal distribution having a mean of 23.65 $\mu g/m^3$ and a standard deviation of 13.525 $\mu g/m^3$. (The log-transformed data are normally distributed with mean and standard deviation of 3.022 and 0.532, respectively.)

B.3.5.2.3 Commercial Worker

The commercial worker population was assumed to be exposed primarily to indoor dust, and so was assigned the indoor dust loading distribution developed for this activity type. This assignment is identical to applying the time-weighted average with zero weight given to outdoor and soil-intrusive activities. The resulting simulated data was fit with a lognormal distribution with a mean of 5.464 $\mu g/m^3$ and standard deviation of 3.505 $\mu g/m^3$. (The log-transformed distribution has a mean of 1.526 and standard deviation of 0.5870). This lognormal distribution is compared to the outdoor distribution in Figure B.3-16.

B.3.6 BODY WEIGHT (FIXED)

B.3.6.1 Estimation of Body Weights

Body weight (BW) is a fixed exposure parameter that is used to estimate PPLVs and risks. In this analysis, body weights were estimated for adults and children. For adults, a body weight of 68.7 kilogram (kg) was calculated. As shown in Table B.3-27, this value is the arithmetic mean of the 50th percentile body weight values for men and women between the ages of 18 and 75. In a similar manner, arithmetic mean body weights for children were estimated for the 18 child age groups (Table B.3-28).

The data used to calculate this parameter were obtained from the second National Health and Nutrition Examination Survey as reported by EPA (1989a). This survey was designed to represent the civilian, noninstitutionalized population of the United States. The survey sampled approximately 28,000 persons ranging in age from 6 months to 74 years.

The adult body weight estimate was used in the PPLV and risk equations for all potentially exposed populations. Because children do not comprise the worker populations, the child body weight estimates were used only for the regulated/casual and recreational visitor population evaluations.

B.3.7 TIME-DEPENDENT VARIABLES

TDVs are those parameters in the PPLV equations that estimate the length of time that exposure to COCs could occur. The following three TDVs are used in this analysis:

- Daily exposure time, TM (hours/day)
- Annual exposure frequency, DW (days/year)
- Exposure duration, TE (years)

Because the length of time that an individual spends at RMA over the course of a lifetime is dependent upon the land use at the site, TDVs are estimated for each of the potentially exposed populations. The length of time that commercial and industrial workers could spend at the site was assumed to be similar, so the same TDVs were used for both these populations.

As described in Appendix B.2, the TDVs for regulated/casual visitors, recreational visitors, and refuge workers reflect the more intense exposure expected from the maximally exposed subpopulations. For the visitor populations, the maximally exposed subpopulations are assumed to be local neighborhood site users. For the refuge worker population, the subpopulation is assumed to be biological workers, a group spending more than 50 percent of their time at work outdoors in soil-intrusive activities. For the purpose of comparison, a discussion of the TDVs for the refuge worker and general visitor populations developed by Shell is provided in Attachment B.3-4. In addition, Shell's development of TDV parameters, which differs from the Army's evaluation contained herein, is also provided in Attachment B.3-5. Nonetheless, the TDVs for the subpopulations, not the general populations developed by Shell, are used in the PPLV equations.

The TDV data compilation and distribution development for each potentially exposed population are described in this appendix as follows: TM is described in Section B.3.7.1, DW is described in Section B.3.7.2, and TE is described in Section B.3.7.3. A summary of data sources used to

develop the TDVs is shown in Table B.3-29, and a summary of the TDV parameters is provided in Tables B.3-30 and B.3-31.

B.3.7.1 Daily Exposure Time (Probabilistic)

Daily exposure time is the number of hours per day that an individual is assumed to be exposed to contamination at a site. Exposure time considers only those days when the individual is present at the site. In this section, a summary of the exposure time distribution for each potentially exposed population is provided, followed by a description of the data compilation and distribution development.

B.3.7.1.1 Regulated/Casual Visitors: Neighborhood Subpopulation

For the neighborhood regulated/casual visitors, the lognormal distribution for TM has a mean of 2.465 hrs/day and a standard deviation of 2.108 hrs/day. The ln(TM) has a mean of 0.628 and a standard deviation of 0.7407. The data compilation and development of this distribution is described below.

Data Compilation

The probability distribution of the number of hours that a regulated/casual visitor at RMA would spend participating in activities is derived from several data sources: Estimates of Visitations to Alternative Recreational Surface Uses Proposed for the Rocky Mountain Arsenal (THK Associates 1990), the National Sporting Goods Association (1989), the National Park Service (NPS) (1984), Walsh (1986), and the U. S. Bureau of Outdoor Recreation (1972). When Colorado participation rates were available, they were used. Local documents such as the Commerce City Comprehensive Plan (1985–1990) and the Gateway Plan (1991) were evaluated. When Colorado data were not available or were not considered applicable to the types of exposures expected at RMA, data for the western region of the continental United States were used (when available). The only regulated/casual visitor activity for which national participation rates were used was wildlife and bird photography.

Although data on the preferences among activities that are specific to Colorado or the western regions are available, no data were known to be available on the average duration of those activities in an environment comparable or nearly comparable to that at RMA. Therefore, national data on the average number of hours of participation per activity day were obtained from Walsh (1986).

Distribution Development

The probability distribution refers to the duration (hrs/day) of a visit to RMA on a day in which the regulated/casual visitor actually visits RMA (not days in which the potential visitor does not visit the RMA) and participates in at least one activity. Representative activities for the regulated/casual visitor are considered to be the following:

- Picnicking
- Walking for pleasure
- Nature walks
- Bird watching
- Wildlife and bird photography

While this list is not exhaustive, the probability distributions of hours of participation per activity day for these five activities should provide a representative sample of the corresponding probability distributions for the possible activities. (An activity day is defined as a day in which a visitor participates in at least one regulated/casual activity at RMA.)

The development of the probability distribution for exposure time for the regulated/casual visitor to RMA involves the following five steps:

1. Determine the probability distribution for each individual activity duration.

2. Determine the proportion of the subpopulations that participate in the different possible activity combinations.

3. Determine the number of days per year of participation in each possible combination of single and multiple activities for each possible subpopulation.

4. Determine the relative frequencies of the different combinations of activities on a given day by utilizing the information from steps (2) and (3) for the entire visitor population.

5. Determine the final probability distribution of the sum of all activity durations occurring on the same day by combining the information from steps (1) and (4).

Step 1. Determine the Probability Distribution for Each Individual Activity Duration

For each of the five representative activities, a normal or lognormal probability distribution with a specified mean number of hours and a specified 5th percentile was used to describe the activity duration on an activity day. As shown in the table below, Walsh (1986) provides data on the average number of hours of participation per activity day in five regulated/casual visitor activities. Although the data only provide mean values and give no indication of distribution shape, it is reasonable to assume that the duration of each representative regulated/casual visitor activity could be described by a lognormal distribution. It is expected that the average hours/day reported by Walsh could be substantially exceeded by an occasional visitor. Therefore, the underlying distribution would likely be positively skewed. The lognormal distribution assigns probability only to positive durations and indicates that a few individuals have activity durations substantially above the mean. The parameters in the lognormal distribution were determined such that the mean of the lognormal distribution equals the activity duration means given by Walsh, with at least 95 percent of the activity durations exceeding 30 minutes. A 5th percentile of 30 minutes was chosen as this time period was expected to comprise the minimum length for a visit. The lognormal distributions for each of the five representative regulated/casual visitor activities are as follows:

Activity	Mean[1]	Standard Deviation	Ln Mean	Ln Standard Deviation
Picnicking	2.7	2.65	0.66	0.82
Walking for Pleasure	1.9	1.42	0.41	0.67
Nature Walks	2.0	1.59	0.45	0.70
Bird Watching	2.1	1.74	0.49	0.72
Wildlife and Bird Photography	1.6	1.05	0.29	0.60

[1] Mean is average number of hours participation per activity day (Walsh 1986).

Step 2. Determine the Proportion of the Subpopulations that Participate in the Different Possible Activity Combinations

People who participate in at least one of the five representative regulated/casual visitor activities may not necessarily participate in all five of the activities. Some people may participate in one activity, some in two activities, etc. There are 31 possible combinations of activities that individuals might participate in at some time during a year. The 31 combinations of activities partition the RMA regulated/casual visitor population into 31 subpopulations. (The use of the term "subpopulation" is not related to the neighborhood subpopulation described in Section B.1 of this appendix. Rather, "subpopulation" here indicates a subset of the neighborhood subpopulation who engage in some or all of the regulated/casual activities described above.) For example, {Picnicking and Nature Walks} is one such combination of regulated/casual activities. The subpopulation corresponding to this combination of activities include all people who picnic at least 1 day per year and participate in nature walks at least 1 day per year. They may engage in both activities on the same day but do not participate in the other three activities. The 31 subpopulations and activities are described below.

Subpopulation Number	Combination of Activities[1] (Annual Participation)					
1	P	WP	WP	NW	BW	WBP
2	P	WP	NW	BW		
3	P	WP	NW		WBP	
4	P	WP	NW			
5	P	WP		BW	WBP	
6	P	WP		BW		
7	P	WP			WBP	
8	P	WP				
9	P		NW	BW	WBP	
10	P		NW	BW		
11	P		NW		WBP	
12	P		NW			
13	P		BW		WBP	
14	P		BW			
15	P				WBP	
16	P					
17		WP	NW	BW	WBP	
18		WP	NW	BW		
19		WP	NW		WBP	
20		WP	NW			
21		WP		BW	WBP	
22		WP		BW		
23		WP			WBP	
24		WP				
25			NW	BW	WBP	
26			NW	BW		
27			NW		WBP	
28			NW			
29				BW	WBP	
30				BW		
31					WBP	

[1] BW = Bird Watching
NW = Nature Walks
P = Picnicking
WBP = Wildlife and Bird Photography
WP = Walking for Pleasure

The proportion of RMA visitors in each of the 31 possible subpopulations was computed from the following data on the percent of population participating in each of the five representative activities:

Activity	Percent of Population Participating
Picnicking	55%[1]
Walking for Pleasure	52%[1]
Nature Walks	23%[1]
Bird Watching	12%[1]
Wildlife and Bird Photography	2.9%[2]

[1] Percent participation in the Western Region (National Park Survey (1984) in THK 1990).
[2] National value given in Bureau of Outdoor Recreation in (Walsh 1986, page 20).

The proportion of RMA visitors in each of the 31 possible subpopulations is equivalent to the probability that an individual is in a particular subpopulation given that the individual is an RMA visitor, or P (A|B), where A is the event that the individual is in subpopulation A and B is the event that the individual is an RMA visitor. The definition of conditional probability states that P (A|B) = P (Both A and B) / P(B). For example, if event A is the event in which an individual participates annually in picnicking and nature walks, but not walking for pleasure, bird watching, or wildlife and bird photography (subpopulation #12 above), then

$$P(\text{both A and B}) = 0.55 * 0.23 * (1 - 0.52) * (1 - 0.12) * (1 - 0.029) \quad (1)$$

The probability that an RMA visitor is in subpopulation #12 is as follows:

$$P(A|B) = P(\text{both A and B}) / [1 - (1 - 0.55) * (1 - 0.52) * (1 - 0.23) * (1 - 0.12) * (1 - 0.029) \quad (2)$$

This latter division causes the 31 probabilities to reflect the assumption that the regulated or casual visitor participates in at least one activity. The probability of both A and B is the proportion of the general population who visits RMA and engages in the combination of visitor activities described for subpopulation A. The probability of P (A|B) is the proportion of RMA visitors who are in subpopulation A. Logically, P (A|B) is always larger than P (A and B).

The following list of 31 subpopulation proportions or probabilities sum to 1.0:

Subpopulation Number	Combination of Activities[1]					Subpopulation Probability
1	P	WP	NW	BW	WBP	0.0002668
2	P	WP	NW	BW		0.0089344
3	P	WP	NW		WBP	0.0019568
4	P	WP	NW			0.0655191
5	P	WP		BW	WBP	0.0008933
6	P	WP		BW		0.0299109
7	P	WP			WBP	0.0065510
8	P	WP				0.2193465
9	P		NW	BW	WBP	0.0002463
10	P		NW	BW		0.0082472
11	P		NW		WBP	0.0018063
12	P		NW			0.0604791
13	P			BW	WBP	0.0008246
14	P			BW		0.0276100
15	P				WBP	0.0060471
16	P					0.2024737
17		WP	NW	BW	WBP	0.0002183
18		WP	NW	BW		0.0073100
19		WP	NW		WBP	0.0016010
20		WP	NW			0.0536065
21		WP		BW	WBP	0.0007309
22		WP		BW		0.0244725
23		WP			WBP	0.0053599
24		WP				0.1794653
25			NW	BW	WBP	0.0002015
26			NW		BW	0.0067477
27			NW		WBP	0.0014779
28			NW			0.0494829
29				BW	WBP	0.0006747
30				BW		0.0225900
31					WBP	0.0049476

[1] BW = Bird Watching
NW = Nature Walks
P = Picnicking
WBP = Wildlife and Bird Photography
WP = Walking for Pleasure

Step 3. Determine the Number of Days Per Year of Participation in Each Possible Combination of Single and Multiple Activities for Each Possible Subpopulation

For each of the 31 subpopulations, the number of days of participation in the 31 different activity combinations was determined. For example, a person who is a member of subpopulation #12 only participates in picnics and nature walks and therefore has three possible types of activity combinations: days involving only picnicking (type #16), days involving only nature walks (type #28), and days involving both picnicking and nature walks (type #12). Likewise, an individual in subpopulation #1 participates annually in all five activities and can, therefore, participate in any one of the 31 different activity combinations in a given day.

Subpopulation Number	Type of Activity Combination[1] (participation on the same day)				
1	P	WP	NW	BW	WBP
2	P	WP	NW	BW	
3	P	WP	NW		WBP
4	P	WP	NW		
5	P			BW	WBP
6	P	WP		BW	
7	P	WP			
8	P	WP			
9	P		NW	BW	WPB
10	P		NW	BW	
11	P		NW		WPB
12	P		NW		
13				BW	WPB
14	P			BW	
15	P				WPB
16	P				
17		WP	NW	BW	WBP
18		WP	NW	BW	
19		WP	NW		WBP
20		WP	NW		
21		WP		BW	WBP
22		WP		BW	
23		WP			WBP
24		WP			
25			NW	BW	WBP

Subpopulation Number	Type of Activity Combination[1] (participation on the same day)		
26	NW	BW	
27	NW		WBP
28	NW		
29		BW	WBP
30		BW	
31			WBP

[1] BW = Bird Watching
NW = Nature Walks
P = Picnicking
WBP = Wildlife and Bird Photography
WP = Walking for Pleasure

The 31 types of activity combinations appear to be the same as the 31 different subpopulations (the notation is identical). However, the meaning is different. For the 31 different subpopulations, the notation refers to the activities an individual participates in at some time during the year (not necessarily in the same day). For the 31 activity combinations, the notation refers to different types of activities an individual participates in on the same day.

Because data are not available on the frequency of participation in two or more activities in a given day, the incorporation of such combinations involves some uncertainty. The derivation below is based on data and statistically rigorous. All assumptions required for this method are stated.

The number of days of participation in each activity combination is dependent on the average annual number of days of participation in the following five single representative activities:

Activity	Average Annual Days for a Participant
Picnicking	6.6[1]
Walking for Pleasure	37.0[1]
Nature Walks	13.8[2]
Bird Watching	47.4[3]
Wildlife and Bird Photography	8.2[1]

[1] National values given in Bureau of Outdoor Recreation (Walsh 1986, page 20).
[2] In Colorado, the number of days/year for day hiking is 13.8 (National Sporting Goods Association 1989). Nationally, the average number of days/year for nature walks is 12.3 (U.S. Bureau of Outdoor Recreation (1972) in THK 1990)
[3] In the western U.S., the number of days/year for bird watching/nature walks is 47.4 (National Park Survey (1984) in THK 1990).

The dependency between the data above and the number of days per activity combination can be easily illustrated. In subpopulation #12, an individual participates in picnics and nature walks. The average number of days involving picnicking is 6.6, and the average number of days involving nature walks is 13.8. These averages are rounded to 7 and 14, respectively. The number of days of participation in both activities on the same day cannot exceed 7. Probability theory is used to estimate the number of days involving only picnicking (type #16 activity days), the number of days involving only nature walks (type #28 activity days), and the number of days involving both picnicking and nature walks (type #12 activity days). All other types of activity days are impossible in this subpopulation and have zero relative frequency.

The assumption was made that the probability that an individual participates in a given activity on a given day is independent of the probability that the individual participates in any other activity. If visits to the RMA occurred completely randomly among the 365 days of a year (no seasons or parts of the week were preferred over others), then the probability of participating in activity A on a given day would be equal to the number of repeat visits for activity A divided

by the total number of days in the year (e.g., 7 days of picnicking / 365). However, all days of the year are not equally preferable.

Walsh (1986) indicates that for most activities approximately 70 percent of the participation is on weekends. Additionally, winter months were assumed to be less preferable than summer months. If the selection of visits is restricted to a reduced number of days, the probability of multiple activities on the same day increases, resulting in an increase in the exposure time distribution. Therefore, for the purpose of estimating the number of days per activity combination, it was assumed that an individual must choose his or her visits from among the 52 weekend days occurring in a 6-month period. Note that one activity (bird watching) averages 47 days per year; therefore, the number of possible days cannot generally be reduced much below 52.

The effect of restricting the number of potential user days to 52 increases the probability of multiple activities on the same day and increases the protection afforded by the exposure time distribution. Note that a restriction of user days does not affect exposure frequency (number of visitation days/year), but merely makes an assumption about when these days of visitation tend to occur (i.e., on the weekends in 6 months of the year). For example, restricting the choices of days for the 7 picnics and the 14 nature walks to only 52 weekend days increases the probability of participation in both activities on the same day. Therefore, exposure time (hrs/day) is increased.

Monte Carlo simulation was used to determine the number of days spent in each activity combination for each subpopulation. For example, for subpopulation #12, 7 different picnic days were drawn at random (without replacement) from among 52 candidate days and 14 different nature walk days were drawn at random (without replacement) from among these same 52 candidate days. If a particular day appeared in both draws, then this day was associated with both activities. The number of days of activity combination #12, #16, and #28 were then counted

to produce one sample of a visitation pattern (a triple). For example, such a process may result in a triple of {1, 6, 13}, i.e., 6 days spent picnicking, 13 days spent nature walking, and 1 day spent both picnicking and nature walking.

The process results in a vector of 31 values, all of which are zero except for the triple corresponding to positions 12, 16, and 28 of the vector. This process was repeated 1,000 times, each time representing the visitation pattern of an individual from subpopulation #12. The expected visitation pattern for subpopulation #12 is required in step (4). It was obtained from the 1,000 samples of visitation pattern by summing the 1,000 values for each activity combination to produce one triple and then dividing by 1,000. An analogous Monte Carlo simulation was performed for each of the 31 subpopulations to estimate the expected visitation pattern, i.e., expected numbers of days spent in each of the 31 possible activity combinations.

Step 4. Determine the Relative Frequencies of the Different Combinations of Activities on a Given Day by Utilizing the Information from steps (2) and (3) for the Entire Visitor Population

In step (3), the expected number of days spent in each activity combination was simulated for each of the 31 subpopulations. The relative frequency of a type of activity combination for the entire population was then calculated as illustrated in the following example for activity combination #12. First, the expected number of days for activity combination #12 was estimated by multiplying the number of days for combination #12 expected for subpopulation #1 (determined in step (3)) by the relative size (frequency) of subpopulation #1 (determined in step (2)), repeating this step for all subpopulations, and then summing the resulting values over the 31 subpopulations. The mathematics of multiplying each subpopulation estimate of the number of days for activity combination #12 by the frequency of that subpopulation, and then summing over subpopulations, is referred to statistically as taking the expected value over subpopulations.

The expected number of days for the other 30 activity combinations was estimated analogously. For each activity combination, the expected value was taken over all 31 subpopulations. The

resulting vector of 31 expected values was interpreted as follows. Each position, 1 through 31, represents the expected value of the number of days of participation in the corresponding activity combination.

Following estimation of the expected number of days spent in each of the 31 activity combinations, the relative frequency of these activity combinations was defined as the number of days spent in each combination divided by the total number of days spent in any activity combination. The resulting frequencies were, equivalently, the probabilities that an individual who visits RMA under the regulated/casual scenario would participate in each of the activity combinations.

The resulting frequencies associated with each of the 31 activity combinations are given below. Approximately 18.6 percent of the simulated activity days involved multiple activities. Days involving 2, 3, 4, and 5 activities were 17.2 percent, 1.4 percent, 0.04 percent, and 0.0002 percent, respectively.

Subpopulation Number	Type of Activity Combination[1] (participation on the same day)					Probability
1	P	WP	NW	BW	WBP	0.0000016
2	P	WP	NW	BW		0.0003388
3	P	WP	NW		WBP	0.0000179
4	P	WP	NW			0.0028718
5	P	WP		BW	WBP	0.0000256
6	P	WP		BW		0.0051988
7	P	WP				0.0002076
8	P	WP				0.0426957
9	P		NW	BW	WPB	0.0000025
10	P		NW	BW	WPB	0.0006386
11	P		NW		WPB	0.0000222
12	P		NW			0.0047787
13	P			BW	WPB	0.0000382
14	P			BW	WPB	0.0092638
15	P				WPB	0.0003654

Subpopulation Number	Type of Activity Combination[1] (participation on the same day)				Probability
16	P				0.0771986
17	WP	NW	BW	WBP	0.0000191
18	WP	NW	BW		0.0045045
19	WP	NW		WPB	0.0001591
20	WP	NW			0.0363988
21	WP		BW		0.0003091
22	WP		BW		0.0674396
23	WP			WBP	0.0024705
24	WP				0.5552974
25	WP	NW	BW	WBP	0.0000326
26		NW	BW		0.0075031
27		NW		WBP	0.0002846
28		NW			0.0625829
29			BW	WBP	0.0005132
30			BW		0.1146319
31				WPB	0.0041879

[1] BW = Bird Watching
NW = Nature Walks
P = Picnicking
WBP = Wildlife and Bird Photography
WP = Walking for Pleasure

Step 5. Determine the Probability Distribution of the Sum of All Activity Durations Occurring on the Same Day by Combining the Information From Steps (1) And (4)

Step (1) provides the probability distributions for the durations of each of the five representative regulated/casual visitor activities. Step (4) provides the probabilities that a visitor will participate in a particular combination of activities on a given day. If a visitor participates in more than one activity, the duration of the visit is equal to the sum of the durations of each activity. The results from these two steps were then combined in a Monte Carlo simulation to estimate the probability distribution of exposure time (hrs/day), where exposure time is the sum of all regulated/casual visitor activities on an activity day. The duration of each activity was assumed to be independent of the duration of other activities. For example, a long nature walk has the same likelihood of being associated with a long picnic as does a short nature walk.

In the simulation, a particular activity combination was drawn from the 31 choices using the probabilities derived in step (4), i.e., approximately 0.077 (7.7%) of the time combination #16 was drawn (picnicking) and 0.48 percent of the time combination #12 (picnicking and nature walking) was drawn. Next, a duration was drawn from the duration distributions of each of the individual activities involved in the chosen combination, and these durations are summed. The frequency distribution of these sums is the simulated probability distribution for exposure time (hours/day).

The percentiles of the simulated probability distribution for exposure time are listed below. Both normal and lognormal distributions were fit to these percentiles. The statistical fitting criterion was weighted least squares where the weights were proportional to the size of the population of activity durations involved as follows:

Percentile	Incremental Proportion of Population of Durations
1.0	1.0
2.5	1.5
5.0	2.5
7.5	2.5
10.0	2.5
25.0	15.0
50.0	25.0
75.0	25.0
90.0	15.0
92.5	2.5
95.0	2.5
97.5	2.5
99.0	1.5

Here, for example, the weight on the fit at the 25th percentile is proportional to the incremental 15 percent of the activity durations between the 25th percentile and the previous percentile (the 10th percentile). The use of these weights ensures that the fitted distribution fits most closely to the percentile increments where the largest proportions of values reside. Except where noted,

all distribution fits for the TDVs were based on the weighted least squares criterion with weights proportional to the incremental percentage of activity durations in the data. The best fit between the normal and lognormal distribution is used to describe the probability distribution of exposure time (hrs/day).

The best fitting probability distribution for exposure time is the lognormal distribution in which exposure time has a mean of 2.465 hrs/activity day and a standard deviation of 2.108 hrs/day. Correspondingly, the ln(TM) has a mean of 0.628 and a standard deviation of 0.7407. The fit of the distribution to the simulated data is as follows:

Percentage	Simulated Percentile	Fitted Percentile
99.0	10.03	10.50
97.5	7.95	8.00
95.0	6.36	6.34
92.5	5.49	5.44
90.0	4.93	4.84
75.0	3.11	3.09
50.0	1.84	1.87
25.0	1.09	1.14
10.0	0.69	0.73
7.5	0.61	0.65
5.0	0.53	0.55
2.5	0.42	0.44
1.0	0.32	0.33

B.3.7.1.2 Recreational Visitors: Neighborhood Subpopulation

The probability distribution for the daily exposure time of the neighborhood recreational visitor is lognormal with a mean of 1.863 hrs/day and a standard deviation of 1.704 hrs/day. The log-transformed values have a mean of 0.3185 and a standard deviation of 0.7795. The data compilations and distribution development are described below.

Data Compilation

The probability distribution of the number of hours that a recreational visitor to RMA would spend at RMA was derived from several data sources: Estimates of Visitations to Alternative Recreational Surface Uses Proposed for the Rocky Mountain Arsenal (THK 1990), the National Sporting Goods Association (NSGA)(1989), National Park Service (NPS) (1984), the U.S. Forest Service in Walsh (1986), and the U.S. Bureau of Outdoor Recreation (1972).

The development of the exposure time distribution for the recreational visitor involved characterizing distributions for the hours of participation for each of the five representative recreational visitor activities. Although there are data on the preferences among activities that are specific to Colorado or the western regions, no data were known to be available on the average duration of those activities in an environment comparable or nearly comparable to that at RMA. National data on the average number of hours of participation per activity day are given in Walsh (1986) for four of the recreational activities. For the fifth activity, running or jogging, the only data available were the U.S. Forest Service data on the Rocky Mountain Region and the nation. The U.S. Forest Service data were used despite the differences in characteristics between RMA and a typical national forest because they are the only data known to be available.

Distribution Development

The probability distribution for the exposure time (hrs/day) of a recreational visit to RMA was developed by considering five representative recreational activities:

- Attending outdoor sports events
- Bicycling
- Playing outdoor team sports
- Walking
- Jogging

The development of the probability distribution for exposure time for a recreational visitor to RMA involves three steps, which are described below.

1. Determine the probability distributions for each individual activity duration.
2. Determine the relative frequency of each activity among recreational activity days.
3. Determine the recreational visitor activity duration distribution by combining the individual activity duration distributions on the basis of the relative frequencies of the different activities and by including picnics.

Step 1. Determine the Probability Distributions for Each Individual Activity Duration

For each of the five representative activities, a normal or lognormal probability distribution with a specified mean number of hours (based on data) and a specified 5th percentile is used to describe the activity duration on an activity day. The distributions for each of the five representative recreational visitor activities are as follows:

Activity	Distribution Type	Mean[1]	Standard Deviation	Ln Mean	Ln Standard Deviation
Attend Outdoor Sports Events	Normal	4.2[2]	1.628	–	–
Bicycling	Lognormal	2.0[2]	1.59	0.45	0.70
Playing Outdoor Team Sports	Lognormal	2.6[2]	2.51	0.63	0.81
Walking	Lognormal	1.9[3]	1.42	-0.41	0.67
Jogging	Lognormal	1.0[3]	0.79	-0.24	0.70

[1] Average number of hours of participation per activity day based on data. It is assumed to be equal to the distribution mean.
[2] U.S. Bureau of Outdoor Recreation (Walsh 1986)
[3] U.S. Forest Service (Walsh 1986)

The mean duration for attending outdoor sports events is somewhat large (4.2 hrs) and falls approximately in the middle of reasonable lower and upper bounds (0 and 8 hrs) for attendance at such an event. Because of this symmetry, the duration distribution for attending sports events

was assumed to be approximately normal, with a mean of 4.2. The 5th percentile of this distribution was assumed to be 1.5 hours to reflect that most sports events last at least 1 hour and that a person attending a 1-hour-long event might reasonably arrive 15 minutes before the event and leave 15 minutes after the event. The 99th percentile of this distribution is 8 hours. The data on which this distribution is based presumably reflect a significant portion of attendance at major professional sports events that tend to have longer durations than the informal team sports activities expected at RMA.

Lognormal distributions were assigned to each of the other activities. The distributions for bicycling, playing outdoor team sports, and walking were assumed to have 5th percentiles equal to 30 minutes. The distribution for the duration of running or jogging was assumed to have a 5th percentile of 15 minutes because most people can walk or run a mile within 15 minutes.

Step 2. Determine the Relative Frequency of Each Activity Among Recreational Activity Days The relative frequency of each activity depends on the average number of days of participation per year for each activity and the percentage of the population participating in each of the five representative activities. The relative contributions are derived from the data on the average number of days of activity participation per participant and/or the proportion of the population who participates in the activity. Colorado participation rates were available for three of the recreational activities and Western Region rates were used for the other two activities. These data are given in the first two columns in the list below.

Activity	Annual Days for an Average Activity Participant	Percent of Population Participating	Annual Days for a General Visitor	Fraction of Total Days
Bicycling	54.8[1]	31	16.99[4]	0.149[5]
Playing Outdoor Team Sports	44.6[2]	35.7[2]	15.92	0.139
Attending Outdoor Sports Events	10.6[2]	35.4[2]	3.75	0.033
Walking	99.2[1]	52[3]	51.58	0.451
Running or Jogging	84.0[1]	31[3]	26.04	0.228
Total			114.28	1.000

[1] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1989) in: (THK 1990).
[2] National Average, (U.S. Bureau of Outdoor Recreation, 1972) in: (Walsh 1986, page 20).
[3] Percent participation in the Western Region (National Park Service Survey, 1984) in: (THK 1990).
[4] 54.8 * 31% = 16.99
[5] 16.99 / 114.28 = 0.149

These figures are interpreted as follows. An individual in the bicycling portion of the population (31 percent of the entire population) spends an average of 54.8 days bicycling each year. It follows that when the entire population is considered (including people who do not ride bikes), an average individual spends 54.8*0.31 = 16.99 days bicycling each year. Similarly, an average individual from the entire population spends 15.92 days per year playing outdoor team sports and so on. These figures imply that the average person in Colorado participates in some recreational activity 114.28 days per year. The important information is not the total number of recreational days, which are spread over many different parks or other facilities. Rather, the important information is that of those 114.28 days, the proportion of days involving bicycling is 0.149, the proportion of days involving playing outdoor team sports is 0.139, etc. This means, for example, that the probability is 0.149 that a randomly selected recreational day involves bicycling.

The probabilities corresponding to the "fraction of total days" are important to the calculation of exposure time of the recreational visitor. These probabilities imply how often the exposure time of the visitor for a recreational activity day should be calculated from the bicycling duration distribution, the playing outdoor team sports distribution, etc.

Step 3. Determine the Recreational Visitor Activity Duration Distribution by Combining the Individual Activity Duration Distributions on the Basis of the Relative Frequencies of the Different Activities and by Including Picnics

The probability distribution for the number of hours spent participating in some general recreational visitor activity on a day that an individual participates in some such activity is determined by combining the probability distributions for hours per day for individual activities together with the relative frequency of the different activities. That is, the individual activity probability distributions are combined on the basis of the recreational visitors' relative preferences among those activities. The activities preferred the most by recreational visitors receive the greatest emphasis. The estimated relative frequencies of the different representative recreational activities are the fractions of total days listed in step (2).

The probability distribution for exposure time of the general recreational visitor can be estimated by simulation techniques using the probability distributions for the individual activity durations, the relative frequencies of the different activities, and the probability distribution for the duration of a picnic that might be combined with a recreational activity. It is assumed that general recreational visitors would tend to participate in only one activity on a given day. For example, a person would not normally run 5 miles and then participate in a team sporting event like soccer or softball. However, a person might combine one of these representative recreational activities with some leisure time such as a picnic. Therefore, the probability distribution for the total number of hours per activity day for recreational visitors is calculated assuming the possibility of either a single recreational activity or a single recreational activity plus a picnic.

The exposure time of the recreational visitor on a given day is simulated by the following sequence of actions:

1. Randomly select one of the five representative recreational activities. The probabilities of selecting bicycling, playing outdoor team sports, attending outdoor sports events, walking, or running/jogging are 0.149, 0.139, 0.033, 0.451, and 0.228, respectively.

2. Randomly select an activity duration from the activity duration distribution corresponding to the activity selected in action (1). Set exposure time of the recreational visitor equal to this duration.

3. Randomly determine whether the selected recreational activity is to be combined with a picnic. If it is, then randomly select the picnic duration from the probability distribution for picnic durations, and add the picnic duration to exposure time of the general visitor.

In action (3), 50 percent of all picnics are assumed to be combined with each type of recreational activity. The national average number of picnicking days is 6.6 days per year among people who picnic. Therefore, 3.3 picnicking days per year are combined with each type of recreational activity. For example, the average number of bicycling days per year for a bicyclist is 54.8 days. Thus, in action (3), if the selected recreational activity is bicycling, then the probability of adding a picnic duration to the recreational activity duration is 3.3/54.8 because this is the proportion of overlap of 3.3 picnicking days among 54.8 days of bicycling. Picnic durations were assumed to have the same distribution as they had for regulated/casual visitors, i.e., a lognormal distribution with a mean of 2.7 hrs and a standard deviation of 2.65 hrs.

This sequence of actions was repeated numerous times. The resulting distribution of exposure-time values was best fit by a lognormal distribution with a mean of 1.863 hrs/day and a standard deviation of 1.704 hrs/day. The log-transformed values have a mean of 0.3185, and a standard deviation of 0.7795. This distribution has the following percentiles:

Probability (TM(recreational visitor) $\leq$ 8.43 hr/activity day) = 0.99
Probability (TM(recreational visitor) $\leq$ 4.96 hr/activity day) = 0.95
Probability (TM(recreational visitor) $\leq$ 2.33 hr/activity day) = 0.75
Probability (TM(recreational visitor) $\leq$ 1.38 hr/activity day) = 0.50

Probability (TM(recreational visitor) ≤ 0.81 hr/activity day) = 0.25

B.3.7.1.3 Commercial/Industrial Workers

The probability distribution for exposure time (hrs/day of work) for a commercial/industrial worker is a normal distribution with a mean of 7.42 hrs/day and a standard deviation of 3.267 hrs/day. The data compilation and distribution development for the commercial/industrial worker is described below.

Data Compilation

Numerous references indicate that the average workday duration for a full-time commercial/industrial worker is nearly 8 hrs/day or in the range between 7 and 9 hrs/day (e.g., Szalai et al. 1972 and EPA 1985b). However, not every full-time worker spends exactly 8 hours/day or 40 hr/week at work, and not all commercial/industrial workers are full-time workers. Many workers spend more than 40 hr/week, and some spend less than 40 hr/week. According to the Exposure Factors Handbook (EPA 1989a), at least one person worked 107 hr/week and more than 20 percent of the population work more than 40 hr/week. Given the considerable variability in people's workday durations, a distribution of workday durations is warranted for this population. The distribution which is described below reflects the percentage of the worker population who works 5, 30, 60, etc. hr/week. Such a probability distribution explicitly incorporates the frequencies of different workday durations among the workers.

The Exposure Factors Handbook (EPA 1989a) provides information on the amount of time spent at work. The handbook indicates the 10th, 20th, ..., and 90th percentiles and the "Max" of the hours/week for men and women combined spent in "Normal Work." Similar distributional information is also given in the handbook for "Lunch at Work," "Coffee Breaks," and "Before/after Work." This information is for all people at least 18 years of age, excluding individuals in college dormitories, nursing homes, and other institutional settings. The information is thought to constitute the total time spent at the workplace, not only the actual working hours.

The work duration distribution is available from the Exposure Factors Handbook (EPA 1989a) in units of hr/week, and much of the information on work frequency is available in units of weeks/year. This information must be converted to hrs/day and days/week using a conversion factor indicating how many days are implied by a "week" in the data sources. It was assumed that "weeks" referred to a typical work week, which is 5 days. This assumption has no impact on the product of TM*DW because

$$(X \text{ hr/week} / [5 \text{ days/week}]) * (Y \text{ weeks/year} * [5 \text{ days/week}] = X*Y \text{ hr/year} \quad (3)$$

and is, therefore, independent of the value chosen for the conversion factor.

This assumption of 5 days/week does impact the exposure frequency distribution, which is used separately from exposure time in several PPLV equations. However, it is believed that the assumption is realistic for the working population and enables accurate determination of the exposure frequency distribution for commercial and industrial workers developed in the next section.

Distribution Development

The probability distribution for the hr/week for commercial/industrial workers is the probability distribution for the sum of the hr/week spent in "Normal Work", "Lunch at Work," "Coffee Breaks," and "Before/after Work." It is important to account for all the time spent at the workplace, not just working hours.

The probability distribution for the sum is relatively sensitive to the upper percentiles of the four component probability distributions, particularly the percentiles between the 90th percentile and the "Max." To estimate these percentiles, the information on the shape of the distribution contained in the given sample data was used. The given sample data were fit to the normal, lognormal, and gamma distributions using a different weighted least squares criterion than that

used for all other distribution fits. Because the fits were only used to interpolate values for the percentiles between the 90th and the "Max," the weights were constructed to ensure that the fitted distribution fits most closely to the largest percentile increments, i.e., the upper tail. The remaining distribution fits to the Exposure Factors Handbook data (EPA 1989a) (presented below) are all based on this same criterion.

The sampled population includes adults who were not working. To characterize the distribution for working adults only, the working population had to be defined based on a minimum number (4) of hours worked per week. The 35th percentile is approximately 4 hr/week; therefore, all non-workers are excluded if the lower 35 percent of the distribution is removed. By removing these individuals, the resulting sample data refer to the specified worker population.

The best fit for "Normal Work" was obtained using the lognormal distribution. The best-fitting distribution corresponds to the logarithm of a normal random variable with a mean of 3.2647 hr/week and a standard deviation of 0.4554 hr/week (the relatively large number of significant digits are provided to facilitate independent mathematical confirmation). The fitted 90th percentile was 46.9 hr/week, which is very close to the sample 90th percentile. The fitted higher percentiles that supplement the sample percentiles are as follows:

92.5th Percentile = 50.41 hr/week
95.0th Percentile = 55.36 hr/week
97.5th Percentile = 63.90 hr/week
99.0th Percentile = 75.49 hr/week
99.5th Percentile = 84.58 hr/week
99.75th Percentile = 93.97 hr/week

The sample information on the percentiles of "Normal Work" is the original sample percentiles from the Exposure Factors Handbook plus (EPA 1989a) the fitted supplementary percentiles, i.e.,

10th	Percentile =	0.00	hr/week
20th	Percentile =	0.06	hr/week
30th	Percentile =	0.34	hr/week
40th	Percentile =	8.31	hr/week
50th	Percentile =	20.22	hr/week
60th	Percentile =	32.08	hr/week
70th	Percentile =	37.68	hr/week
80th	Percentile =	41.33	hr/week
90th	Percentile =	46.88	hr/week
92.5th	Percentile =	50.41	hr/week
95.0th	Percentile =	55.36	hr/week
97.5th	Percentile =	63.90	hr/week
99.0th	Percentile =	75.49	hr/week
99.5th	Percentile =	84.58	hr/week
99.75th	Percentile =	93.97	hr/week
	Max =	107.00	hr/week

When 35 percent of the sample was removed (to remove the effect of adults who are not working), the individuals who made up 10 percent of the original sample represented approximately 15.4 percent of the remaining worker population (10%/(1-.35) = 10%/0.65 = 15.4%). The sample percentiles (with the original percentage minus 35 percent divided by 0.65, e.g., (95%-35%)/0.65 = 92.3%), for the worker population and "Normal Work" are as follows:

0.0th	Percentile =	4.00	hr/week
7.7th	Percentile =	8.31	hr/week
23.1th	Percentile =	20.22	hr/week
38.5th	Percentile =	32.08	hr/week
53.9th	Percentile =	37.68	hr/week
69.3th	Percentile =	41.33	hr/week
84.7th	Percentile =	46.88	hr/week
88.5th	Percentile =	50.41	hr/week
92.3th	Percentile =	55.36	hr/week
96.2th	Percentile =	63.90	hr/week
98.5th	Percentile =	75.49	hr/week
99.2th	Percentile =	84.58	hr/week
99.6th	Percentile =	93.97	hr/week
	Max =	107.00	hr/week

The Exposure Factors Handbook information (EPA 1989a) on "Lunch at Work Coffee Breaks and "Before/after Work" was treated analogously.

The handbook sample percentiles for "Lunch at Work" are as follows:

10th Percentile = 0.00 hr/week
20th Percentile = 0.00 hr/week
30th Percentile = 0.00 hr/week
40th Percentile = 0.14 hr/week
50th Percentile = 0.30 hr/week
60th Percentile = 0.46 hr/week
70th Percentile = 1.07 hr/week
80th Percentile = 2.41 hr/week
90th Percentile = 3.16 hr/week
Max = 9.00 hr/week

The given sample data were fit to the normal, lognormal, and gamma distributions, again based on the weighted least squares criterion discussed earlier in this section. The best fit for "Lunch at Work" was obtained using the gamma distribution. The best-fitting distribution has a mean of 1.4223 hr/week and a variance of 1.7521 hr/week. The fitted 90th percentile is identical to the sample 90th percentile. The fitted higher percentiles that supplement the sample percentiles are as follows:

92.5th Percentile = 3.53 hr/week
95.0th Percentile = 4.05 hr/week
97.5th Percentile = 4.94 hr/week
99.0th Percentile = 6.10 hr/week
99.5th Percentile = 6.97 hr/week
99.75th Percentile = 7.85 hr/week

All non-workers were excluded by removing the lower 35 percent of the sample. By removing these individuals, the resulting sample data refer to the worker population. When the lower 35

percent of the sample is removed, the sample percentiles for the worker population and "Lunch at Work" are as follows:

0.0th Percentile =	0.00	hr/week
7.7th Percentile =	0.14	hr/week
23.1th Percentile =	0.30	hr/week
38.5th Percentile =	0.46	hr/week
53.9th Percentile =	1.07	hr/week
69.3th Percentile =	2.41	hr/week
84.7th Percentile =	3.16	hr/week
98.5th Percentile =	3.53	hr/week
92.3th Percentile =	4.05	hr/week
96.2th Percentile =	4.94	hr/week
98.5th Percentile =	6.10	hr/week
99.2th Percentile =	6.97	hr/week
99.6th Percentile =	7.85	hr/week
Max =	9.00	hr/week

The sample percentiles for "Coffee Breaks" are as follows:

10th Percentile =	0.00	hr/week
20th Percentile =	0.00	hr/week
30th Percentile =	0.00	hr/week
40th Percentile =	0.03	hr/week
50th Percentile =	0.16	hr/week
60th Percentile =	0.29	hr/week
70th Percentile =	0.43	hr/week
80th Percentile =	0.83	hr/week
90th Percentile =	1.74	hr/week
Max =	12.00	hr/week

The given sample data were fit to the normal, lognormal, and gamma distributions. The best fit for "Coffee Breaks" is obtained using the gamma distribution. The best-fitting distribution has a mean of 0.5756 hr/week and a standard deviation of 1.6948 hr/week. The fitted 90th percentile is identical to the sample 90th percentile. The fitted higher percentiles that supplement the sample percentiles are as follows:

92.5th Percentile = 2.23 hr/week
95.0th Percentile = 2.98 hr/week
97.5th Percentile = 4.39 hr/week
99.0th Percentile = 6.42 hr/week
99.5th Percentile = 8.04 hr/week
99.75th Percentile = 9.72 hr/week

All non-workers were excluded by removing the lower 35 percent of the sample. When the lower 35 percent of the sample is removed, the sample percentiles for the worker population and "Coffee Breaks" are as follows:

0.0th Percentile = 0.00 hr/week
7.7th Percentile = 0.03 hr/week
23.1th Percentile = 0.16 hr/week
38.5th Percentile = 0.29 hr/week
53.9th Percentile = 0.43 hr/week
69.3th Percentile = 0.83 hr/week
84.7th Percentile = 1.74 hr/week
88.5th Percentile = 2.23 hr/week
92.3th Percentile = 2.98 hr/week
96.2th Percentile = 4.39 hr/week
98.5th Percentile = 6.42 hr/week
99.2th Percentile = 8.04 hr/week
99.6th Percentile = 9.72 hr/week
Max = 12.00 hr/week

The sample percentiles for "Before/after Work" are as follows:

10th Percentile =	0.00	hr/week
20th Percentile =	0.00	hr/week
30th Percentile =	0.00	hr/week
40th Percentile =	0.00	hr/week
50th Percentile =	0.11	hr/week
60th Percentile =	0.23	hr/week
70th Percentile =	0.35	hr/week
80th Percentile =	0.48	hr/week
90th Percentile =	1.23	hr/week
Max =	11.00	hr/week

The given sample data was fit to the normal, lognormal, and gamma distributions. The best fit for "Before/after Work" was obtained using the gamma distribution. The best-fitting distribution has a mean of 0.4187 hr/week and a standard deviation of 1.2400 hr/week. The fitted 90th percentile is identical to the sample 90th percentile. The fitted higher percentiles that supplement the sample percentiles are as follows:

92.5th Percentile =	1.66	hr/week
95.0th Percentile =	2.33	hr/week
97.5th Percentile =	3.63	hr/week
99.0th Percentile =	5.56	hr/week
99.5th Percentile =	7.13	hr/week
99.75th Percentile =	8.76	hr/week

All non-workers were excluded by removing the lower 35 percent of the sample. When the lower 35 percent of the sample is removed, the sample percentiles for the worker population and "Before/after Work" are as follows:

0.0th Percentile =	0.00	hr/week
7.7th Percentile =	0.00	hr/week
23.1th Percentile =	0.11	hr/week
38.5th Percentile =	0.23	hr/week
53.9th Percentile =	0.35	hr/week
69.3th Percentile =	0.48	hr/week
84.7th Percentile =	1.23	hr/week

88.5th Percentile = 1.66 hr/week
92.3th Percentile = 2.33 hr/week
96.2th Percentile = 3.63 hr/week
98.5th Percentile = 5.56 hr/week
99.2th Percentile = 7.13 hr/week
99.6th Percentile = 8.76 hr/week
Max = 11.00 hr/week

The total time spent at work is the sum of the hr/week for "Normal Work", "Lunch at Work," "Coffee Breaks", and "Before/after Work." These variables were assumed to be independent of each other. Therefore, the probability distribution for the total time (hr/week) at work was determined using a standard Monte Carlo simulation method. This method proceeds by drawing one sample from each of the four component distributions, summing these four values to form a sample of total time, and repeating this process until a large number, N, of samples of total time are produced, e.g., N = 10,000. The percentiles of total time in hr/week are as follows:

Probability (Duration ≤ 104.30 hr/week) = 0.999
Probability (Duration ≤ 100.00 hr/week) = 0.9975
Probability (Duration ≤ 94.81 hr/week) = 0.995
Probability (Duration ≤ 85.83 hr/week) = 0.99
Probability (Duration ≤ 73.74 hr/week) = 0.975
Probability (Duration ≤ 64.55 hr/week) = 0.95
Probability (Duration ≤ 59.59 hr/week) = 0.925
Probability (Duration ≤ 55.87 hr/week) = 0.90
Probability (Duration ≤ 48.79 hr/week) = 0.80
Probability (Duration ≤ 46.87 hr/week) = 0.75
Probability (Duration ≤ 45.28 hr/week) = 0.70
Probability (Duration ≤ 42.18 hr/week) = 0.60
Probability (Duration ≤ 39.28 hr/week) = 0.50
Probability (Duration ≤ 35.38 hr/week) = 0.40
Probability (Duration ≤ 28.95 hr/week) = 0.30
Probability (Duration ≤ 24.91 hr/week) = 0.25
Probability (Duration ≤ 21.09 hr/week) = 0.20
Probability (Duration ≤ 13.61 hr/week) = 0.10
Probability (Duration ≤ 11.56 hr/week) = 0.075
Probability (Duration ≤ 9.80 hr/week) = 0.05

The N samples of total time in hr/week were then converted to hrs/day by dividing by 5.0 days/week. The factor of 5 days/week is a realistic assumption regarding the average work week of commercial and industrial workers. The final probability distribution for the hrs/day at work for a commercial/industrial worker on a workday is as follows:

Probability (Duration ≤ 20.86 hrs/day)	= 0.999
Probability (Duration ≤ 20.00 hrs/day)	= 0.9975
Probability (Duration ≤ 18.96 hrs/day)	= 0.995
Probability (Duration ≤ 17.17 hrs/day)	= 0.99
Probability (Duration ≤ 14.75 hrs/day)	= 0.975
Probability (Duration ≤ 12.91 hrs/day)	= 0.95
Probability (Duration ≤ 11.92 hrs/day)	= 0.925
Probability (Duration ≤ 11.17 hrs/day)	= 0.90
Probability (Duration ≤ 9.76 hrs/day)	= 0.80
Probability (Duration ≤ 9.37 hrs/day)	= 0.75
Probability (Duration ≤ 9.06 hrs/day)	= 0.70
Probability (Duration ≤ 8.44 hrs/day)	= 0.60
Probability (Duration ≤ 7.86 hrs/day)	= 0.50
Probability (Duration ≤ 7.08 hrs/day)	= 0.40
Probability (Duration ≤ 5.79 hrs/day)	= 0.30
Probability (Duration ≤ 4.98 hrs/day)	= 0.25
Probability (Duration ≤ 4.22 hrs/day)	= 0.20
Probability (Duration ≤ 2.72 hrs/day)	= 0.10
Probability (Duration ≤ 2.31 hrs/day)	= 0.075
Probability (Duration ≤ 1.96 hrs/day)	= 0.05

The normal and lognormal distributions were fit to these percentiles. The best fitting distribution for exposure time is a normal distribution with a mean of 7.42 hrs/day and a standard deviation of 3.26 hrs/day. The fit is described as follows:

Percentage	Simulated Distribution (hrs/day)	Normal Distribution (hrs/day)
99.0	17.16	15.02
97.5	14.75	13.82
95.0	12.91	12.79
92.5	11.92	12.12
90.0	11.17	11.60
75.0	9.37	9.62
50.0	7.86	7.42
25.0	4.98	5.21
10.0	2.72	3.23
7.50	2.31	2.72
5.00	1.96	2.04

B.3.7.1.4 Biological Worker

In general, data used to develop the biological worker TDV distributions were obtained from a survey of National Wildlife Refuges (see Appendix B.2). The survey responses indicated the number of hrs per year worked by each of the workers interviewed, but did not always indicate the breakdown of these hours into hrs per day and days per year. Therefore, TM was fixed at 8 hrs/day. As described in Section B.3.7.2, the annual exposure frequency (days/year) of the biological worker was assigned a distribution fit to survey data on hrs per year per 8.

B.3.7.2 Annual Exposure Frequency (Probabilistic)

DW refers to the annual exposure frequency for an individual at a site. In this section, the exposure frequency distributions for each of the potentially exposed populations are described.

B.3.7.2.1 Regulated/Casual Visitor: Neighborhood Subpopulation

The distribution of exposure frequency for neighborhood regulated/casual visitors is lognormal with a mean of 34.9 days/year and a standard deviation of 22.4 days/year. The log-transformed values have a mean of 3.376 and a standard deviation of 0.583. The data compilation and distribution development are described below.

Data Compilation

In the time available for the subpopulation investigation, no data were found that characterized the repeat visitation patterns of a neighborhood subpopulation to an open space facility comparable to RMA. In addition, there were no available data on the fraction of an individual's activity days (e.g., walks) that would occur at a neighborhood park vs. another location. Therefore, the assumptions described below were used to characterize the exposure frequency distribution.

Distribution Development

The number of activity days was assumed to vary between 5 days/year and 104 days/year (2 days/week), depending on the individual and the activity (e.g., nature walk, bird watching, walking for pleasure, picnics). A triangular distribution with this range and a mode of 26 days per year was assigned to represent activity days/year. The fraction of these activity days that occur at RMA was assumed to vary uniformly between 0.5 and 1.0. The exposure frequency distribution was estimated by multiplying the triangular distribution describing number of activity days by the uniform distribution describing fraction of visits to RMA. The simulated data was best fit by a lognormal distribution with a mean of 34.9 days/year and a standard deviation of 22.4 days/year.

B.3.7.2.2 Recreational Visitor: Neighborhood Subpopulation

The exposure frequency distribution for the neighborhood recreational visitor subpopulation was assigned a lognormal distribution with a mean of 63.14 days/year and a standard deviation of 67.02 days/year. The log-transformed values have a mean of 3.768 and a standard deviation of 0.8687. The data compilation and distribution development are described below.

Data Compilation

In time available for the subpopulation investigation, no data were found that characterized the repeat recreational visitation patterns of a neighborhood subpopulation to an open space facility comparable to RMA-IEA. Data on activity days per year were available for jogging and bicycling from Gallup (1986) and NSGA (1989), respectively. The activity-specific distributions for these two activities were developed based on these data supplemented with best professional judgment. A third activity-specific distribution was developed to represent "other" activities including hiking, cross country skiing, frisbee, and informal team sports.

Distribution Development

The three activity-specific distributions (jogging, biking, and "other recreational activities") were combined using a Monte Carlo simulation to produce a single distribution for exposure frequency for the neighborhood recreational visitor. The development of the activity-specific distributions and the relative weights used to combine these distributions are described in the three steps discussed below.

Values of exposure frequency were simulated using Monte Carlo simulation by repeating the following steps 10,000 times.

1. Randomly select a type of visitor from the three activity classes (i.e., jogging or walking for exercise, biking, other activities).

2. Draw a random sample from the activity-specific distribution for number of activity days.

3. Multiply the number of activity days by the distribution for fraction of activity days spent at RMA.

Step 1: Randomly Select a Type of Visitor from the Three Activity Classes (i.e., Jogging or Walking for Exercise, Biking, other Activities

In step (1), relative frequency (i.e., relative weight) of each type of visitor was estimated as follows: NPS (1984) reported the national percent participation in a range of recreational activities. The percent participation was assumed to reflect the relative popularity of these activities in the neighborhood population. The relative weight for each activity is as follows:

In step (1), the relative frequency (i.e., relative weight) of each type of visitor was estimated as follows. NPS (1984) reported the national percent participation in a range of recreational activities. The percent participation was assumed to reflect the relative popularity of these activities in the neighborhood population. The relative weight for each activity is as follows:

Activity	Percent Participation[1]	Percent for Combined Activities	Relative Weight
Run, walk	11, 9	20	0.455[2]
Bike	9	9	0.205
Other activities (cross country ski, day hike)	7,8	15	0.340
Total		44	100.0

[1] NPS (1984)
[2] 0.455 = 20/44

Step 2: Draw a Random Sample from the Activity-Specific Distribution for Number of Activity Days

The distributions for activity days are as described below:

Jogging or Walking for Exercise

In step (2), the distribution of days/week for walking for exercise was assumed to be similar to that for jogging, so these activities were combined. The exposure frequency distribution for jogging or walking for exercise was based on data reported in the 1986 Gallup survey. The data pertain to individual respondents who describe themselves as joggers. According to the survey, such individuals comprise 15 percent of the national population. The survey reports the following percentiles for days of jogging per week:

Frequency	Joggers
Less than once a week	18%
Once or twice a week	31%
3 or 4 times a week	28%
Every day or almost every day	21%
Not sure	2%
Total	100%
Average times per week	3

Because the survey does not state the number of weeks the respondent jogged during the year, an assumption regarding the number of weeks per year was required. Although it is likely that most respondents did not jog every week out of the year, the conservative assumption was made that all joggers jogged 52 weeks out of the year. The survey results did not indicate the lower-bound jogging frequency, so an assumption regarding the lower bound was also required. A jogger was considered to be someone who jogs at least 1 day per month or 12 days per year.

The distribution for activity days (both on and off post) for jogging or walking for exercise was defined by a step distribution matching the percentiles given above multiplied by 52 and with a lower bound of 12 days per year. The percentages were adjusted to remove the 2 percent "not sure." This distribution has the following percentiles:

Gallup Percentiles (1986)	Days/Year	Cumulative Probability
——	10	0.0000
Less than once a week	52	0.1837
Once or twice a week	104	0.5000
3 or 4 times a week	208	0.7857
Everyday or almost everyday	365	1.0000

Biking

The number of biking activity days was assumed to have a triangular distribution with an apex equal to the NPS (1984) mean number of bike rides per year (54.7), a judgment based on the lower bound of 10 days per year, and a judgment based on the upper bound of 156 days per year (3 days per week).

Other Recreational Activities

No data were available to characterize the frequency of individual use of RMA for other recreational activities (e.g., hiking, cross country skiing, frisbee, and informal team sports). The number of activity days for activities other than jogging, walking for exercise, and biking was assigned a judgment distribution based on the following simple assumptions.

The number of activity days was assumed to vary between 5 days/year and 52 days/year (1 day/week), depending on the individual and the activity. A triangular distribution with this

range and a mode (most common value) of 26 days per year was assigned to represent activity days/year.

Step 3. Multiply the Number of Activity Days by the Distribution for Fraction of Activity Days Spent at RMA

The fraction of activity days spent at RMA was assumed to vary uniformly with a range of 0.5 to 1.0. The exposure frequency distributions for jogging or walking, biking, and other recreational activities were estimated by multiplying the step distributions given above for activity days by the uniform distribution for the fraction of activity days spent at RMA. The simulated data was best fit by a lognormal distribution with a mean of 20.91 and a standard deviation of 9.203.

The exposure frequency distribution for the neighborhood recreational visitor was assigned a lognormal distribution with a mean of 63.14 days/year and a standard deviation of 67.02 days/year. The log-transformed values have a mean of 3.768 and a standard deviation of 0.8687. This distribution has the following percentiles:

Probability (DW $\leq$ 327 days/year)	=	0.99
Probability (DW $\leq$ 181 days/year)	=	0.95
Probability (DW $\leq$ 77.8 days/year)	=	0.75
Probability (DW $\leq$ 43.3 days/year)	=	0.50
Probability (DW $\leq$ 24.1 days/year)	=	0.25

B.3.7.2.3 Commercial/Industrial Workers

The probability distribution for exposure frequency (days/year) for the commercial/industrial workers population is a normal distribution with a mean of 236.31 and a standard deviation of 2.777.

Data Compilation

The number of days per year worked by employees was derived by evaluating the data on the duration of vacation time, paid time off (holidays) and unscheduled job absences. Sick leave was not included because of the lack of data on the utilization of sick leave by employees. While

a number of sources exist for this data on a nationwide or industrial basis, only information of geographical relevance and representative of the broad range of industries in the metropolitan Denver area was used. The information provided in each study referred to a combined population of workers from both commercial and industrial organizations as discussed below, so could not be developed for commercial and industrial populations.

Relevant quantitative data on the number of weeks of vacation was found in the Mountain States Employers Council 1990 Colorado Paid Time Off Policies Survey. Only data from 1990 were used since the values have not changed significantly over the years (according to Mountain States Employers Council). It is clear that some employees have very limited vacation time. Most have 2 weeks (Exposure Factors Handbook, EPA 1989a), and still others have "three weeks of vacation clustering around 10 years of service" in Colorado (personal communication with J. Sandberg, July 7, 1991, and January 8, 1992). Therefore, the number of weeks of vacation was estimated to be 1, 2, or 3 with probabilities 0.25, 0.50, and 0.25, respectively.

Data regarding company paid timeoff (holidays) also varied, but not as widely as vacation time. The Mountain States Employers Council reports in the 1990 Colorado Paid Time Off Policies Survey that holiday time and "other paid time off benefits do not change much over time," according to Mountain States Employers Council's Research Director (personal communication with J. Sandberg July 15, 1991). This survey, as well as earlier surveys, supports 8, 9, or 10 days paid time off. To account for the small number of workers who may receive fewer days, a distribution was fit to account for either 1 or 2 weeks of paid time off.

The Bureau of National Affairs (1974-1990) has tracked unscheduled job absence nationally since 1974 and regionally since 1978. These data are collected as a part of the turnover survey discussed in Section B.3.7.3. The data indicate that the probabilities of 0, 1, and 2 weeks of unscheduled job absences are approximately 0.17, 0.74 and 0.09, respectively. Colorado job absence data was tracked by the Department of Labor and Employment from 1971 to 1981 as

a part of its turnover surveys. These data suggest that job absence rates were considerably higher during that time period. To avoid introduction of non-conservative elements that may have only historical note and about which no further explanation is available, these data were not included in the development of the exposure frequency distribution.

Sick time provided as a company benefit is reported in Mountain States Employers Council Colorado Paid Time Off Surveys over a number of years. However, data were not available on the use of sick time by workers. It is recognized that workers occasionally miss work due to illness, but because data are not available, no use of sick time was assumed in the development of this parameter.

The probability distribution for exposure frequency (days/year) worked by a commercial/industrial worker can be determined from the distribution of weeks/year worked. Just as 5 days/week was used in Section B.3.7.1 to transform hr/week to hrs/day, the probability distribution for total weeks worked per year is again transformed using 5 days/week to obtain the distribution of exposure frequency (days/year) for a commercial/industrial worker. Because 5 days/week was assumed for both transformations, the PPLV equations dependent on TM * DW are not affected by the assumption of 5 days/week. However, this assumption does influence the distribution defined for exposure frequency. The assumption of an average work week consisting of 5 days is considered realistic for commercial/industrial workers. It is believed that this assumption allows for an accurate characterization of exposure frequency.

Distribution Development

The number of weeks per year worked by employees was derived by evaluating three component probability distributions, the duration of vacation time, unscheduled job absence time, and company paid time off (holidays), and subtracting these time-off durations from the 52 weeks in a year. To make the combination of holidays, vacation time, and unscheduled absences

mathematically tractable, the distributions for the components were defined for whole weeks rather than for days.

As stated above, the number of weeks of vacation was assumed to be 1, 2, or 3 with probabilities 0.25, 0.50, and 0.25, respectively, based on data on the number of weeks of vacation found in the Mountain States Employers Council survey. The Mountain States Employers Council Survey also reports holiday time. The 1990 survey, as well as earlier surveys, supports 8, 9, or 10 days paid time off. Although the minimum number of days of paid time off for holidays is given as 8 in the Mountain States Employers Council survey, a distribution was fit that conservatively assumed 50 percent of the workers would have only 1 week (5 days) of holiday time off. The distribution also assumed 50 percent of the workers would have 2 weeks (10 days) of holiday time off.

The Bureau of National Affairs, Inc. reports survey data (from 1974 through 1990) on unscheduled job absences, which include absences for jury duty, disciplinary reasons, a death in the family, and excused absences for personal reasons. The Bureau of National Affairs definition of unscheduled job absence excludes scheduled absences for vacation, holiday, or leave and absence for less than 1 full day. Furthermore, only the first 4 days of an absence from a long-term disability are counted. Hence, the Bureau of National Affairs statistics on unscheduled job absences provide only a conservative lower bound on the number of weeks per year that a commercial/industrial worker would be absent from work.

The Bureau of National Affairs defines job absence rates using the following formula:

job absence rate = 100 * (# of worker days lost through job absence during month)/
[(Average # of Employees) * (# of workdays)]

The report provided both regional and national job absence rates. Regional (western) data for the yearly average of the monthly median job absence rates (using the formula above) are as follows:

Year	Average Monthly Median Job Absence Rate
1978	2.7
1979	2.6
1980	2.6
1981	2.3
1982	1.8
1983	1.9
1984	1.7
1985	1.9
1986	1.9
1987	1.8
1988	1.9
1989	1.8

For each year, the probability of an unscheduled absence on a given workday equals the number of unscheduled absences for all workers divided by the number of scheduled workdays in a month for all workers. This probability equals the Bureau of National Affairs job absence divided by 100. The average of the yearly absence averages since 1982 is approximately 1.8. Therefore, the average probability of an unscheduled absence on a given workday is equal to 0.018.

If, as is commonly accepted, 250 scheduled workdays (2 weeks of vacation) are assumed, if a probability of 0.018 of an absence on any given day is considered, and if on any day the outcome (presence or absence) is independent of the outcome of any other days, then the number of unscheduled absences follows a binomial distribution with parameters $n = 250$ and $p = 0.018$, a distribution that implies the following probabilities:

Probability (0 days of unscheduled absence)	=	0.011
Probability (1 day of unscheduled absence)	=	0.049
Probability (2 days of unscheduled absence)	=	0.112
Probability (3 days of unscheduled absence)	=	0.169
Probability (4 days of unscheduled absence)	=	0.191
Probability (5 days of unscheduled absence)	=	0.172
Probability (6 days of unscheduled absence)	=	0.129
Probability (7 days of unscheduled absence)	=	0.082
Probability (8 days of unscheduled absence)	=	0.046
Probability (9 days of unscheduled absence)	=	0.023
Probability (10 days of unscheduled absence)	=	0.010
Probability (11 days of unscheduled absence)	=	0.004
Probability (12 days of unscheduled absence)	=	0.002

Considering a 5-day work week, 0–2 days corresponds to 0 weeks, 3–7 days corresponds to 1 week, and 8–12 days corresponds to 2 weeks. By summing the probabilities for the days corresponding to 0, 1, and 2 weeks of unscheduled absence, the following probability distribution was obtained:

Unscheduled Absence Probability	Distribution
Probability (0 weeks of unscheduled absences)	0.17[1]
Probability (1 week of unscheduled absences)	0.74[2]
Probability (2 weeks of unscheduled absences)	0.09[3]

[1] 0.011 + 0.049 + 0.112
[2] 0.169 + 0.191 + 0.172 + 0.129 + 0.082
[3] 0.046 + 0.023 + 0.010 + 0.004 + 0.002

The probability distribution of the number of weeks worked was determined by explicitly evaluating the probability of each of the 18 possible combinations of the three vacation

possibilities, the two holiday-week possibilities, and three job-absence probabilities. These calculations are as follows:

Vacation Weeks		Holiday Weeks		Unscheduled Absence Weeks		Product of 3 Total Probabilities	
Weeks	Prob.	Weeks	Prob.	Weeks	Prob.	Weeks	Prob.
1	0.25	1	0.50	0	0.17	2	0.02125
1	0.25	1	0.50	1	0.74	3	0.09250
1	0.25	1	0.50	2	0.09	4	0.01125
1	0.25	2	0.50	0	0.17	3	0.02125
1	0.25	2	0.50	1	0.74	4	0.09250
1	0.25	2	0.50	2	0.09	5	0.01125
2	0.50	1	0.50	0	0.17	3	0.04250
2	0.50	1	0.50	1	0.74	4	0.18500
2	0.50	1	0.50	2	0.09	5	0.02250
2	0.50	2	0.50	0	0.17	4	0.04250
2	0.50	2	0.50	1	0.74	5	0.18500
2	0.50	2	0.50	2	0.09	6	0.02250
3	0.25	1	0.50	0	0.17	4	0.02125
3	0.25	1	0.50	1	0.74	5	0.09250
3	0.25	1	0.50	2	0.09	6	0.01125
3	0.25	2	0.50	0	0.17	5	0.02125
3	0.25	2	0.50	1	0.74	6	0.09250
3	0.25	2	0.50	2	0.09	7	0.01125

For example, 0.02125=0.25*0.50*0.17 is the probability of the combination of 1 week of vacation, 1 week of holidays, and zero weeks of unscheduled job absences. The number of digits shown reflects only the actual arithmetic, and not the underlying precision of the numbers, which is much less.

Adding the probabilities of combinations of events leading to the same number of weeks not worked and subtracting the number of weeks not worked from 52 weeks implies the following

probability distribution on the number of weeks worked by a commercial/industrial worker in 1 year:

Weeks Not Worked	Weeks Worked	Probability
2	50	0.02125
3	49	0.15625
4	48	0.35250
5	47	0.33250
6	46	0.12625
7	45	0.01125

The probabilities of the number of weeks of vacation and holidays were roughly estimated, and only some of the unscheduled job absences were accounted for. Therefore, the resulting distribution of the total number of weeks worked per year is expected to be generally conservative, and reflects the commonly held knowledge that the number of weeks worked per year does vary from worker to worker and from year to year for the same worker.

The probability distribution for exposure frequency (days/year) by a commercial/industrial worker was determined from the distribution given above for weeks/year by multiplying weeks/year by 5 days/week. The factor of 5 days/week is canceled out when the distributions for exposure time and exposure frequency are multiplied together, and so does not change the PPLV outcome. The resulting probability distribution for exposure frequency (days/year) implies:

Probability (DW = 250 days/year) = 0.02125
Probability (DW = 245 days/year) = 0.15625
Probability (DW = 240 days/year) = 0.35250
Probability (DW = 235 days/year) = 0.33250
Probability (DW = 230 days/year) = 0.12625
Probability (DW = 225 days/year) = 0.01125

and

Probability (DW ≤ 250 days/year) = 1.00000
Probability (DW ≤ 245 days/year) = 0.97875
Probability (DW ≤ 240 days/year) = 0.82250
Probability (DW ≤ 235 days/year) = 0.47000
Probability (DW ≤ 230 days/year) = 0.13750
Probability (DW ≤ 225 days/year) = 0.01125

The normal and lognormal distributions were fit to these percentiles. The best-fitting distribution for exposure frequency (days/year) is a normal distribution with a mean of 236.61 and a standard deviation of 2.777. The fit is described as follows:

Percentage	Estimated Distribution (days/year)	Normal Distribution (days/year)
100.0	250.0	257.14
97.875	245.0	241.94
82.25	240.0	238.88
47.00	235.0	236.10
13.75	230.0	233.28
1.125	225.0	229.97
0.0	220.0	215.48

The normal distribution has the following percentiles:

Probability (DW ≤ 244.87 days/year) = 0.999
Probability (DW ≤ 244.09 days/year) = 0.9975
Probability (DW ≤ 243.45 days/year) = 0.995
Probability (DW ≤ 242.75 days/year) = 0.99
Probability (DW ≤ 241.74 days/year) = 0.975
Probability (DW ≤ 240.87 days/year) = 0.95

Probability (DW ≤ 240.30 days/year) = 0.925
Probability (DW ≤ 239.86 days/year) = 0.90
Probability (DW ≤ 238.64 days/year) = 0.80
Probability (DW ≤ 238.18 days/year) = 0.75
Probability (DW ≤ 237.76 days/year) = 0.70
Probability (DW ≤ 237.01 days/year) = 0.60
Probability (DW ≤ 236.31 days/year) = 0.50
Probability (DW ≤ 235.61 days/year) = 0.40
Probability (DW ≤ 234.86 days/year) = 0.30
Probability (DW ≤ 234.44 days/year) = 0.25
Probability (DW ≤ 233.98 days/year) = 0.20
Probability (DW ≤ 232.76 days/year) = 0.10
Probability (DW ≤ 232.32 days/year) = 0.075
Probability (DW ≤ 231.75 days/year) = 0.05

B.3.7.2.4 Biological Workers

The annual exposure frequency for the biological worker fits a normal distribution with a mean of 225 days per year and a standard deviation of 10.23. The data compilation and distribution development for this subpopulation are described below.

Data Compilation

Refuge workers were requested to provide time/activity/soil interval breakdowns. Their answers were recorded and accepted in whatever manner they were given as long as their answers could be used in conjunction with other available data to calculate their total number of hrs on the refuge per year. For example, a respondent might have indicated annual attendance at off-refuge training classes for 2 weeks. Because length of service in the U.S. Fish and Wildlife Service was known, the respondent's number of vacation days and holidays were known. In this example, the total hours per year on the refuge would be calculated as follows:

$$TM \times DW = [(260 \text{ weekdays/year}) - (\text{number of vacation days and holidays}) - (10 \text{ weekdays at classes})] \times [8 \text{ hrs/day}] \quad (4)$$

where the total number of hours on the refuge is denoted by TM × DW, with TM denoting the number of hours spent at the refuge per day and DW denoting the number of days spent at the refuge per year. The total number of hours per year on the refuge excludes only vacation days, holidays, and the "time spent off-refuge in the conduct of job."

For the purposes of time-dependent exposure parameter development, TM was fixed at 8 hours per day (as described in Section B.3.7.2), and DW is defined as the number of 8-hour days spent at the refuge during a year. Hence, DW is calculated as follows:

$$DW = [TM \times DW\ (hr/year)] / [8\ (hrs/day)] \quad (5)$$

Table B.3-4 indicates the duration data on each of the 33 refuge workers interviewed. Included in this table are the survey data on hours per year (i.e., TM × DW) for each of the respondents. Table 3 in Attachment B.3-4 indicates the frequency distribution of DW values (i.e., "Hrs/Yr"/8) among the 33 respondents. Data for the 20 most exposed members constituting the biological worker subpopulation are used to develop this distribution. Based on the weighted least squares criteria, the best-fitting normal, lognormal, or Weibull distribution of these data for the 20 most-exposed members was the normal distribution with a mean of 225 days and a standard deviation of 10.23.

B.3.7.3 Exposure Duration (Probabilistic)

TE is the number of years that an individual is expected to be exposed to the contamination at RMA. The exposure duration distributions for the potentially exposed populations are described below.

B.3.7.3.1 Regulated/Casual Visitor and Recreational Visitor: Neighborhood Subpopulations

The probability distribution for the number of years of residence is used to characterize the probability distribution for the number of years in which RMA is visited for regulated/casual and recreational purposes. The lognormal distribution for visitor exposure duration has a mean of 10.07 years/lifetime and a standard deviation of 15.65. The ln(TE) has a mean of 1.696 and a standard deviation of 1.108. The 95th percentile of this probability distribution is 34 years, which exceeds the 30-year default RME value suggested by EPA (1991a). The data compilation and distribution development are described below.

Data Compilation

Ideally, the probability distribution for exposure duration would be determined from data on the number of years in which particular visitors return to RMA. The 1988 Visitor Survey found that most visitation to Denver metropolitan-area parks was made by Denver metropolitan-area residents (Colorado DPOR 1989). If it is assumed that the number of years in which an area resident visits RMA does not exceed the number of years he or she is a resident in the area, the number of years of residence in the Denver metropolitan area should provide an upper bound on the exposure duration (i.e., the number of years in which there are RMA visits).

US WEST Communications was contacted for residential mobility information that the company tracks via telephone records. Three categories of data are maintained on a monthly basis by US WEST, i.e., number of new connects, number of moves within the same service area, and number of disconnects. However, none of this data is correlated, i.e., the length of time a household may have telephone service (taken to be the length of residence at a given location) is not deducible. For example, in the Commerce City zip code, there are approximately 100 transactions per month in the categories defined above. However, it is not known how frequently an individual household changes addresses.

Other potential sources of data were suggested by Mr. Pavicic. These sources included MCI, Sprint, and the Public Service Company. MCI and Sprint have only partial area market saturation in Adams County, and do not track data of use in a residential mobility distribution.

However, the Public Service Company of Colorado (PSCo) was able to provide highly relevant data for the determination of exposure duration. PSCo, the primary utility provider in the Denver metropolitan area, provides electricity and natural gas to 80 percent of the residences in Colorado, and to virtually all of Adams County, the balance being provided by rural cooperatives or self-sufficient families (residences who do not use utilities), etc. The company conducts a comprehensive biannual survey of its customers entitled Residential Energy Use Survey (PSCo 1989).

The PSCo survey is sent to "every nth account" in the customer base (964,482 households in 1989) for the purpose of predicting energy demand in the future, characterizing the customer base, and gathering other information. In survey years 1985, 1987, and 1989, the question "How long have you lived at this address?" was asked. The mean and median values reported by the respondents were as follows:

Year	Mean Value	Median Value
1985	8.4 years	3.7 years
1987	9.6 years	4.3 years
1989	9.7 years	4.5 years

In addition, probability distributions ranging from less than 1 to greater than 50 years are provided for these 3 survey years. It is possible that the small increase seen in 6 years of data reveals a trend of decreasing mobility (this may be also due to random variability). Therefore, to avoid the introduction of a potential bias due to higher rates of mobility in 1985 and 1987, only 1989 data were used in developing the probability distribution for exposure duration. In

1989, 5,380 surveys were sent and 2,998 were returned, which results in response rate of 55.7 percent. The PSCo considers this response rate to be exceptionally high.

A positive-response bias was introduced by the fact that the "more stable, higher income population" responded at a greater rate (and is therefore overrepresented) than did the "more transient, lower income population." This was determined in a subsequent PSCo analysis that correlates residence consumption history with the rate of response (personal communication with Ron Fish, August 23, 1991).

PSCo residence-duration data was used as an estimate of the probability distribution for exposure duration. The estimate represents several unavoidable biases. However, as discussed below, the positive (conservative) biases are expected to compensate for the negative biases.

PSCo data represent years of residence at one address only, and so give a slightly negatively biased estimate of the years of residence in the Denver metropolitan area. The negative bias arises because there is some probability that a regulated/casual visitor to RMA would move from one address to another address within the Denver metropolitan area. In addition, a negative bias results because PSCo data are censored, i.e., residence duration is always as long or longer than that reported because the occupants do not move at the time of the survey. These biases imply that the distribution of years of residence in the Denver metropolitan area is negatively biased. However, as discussed below, this bias does not imply that exposure duration values are underestimated.

The use of years of residence to represent the exposure duration distribution introduces several positive biases, which are expected to at least compensate for the negative biases just discussed. First, the years of residence is usually an upper bound on the number of years of visitation at a particular state or national park or recreation facility. Second, the large number of opportunities for outdoor pursuits in the Denver metropolitan area increases the probability that individuals

would not visit RMA every year that they reside at a given address. In addition, a move from one address to another address within the Denver metropolitan area could tend to place the potential RMA visitor closer to another outdoor facility, which would lessen the likelihood of visits to RMA. In addition to the Colorado state park system, the U.S. Forest Service, the City and County of Denver, Jefferson County, and Boulder County maintain parks offering picnic sites, campgrounds, and hiking trails within a 30- to 45-minute drive from most residential districts in the Denver metropolitan area (THK 1990). Third, as discussed above, PSCo data over-represent the frequency of "more stable, higher income" individuals. Therefore, the likelihood of medium and high exposure duration values may be overestimated.

Data provided in the Exposure Factors Handbook (EPA 1989a) indicate that the mobility of the residential population in Colorado was among the highest in the nation. These data measured mobility in a manner not directly comparable to RMA, but do not refute the mobility shown in the PSCo data.

Distribution Development

The distribution for exposure duration was estimated by the probability distribution defined by years of residence data reported in the PSCo Residential Energy Use Survey (1989). This survey indicates the following percentages among the survey respondents:

Years at Current Address	Percent of Customers
1	13.3
1	7.2
2-3	17.6
4-5	10.2
6-10	15.3
11-15	11.1
16-20	7.8
21-25	4.6
26-30	3.6
31-40	4.5
41-50	1.0
> 50	0.4

The percentage of survey respondents who responded to the question "How long have you lived at this address?" was 96.6 percent. For example, on the average, 13.3 out of every 96.6 responses (which is 13.8 percent of every 100 responses) indicate that they had lived at their current address for less than 1 year. The probability distribution for the 3.4 percent that did not respond to this question was assumed to be equal to the distribution for the respondents. Therefore, after dividing each of the above percentages by 0.966 to adjust for non-response to this particular question, the percentages reported above for the 96.6 percent of the survey respondents who responded to the question "How long have you lived at this address?" were adjusted as follows:

Years at Current Address	Percent of Customers	Cumulative Percent
<1	13.8	13.8
1	7.4	21.2
2-3	18.2	39.4
4-5	10.6	50.0
6-10	15.8	65.8
11-15	11.5	77.3
16-20	8.1	85.4
21-25	4.8	90.2
26-30	3.7	93.9
31-40	4.7	98.6
41-50	1.0	99.6
>50	0.4	100.0

The residence data probability distribution identifies the following probabilities:

Probability (Years < 1) = 0.138
Probability (Years < 2) = 0.212
Probability (Years < 4) = 0.394
Probability (Years < 6) = 0.500
Probability (Years < 11) = 0.658
Probability (Years < 16) = 0.773
Probability (Years < 21) = 0.854
Probability (Years < 26) = 0.902
Probability (Years < 31) = 0.939
Probability (Years < 41) = 0.986
Probability (Years < 51) = 0.996

These probabilities were fit to the normal and lognormal distributions using the weighted least squares estimation procedure described in Section B.3.7.1 for step (5). The best-fitting distribution is a lognormal distribution. The best-fitting lognormal distribution has a mean of 10.07 and a standard deviation of 15.65. This corresponds to the logarithm of a normal random

variable with a mean of 1.696 and a standard deviation of 1.108. The fit itself can be described as follows:

Percentage	Observed Percentile	Fitted Percentile
99.6	51	102.89
98.6	41	62.17
93.9	31	30.23
90.2	26	22.83
85.4	21	17.52
77.3	16	12.49
65.8	11	8.56
50.0	6	5.45
39.4	4	4.05
21.2	2	2.25
13.8	1	1.63

The probability distribution for exposure duration (years) in which a visitor would visit RMA in a lifetime is set equal to the probability distribution for residence duration. This distribution is expected to provide a potentially conservative estimate of the exposure-duration distribution, as previously discussed. The lognormal distribution for exposure duration has a mean of 10.07 and a standard deviation of 15.65. The ln(TE) has a mean of 1.696 and a standard deviation of 1.108, which is the exposure duration (years/lifetime) distribution for regulated/casual visitors to RMA. The distribution has the following percentiles:

Probability (TE ≤ 71.78 years/lifetime) = 0.99
Probability (TE ≤ 47.83 years/lifetime) = 0.975
Probability (TE ≤ 33.73 years/lifetime) = 0.95
Probability (TE ≤ 26.87 years/lifetime) = 0.925
Probability (TE ≤ 22.56 years/lifetime) = 0.90
Probability (TE ≤ 11.51 years/lifetime) = 0.75
Probability (TE ≤ 5.45 years/lifetime) = 0.50
Probability (TE ≤ 2.58 years/lifetime) = 0.25
Probability (TE ≤ 1.32 years/lifetime) = 0.10
Probability (TE ≤ 1.11 years/lifetime) = 0.075
Probability (TE ≤ 0.88 years/lifetime) = 0.05

Probability (TE ≤ 0.62 years/lifetime) = 0.025
Probability (TE ≤ 0.41 years/lifetime) = 0.01

B.3.7.3.2 Commercial/Industrial Workers

The probability distribution for exposure duration (years/lifetime) for commercial/industrial workers at RMA is a lognormal distribution with a mean of 4.374 years per lifetime and a standard deviation of 6.974. The corresponding probability distribution for ln(TE) is a normal distribution with a mean of 0.8453 and a standard deviation of 1.1246. The data compilation and distribution development for the commercial/industrial workers are described below.

Data Compilation

The probability distribution for exposure duration, the years/lifetime that a commercial/industrial worker would work at RMA, was approximated by the probability distribution for the length of employment of commercial and industrial workers in the Denver metropolitan area. Information on the variability in commercial/industrial worker turnover (employer and occupational) is available from several Colorado and national sources including the Mountain States Employers Council, Inc., the State of Colorado, and the Bureau of Labor Statistics, United States Department of Labor. The relevant quantitative information provided by these sources refers to a combined population of workers from both commercial and industrial groups as discussed below. Therefore, separate probability distributions were not individually developed for these populations. The years/lifetime that a commercial/industrial worker works at a given job for a given employer depends on the individual worker, salary issues, better opportunities, the economy, the worker's family considerations, the job, and a number of economic and other factors affecting the employer.

The probability distribution for exposure duration for the commercial/industrial worker at RMA was calculated from the distribution ages at which one may start working (i.e., the "job-starting ages") and the age-dependent probabilities of leaving a job in the next year and each year

thereafter. However, neither of these types of information was directly available. To derive this information, the following was obtained from the literature: national data regarding tenure at current job (used to obtain the job-starting age), national age-dependent pattern of occupational mobility, and job turnover rates specific to the Denver metropolitan area (the latter two being used to derive the age-dependent probability of leaving a job). The sources for these data are described below.

The job-starting age distribution might have been estimated from past employment records for jobs at RMA. However, most of the data is several years old, and the job types are not considered to be necessarily representative of possible future jobs at RMA. To obtain more timely information on the job-starting age distribution and to include a greater diversity of job types, the data regarding tenure given in the Current Population Survey conducted by the Bureau of Census for the Bureau of Labor Statistics were used. The starting-age distributions for both sexes combined were averaged from two recent tenure tables available from the Bureau of Labor Statistics (Bureau of Census 1981, 1983).

The probability that a current job holder will leave his or her job in the next year is influenced by the age of the jobholder. On the average, older workers are less likely to change occupations than younger workers. In a 1989 article in the Monthly Labor Review, J.P. Markey and Parks report the occupational mobility rates for employed civilians by sex and age in selected years between 1965 and 1987. The occupational mobility rate (also known as the occupational separation rate) is defined by the Bureau of Labor and Statistics as the number of persons employed in a different occupation in the prior year as a proportion of the total employed in both years. The occupational mobility rates underestimate the age-dependent probability of leaving a job because job changes within an occupation are not included. However, the relative pattern of age-dependent occupational mobility was assumed to be similar to the age-dependent pattern for job mobility. This assumption of similarity allowed the age-dependent occupation mobility rates to be converted to job mobility rates by multiplying by a constant.

The derivation of the appropriate constant (2.4) is based on data on job turnover in the Denver metropolitan area between 1983 and 1990 (Mountain States Employers Council 1981–1990). The job turnover rate is defined by Mountain States Employers Council as the total number of separations during a year divided by the average number of employees during the same year. Separations include voluntary and non-voluntary termination of jobs as well as transfers within the same company but to another location. Turnover does not track subsequent employment and is not an index of unemployment.

The derivation of the probability distribution for exposure duration does not account for the relatively low number of workers who might have more than one job at RMA. However, the exposure duration distribution developed in Section B.3.7.2 appears to provide a conservative characterization of job turnover when compared to the average job turnover rates for the manufacturing industry in the Denver metropolitan area (see below). The job duration distribution implies an average annual turnover rate of 25 percent, which is less than values reported by Mountain States Employers Council: 26.3 percent (1990), 28.1 percent (1989), and 27 percent (the average for 1983–90). The average turnover rate implied by the job duration distribution is also much less than the turnover rates reported by the Labor Market Information Unit of the Colorado Division of Employment and Training (1971 through 1980) for the manufacturing industry (both durable and non-durable goods sectors). These rates were tracked by the State of Colorado between 1971 and 1981. As was mentioned in the discussion of job absence, no further information is available from the State of Colorado regarding the collection of this information. It is known that the data reflect a much narrower segment of the economy than do Bureau of Labor and Statistics or Mountain States Employers Council data. Therefore, although these data have not been used quantitatively in the development of the distribution for exposure duration, their magnitude is of qualitative importance. These rates are as follows:

Total Separations	Separations Excluding Layoffs
1971: 61.3%	38.0%
1972: 59.7%	46.9%
1973: 65.9%	54.3%
1974: 59.9%	47.1%
1975: 46.8%	31.1%
1976: 46.5%	33.3%
1977: 45.0%	37.2%
1978: 57.3%	50.5%
1979: 59.2%	54.1%
1980: 44.8%	35.7%
1981: 34.9%	28.0

Mountain States Employers Council also reports the proportion of job durations less than or equal to 5 years among employees separated in a particular year. These proportions provide another indication of the conservatism in the job duration distribution relative to the Denver metropolitan area. The exposure duration distribution's calculated probability of a job duration being less than or equal to 5 years is 0.75, which is less than the observed proportions in 1989 (0.82) and 1990 (0.88). In addition, the exposure duration distribution predicts that 25 percent of the commercial/industrial workers at RMA will work there for more than 5 years, whereas only 18 percent of job durations ending in 1989 lasted more than 5 years, according to Denver metropolitan-area observations. In 1990, even fewer (12 percent) job durations lasted more than 5 years.

The method for calculating the percentage of terminations for jobs lasting less than 5 years for 1989 in the Denver metropolitan area is described in detail in order to illustrate how these observed proportions were determined. The calculation starts with the data provided by the

Mountain States Employers Council. These data were reported as turnover rates for all employees, subcategorized as exempt and non-exempt employees, as follows:

Category	1989 Turnover Rate
All Employees	28.1
Exempt Employees	17.5
Non-Exempt Employees	31.7

and

Category	Percent Job Durations ≤ 5 years
Employee-Initiated Terminations	
Exempt Employees	70
Non-Exempt Employees	86
Employer-Initiated Terminations	
Exempt Employees	63
Non-Exempt Employees	86

The turnover rate data imply that the proportion of employees that were exempt and non-exempt (as defined by eligibility for overtime pay) were approximately 25 percent and 75 percent, respectively (25%*17.5% + 75%*31.7% = 28.1%). It has also been reported by Markey and Parks (1989) that about seven out of eight persons who change occupations do so voluntarily, i.e., approximately 87.5 percent of the above terminations were expected to be employee-initiated terminations. The overall percentage of terminations with job durations not exceeding 5 years is calculated as follows:

$$0.875*[\ 0.25*70\% + 0.75*86\%\ ] + 0.125*[\ 0.25*63\% + 0.75*86\%\ ] = 82\%. \qquad (6)$$

Therefore, as indicated above, 18 percent of jobs ending in 1989 had lasted more than 5 years.

The job duration probability distribution (adjusted to reflect the Denver metropolitan area) is used to approximate the probability distribution of exposure duration, the years/lifetime that a commercial/industrial worker would work at RMA.

Distribution Development

The probability distribution for the number of years that a commercial/industrial worker at RMA would be on a job was calculated from the probability distribution on the age at which the worker starts that job and the age-dependent probability that the worker leaves that job in each year thereafter. The job-starting age distribution is based on the 1981 and 1983 job tenure data. The age-dependent probabilities of leaving a job were based on national age-dependent probabilities of leaving an occupation, adjusted to reflect the 1983 to 1990 Denver metropolitan-area job turnover statistics. These components are developed below.

The probability distribution of the commercial/industrial worker's age at the time a job is started can be estimated from tables prepared by the Bureau of Census for the Bureau of Labor Statistics (1981, 1983). These tables show the probability distribution of age and tenure on the current job. Such tables were available for 1981 and 1983 and are reproduced in Attachment B.3-6 along with the mathematical derivation of the job-starting age distribution. The job-starting age distribution was obtained from each table separately and then the results averaged. The specific results are produced as tables in Attachment B.3-6.

The distribution among current job holders of the age at which they started their current jobs indicates the probability distributions for the starting age for workers taking such jobs. This distribution was assumed to describe the relative frequencies of starting ages for jobs at RMA in a future commercial/industrial land-use scenario. Of course, workers may take several jobs during their lifetime and their first job may or may not be at RMA. Hence, the distribution of starting ages for RMA jobs was not assumed to be the same as the distribution of starting ages for an individual's first job.

The age-dependent probabilities of leaving an occupation were derived from the data on age-dependent occupational mobility as described below. The number of persons employed in a different occupation in 1987 than in 1986 as a proportion of the total employed in both 1986 and 1987 (men and women combined) were reported in the Monthly Labor Review by the Bureau of the Census as follows:

Ages 16 to 19 years:	0.2905
Ages 20 to 24 years:	0.2160
Ages 25 to 34 years:	0.1160
Ages 35 to 44 years:	0.0775
Ages 45 to 54 years:	0.0480
Ages 55 to 64 years:	0.0295
Ages 65 years and older:	0.0115

These proportions provide information on the relative magnitude of age effects. However, the proportions will likely underestimate the absolute magnitudes of the age-dependent probability of leaving a job because job changes within an occupation were not included and because they do not include persons who left a job in 1986 but were not employed in 1987. For example, if out of 100 workers on jobs in 1986, 50 of them leave in 1986, and 25 of these 50 workers take new jobs in 1987, then the above turnover rate is calculated to be 25/75, whereas 50/100 actually left their jobs in 1986. To adjust the absolute magnitudes of these proportions and to account for the differences between national and Denver metropolitan-area probabilities, these proportions were multiplied by the constant 2.4. As discussed below, this constant was derived from job turnover data in the Denver metropolitan area between 1983 and 1990.

For a given job-starting age distribution and a given set of age-dependent probabilities of leaving a job, the probability distribution of the duration (years/lifetime) of a job for a commercial/industrial worker was calculated as follows:

PLJ_i = probability of a worker leaving a job during a year when the worker is age i years

and

PSA_i = probability that the age of the worker starting a job is i years (7)

The probability that a worker starts a job at age i and leaves this job k years later is

$$PSA_i * [(1-PLJ_i) * (1-PLJ_{i+1}) *...* (1-PLJ_{i+k-1}) * PLJ_{i+k}] \quad (8)$$

which is simply the probability of starting a job at age i multiplied by the product of the probabilities of not leaving the job in first k years after starting the job at age i and multiplied by the probability of leaving the job in the (k+1)th year.

The probability P(k) that a worker's total duration in a job is k years is simply the sum of the above probabilities over all possible starting ages (i = 5, 6, ..., 69, assuming mandatory retirement at age 70 years):

$$P(k) = \sum_{i=5,6,...,69} PSA_i * [(1-PLJ_i) * (1-PLJ_{i+1}) * ... (1-PLJ_{i+k-1}) * (PLJ_{i+k})$$

This equation defines the probability distribution for exposure duration (years of work at the RMA per lifetime) as estimated by job duration P(k).

However, the age-dependent probabilities of leaving a job after i years (PLJ_i) are not available directly from the data. They were assumed to follow the same relative pattern as age-dependent probabilities of leaving an occupation (PLO_i), and so are equal to some constant times the age-dependent probabilities of leaving an occupation. In the above equation, $PLO_i * C$ was substituted for PLJ_i and the corresponding mean of this distribution was derived with C as an unknown.

The reciprocal of the mean job duration is the job turnover rate. For example, if the mean job duration is 5 years, then the average employee experiences one job change (separation) every 5 years, so the probability of a separation in a given year is 1/5th. If a single worker experiences one separation out of every 5 years, then five workers will experience a total of one separation in a year, and 100 workers will experience a total of 20 separations in a year, etc., implying that the job turnover rate defined by Mountain States Employers Council (1989) is 1/5, i.e., one separation per five workers per year.

The reciprocal of the mean job duration was equated to a Denver metropolitan-area job turnover rate based on the following job turnover rates between 1983 and 1990 (MSEC 1989):

Year	Turnover Rate
1990:	26.3%
1989:	28.1%
1988:	24.1%
1987:	23.3%
1986:	26.1%
1985:	27.4%
1984:	31.4%
1983:	27.9%
Average:	26.825%

To assess whether prevailing economic conditions over the 1983 to 1990 time period may have influenced turnover, several economists were contacted. According to Richard Wobbekind, Director of the Research Division of the School of Business, Colorado University, economic conditions in the State of Colorado from 1982 to 1991 covered a broad spectrum of "boom and bust" (growth and recession) cycles. He described each year as follows:

Year	Economic Condition	Mountain States Employers Council Average Turnover
1982	Boom	Not given
1983	Boom	27.9 %
1984	Transition: stability→bust	31.4 %
1985	Bust	27.4 %
1986	Bust	26.1 %
1987	Transition: bust→stability	23.3 %
1988	Boom	24.1 %
1989	Boom	28.1 %
1990	Boom	26.3 %
1991	Boom	Not yet available

Boom or bust determinations are based on several economic indices, such as employment by industry sector and revenues, as provided in the annual Colorado University School of Business research publication, Business Economic Outlook. Dr. Wobbekind stated that the years 1988 to 1991 are being used to predict economic growth rate for 1992 through the year 2000 (personal communication, R. Wobbekind, January 7, 1992). He reports that a 2 percent annual growth rate in the Colorado economy is predicted.

Turnover data used in development of the probability distribution for exposure duration were compiled by the Mountain States Employers Council (1981-1990). This association of public and private employers provides member services to 1,400 employer entities representing a broad industry spectrum including manufacturing, oil and gas, financial services, health care, transportation, utilities, communications, government, insurance, retail/wholesale, and mining. Member companies providing survey data are located throughout Colorado, but the majority are

from the Denver metropolitan area. Data used in the development of exposure duration include average annual percent turnover for the years 1983 to 1990. Data from each year were equally weighted in the development of exposure duration.

The components of turnover rates are terminations initiated by employees and terminations initiated by employers. According to economists, in a boom economy, employee-initiated terminations tend to increase as more favorable opportunities become available; employer-initiated terminations tend to decrease. In a bust economy, employees tend to be less occupationally mobile and employer-initiated terminations tend to increase (personal communication with F. Ruppel et al. 1992; R. Wobbekind 1992; J. Sandberg 1992). These factors, therefore, buffer one another in the occurrence of turnover during growth or recession economic conditions.

It can be seen from the Mountain States Employers Council data given above that turnover in boom years would not be very different from turnover in bust years. On the other hand, unemployment would be expected to vary with prevailing economic conditions, although it would not be synonymous with turnover.

The national age-dependent probabilities of an occupational change in a year imply a national occupational turnover rate of slightly more than 10 percent. If these age-dependent probabilities are multiplied by 2.4, then the turnover rate is 25 percent, which is close to the average Denver metropolitan area job turnover rate (26.825 percent) between 1983 and 1990, but still somewhat conservative. Thus, multiplying the national age-dependent probabilities of an occupational change by 2.4 effectively transforms them to probabilities of "Denver metropolitan area job changes instead of "national occupational" job changes. The constant multiplier allows the data on age dependence to be combined with local job turnover data.

After an appropriate value for C (2.4) was determined, this value was inserted into the probability distribution formula for exposure duration:

$$P(k) = \sum_{i=5,6,\ldots,69} PSA_i * [(1-PLO_{iC}) * (1-PLO_{i+1}C) * \ldots (1-PLO_{i+k-1}C) * (PLO_{i+k}C) \qquad (9)$$

These calculated values give the probability that the job duration is k years for k = 0, 1, 2.... The probability that the job duration is ≤ k years is the sum

$$P(0) + P(1) + P(2) + \ldots + P(k).$$

These calculated cumulative probabilities represent the following job duration probabilities:

Probability (Job Duration ≤ 45 years) = 1.0000
Probability (Job Duration ≤ 44 years) = 0.9999
Probability (Job Duration ≤ 43 years) = 0.9999
Probability (Job Duration ≤ 42 years) = 0.9998
Probability (Job Duration ≤ 41 years) = 0.9997
Probability (Job Duration ≤ 40 years) = 0.9996
Probability (Job Duration ≤ 39 years) = 0.9995
Probability (Job Duration ≤ 38 years) = 0.9993
Probability (Job Duration ≤ 37 years) = 0.9991
Probability (Job Duration ≤ 36 years) = 0.9987
Probability (Job Duration ≤ 35 years) = 0.9983
Probability (Job Duration ≤ 34 years) = 0.9978
Probability (Job Duration ≤ 33 years) = 0.9972
Probability (Job Duration ≤ 32 years) = 0.9965
Probability (Job Duration ≤ 31 years) = 0.9957
Probability (Job Duration ≤ 30 years) = 0.9947
Probability (Job Duration ≤ 29 years) = 0.9936
Probability (Job Duration ≤ 28 years) = 0.9922
Probability (Job Duration ≤ 27 years) = 0.9905
Probability (Job Duration ≤ 26 years) = 0.9886
Probability (Job Duration ≤ 25 years) = 0.9863
Probability (Job Duration ≤ 24 years) = 0.9838
Probability (Job Duration ≤ 23 years) = 0.9811

Probability (Job Duration ≤ 22 years) = 0.9780
Probability (Job Duration ≤ 21 years) = 0.9744
Probability (Job Duration ≤ 20 years) = 0.9705
Probability (Job Duration ≤ 19 years) = 0.9662
Probability (Job Duration ≤ 18 years) = 0.9613
Probability (Job Duration ≤ 17 years) = 0.9557
Probability (Job Duration ≤ 16 years) = 0.9494
Probability (Job Duration ≤ 15 years) = 0.9423
Probability (Job Duration ≤ 14 years) = 0.9344
Probability (Job Duration ≤ 13 years) = 0.9254
Probability (Job Duration ≤ 12 years) = 0.9150
Probability (Job Duration ≤ 11 years) = 0.9031
Probability (Job Duration ≤ 10 years) = 0.8891
Probability (Job Duration ≤ 9 years) = 0.8725
Probability (Job Duration ≤ 8 years) = 0.8522
Probability (Job Duration ≤ 7 years) = 0.8270
Probability (Job Duration ≤ 6 years) = 0.7952
Probability (Job Duration ≤ 5 years) = 0.7544
Probability (Job Duration ≤ 4 years) = 0.7007
Probability (Job Duration ≤ 3 years) = 0.6267
Probability (Job Duration ≤ 2 years) = 0.5181
Probability (Job Duration ≤ 1 years) = 0.3407

The normal and lognormal distributions were fit to these cumulative probabilities. The best-fitting distribution for exposure duration (years/lifetime) is a lognormal distribution with a fit described as follows:

Cumulative Probability	Calculated Probability (years/lifetime)	Lognormal Distribution (years/lifetime)
0.9905	27.00	32.50
0.9886	26.00	30.08
0.9863	25.00	27.77
0.9838	24.00	
		25.77
0.9811	23.00	24.03
0.9780	22.00	22.38
0.9744	21.00	20.82
0.9705	20.00	19.43

0.9662	19.00	18.15
0.9613	18.00	16.93
0.9557	17.00	15.77
0.9494	16.00	14.68
0.9423	15.00	
		13.65
0.9344	14.00	12.69
0.9254	13.00	11.77
0.9150	12.00	10.88
0.9031	11.00	10.02
0.8891	10.00	9.18
0.8725	9.00	8.36
0.8522	8.00	7.53
0.8270	7.00	6.71
0.7952	6.00	
		5.87
0.7544	5.00	5.04
0.7007	4.00	
		4.20
0.6267	3.00	3.34
0.5181	2.00	
		2.45
0.3407	1.00	
		1.46
0.0600	0.25	0.40

The probability distribution has the following percentiles:

Probability (TE ≤ 75.08 years) = 0.999
Probability (TE ≤ 54.60 years) = 0.9975
Probability (TE ≤ 42.10 years) = 0.995
Probability (TE ≤ 31.80 years) = 0.99
Probability (TE ≤ 21.06 years) = 0.975
Probability (TE ≤ 14.78 years) = 0.95
Probability (TE ≤ 11.73 years) = 0.925
Probability (TE ≤ 9.82 years) = 0.90
Probability (TE ≤ 5.99 years) = 0.80
Probability (TE ≤ 4.96 years) = 0.75
Probability (TE ≤ 4.19 years) = 0.70
Probability (TE ≤ 3.09 years) = 0.60
Probability (TE ≤ 2.32 years) = 0.50
Probability (TE ≤ 1.75 years) = 0.40

Probability (TE ≤ 1.29 years) = 0.30
Probability (TE ≤ 1.09 years) = 0.25
Probability (TE ≤ 0.90 years) = 0.20
Probability (TE ≤ 0.55 years) = 0.10
Probability (TE ≤ 0.46 years) = 0.075
Probability (TE ≤ 0.37 years) = 0.05

B.3.7.3.3 Biological Worker

The best-fitting distribution of exposure duration was a normal distribution with a mean of 7.18 years and a standard deviation of 7.00 years. The data compilation and distribution development for the biological worker are described below.

Data Compilation

The survey provides data on the duration of a refuge worker's tenure at a particular refuge (TE). Here, TE refers to the number of years a refuge worker spends at one refuge and does not necessarily equal the number of years spent in U.S. Fish and Wildlife Service. The survey data are presented in Table 4 in Attachment B.3-4. These data include the total time spent at a refuge regardless of whether that time was in one or more jobs and regardless of whether the periods of time were consecutive, i.e., observations include all of the time spent at the same refuge. The incomplete tenures represent a worker who is still on the job and therefore will have a completed tenure greater than the current tenure given in Table 4 in Attachment B.3-4. Because the incomplete tenure observations imply values greater than the current tenure, the data set is "censored" and requires a statistical estimation method to accommodate the censored data.

An incomplete tenure is only a lower bound on that worker's tenure at that refuge. For example, if a refuge worker has been at a refuge for 7 years and is still on the job, then the refuge worker's completed tenure will be some number greater than 7 years. The "greater than" symbol (>) associated with the last tenure observation for each worker indicates that observation is an incomplete tenure and that the lifetime tenure at the current refuge will exceed the reported value for years at the current job.

Some of the refuge workers interviewed at the Crab Orchard, Malheur, and Minnesota Valley refuges had held other jobs with the U.S. Fish and Wildlife Service at other refuges. The tenures at these other refuges were assumed to be completed tenures, i.e., it was assumed that these refuge workers will not return to work at their earlier refuges.

Distribution Development

The 33 incomplete tenures are the only tenures known to have occurred on the three selected refuges (the complete tenures occurred on different refuges). However, it is impossible to statistically estimate the TE distribution without some completed tenure observations. The only completed tenures available at the time the TE distribution was being estimated were the 47 completed tenures for the refuge workers who had previously completed tenures at other refuges. The completed tenures are tenures completed at a single refuge and are therefore a sample data set drawn from the pool of all tenures completed at any single refuge in the U.S. Fish and Wildlife Service system. The uncompleted tenures, with some unknown future increment, are also samples drawn from the pool of all completed tenures. The sample set of all 80 tenures combined is not a completely random sample because there are two mitigating factors. The first factor is the special, nonrandom selection of the three refuges. This factor is intentional and beneficial as it increases the relevance of the data to RMA. The second factor is the possible correlation, whether positive or negative, between the tenures reported by a given individual. Any such correlation might introduce some unknown bias into the estimated TE distribution, but this bias and its impact are expected to be small relative to the tendency of the normal distribution (as estimated below) to overestimate the probability of tenures exceeding 2 to 13 years.

The 33 incomplete tenures and 47 completed tenures each provide some information about refuge worker tenure. When the lognormal, normal, and gamma distributions were fit to these 80 observations, the fitting procedure had to reflect the differences between completed and incomplete tenures. The maximum likelihood estimation procedure used to fit these distributions reflects the differences in the information contained in completed and incomplete tenures. The maximum likelihood estimation procedure identifies the parameters in the fitting distribution that

maximize the likelihood of observing the 80 observations that were, in fact, observed. The likelihood function being maximized is a product of 80 likelihood terms. If the observation is a completed tenure, then the likelihood term is the probability density function evaluation at the observed duration.

For example, if TE is the tenure and an observation of a completed tenure is 10 years, then the likelihood term is the probability density function (PDF) evaluated at TE = 10.0. The probability density function then becomes PDF (TE = 10.0). If the observation is an incomplete tenure, then the likelihood term is the probability that the tenure is greater than the observed duration. For example, if an observation of an incomplete tenure is 8 years, then the likelihood term is the probability that TE > 8.0. In this case, the probability takes the form P(TE > 8.0). This probability is equal to 1.0—the cumulative distribution function evaluated at 8.0. The likelihood function being maximized is the product of 33 likelihood terms of the form PDF(TE = t) and 47 likelihood terms of the form P(TE > t).

A subset of the survey data discussed in Appendix B.2 provides information on the duration of the biological worker's tenure at a particular refuge (TE). There are 47 refuge tenure observations associated with the 20 biological workers. There are 27 completed tenures and 20 incomplete tenures in this data set.

When the lognormal, normal, and gamma distributions were fit to these 47 observations using the maximum likelihood estimation described below, the best-fitting distribution was a normal distribution with a mean of 7.18 years and a standard deviation of 7.00 years. To avoid negative values of TE arising from a random sample, this normal distribution was truncated at its 20th percentile. The truncation results in approximately 20 percent of the samples being assigned a value of 1.29 and no values being assigned a value less than 1.29.

Figure B.3-17 provides a graphical comparison between observed and predicted TE values for the biological refuge worker. The predicted values, which do not reflect the subsequent truncation, underpredict for values equal to 1 or greater than 14 and overpredict for values

between 2 and 14. For example, at t = 2, the prediction is that the completed tenure of a refuge worker will exceed 2 years approximately 77.0 percent of the time, whereas the observed data suggests that completed tenures will only exceed 2 years 73.6 percent of the time.

In order to appropriately reflect the information in the incomplete tenure observations, the observed value of the proportion of the data with TE > t is calculated as follows:

Step 1. Let SUM equal the number of completed tenures exceeding t plus the number of incomplete tenures exceeding t.

Step 2. For each incomplete tenure observation not exceeding t, increase the SUM by the predicted conditional probability that the incomplete tenure will last long enough to exceed t. This conditional probability is the likelihood that the completed tenure will exceed t given that the completed tenure exceeds the current duration of the incomplete tenure. For each of the observations described in step (1), 1 was added to SUM because these observations are known to exceed t. In contrast, for each incomplete tenure not exceeding t, the fraction corresponding to the conditional probability is added.

Step 3. The "observed value" is SUM divided by the number of tenure observations (i.e., SUM/80).

The maximum likelihood estimation procedure is a standard procedure for fitting a distribution to data with "greater than" values, constituting right-censored data.

B.3.8 BASEMENT PARAMETERS

The evaluation of enclosed space vapor inhalation by workers in a basement includes several parameters that are specifically related to a basement structure: basement depth, length, width, area, volume, ventilation rate (Qa); time for basement air exchange (TAC); and basement volume to area ratio (VAR). The specific uses of these parameters are described in Appendix Section B.1. With the exception of basement depth, which is fixed, distributions are assigned to all other basement parameters. The development of these parameters is described in this appendix section.

B.3.8.1 Basement Depth (Fixed)

The depth parameter could not be varied (i.e., have a distribution assigned) because the floor of the basement must remain at a depth of 2 meters (m) to be consistent with the criteria for basement site selection (groundwater depth greater than 10 feet) and with the calculation of the depth to contaminated soil intervals at a given site. It is assumed that one-third of the basement height (1 m) is above the ground such that the effective basement depth (D) is 2 m.

B.3.8.2 Basement Length (Probabilistic)

The length of the basement was treated as an independent parameter and assigned a distribution. The length was assumed to vary between 3 and 17 m based on best professional judgment. Since large and small basements were assumed to occur with equal frequency, a uniform distribution was assigned.

B.3.8.3 Basement Width (Probabilistic)

The width of the basement was treated as an independent parameter and assigned a distribution. The range of possible widths was determined based on best professional judgment and assumed to vary between 3 and 14 m. Since small and large basements were assumed to occur with equal frequency, a uniform distribution was assigned.

B.3.8.4 Basement Area (Probabilistic)

The effective area of a basement is the sum of the basement surfaces exposed to soil. These surfaces include the floor and the four walls up to a height of 2 m. Basement area is calculated from the distributions for basement length (L), basement width (W), and the effective basement depth of 2 m as follows:

$$\text{Area} = \underset{\text{floor}}{(L*W)} + \underset{\text{sides}}{2[(D*L) + (D*W)]} \quad (1)$$

B.3.8.5 Basement Volume (Probabilistic)

The volume of the basement is the total volume contained within the floor, walls, and ceiling. It was calculated from the distributions of basement length and width and the total basement depth of 3 m.

B.3.8.6 Basement Ventilation Flow Rate (Probabilistic)

The ventilation rate is the air flow rate in cubic centimeters per second (cm^3/s) out of the basement. The data for Qa were obtained from the Commerce City and Denver 1988 Uniform Building Codes Handbook. Ventilation codes for "assembly buildings" (buildings holding 50 or more people in a room) and industrial buildings are expressed in terms of air flow rates per occupant. Therefore, depending upon the number of people using the basement and the size of the basement, the ventilation rate may vary considerably. Since Qa rate is expressed in units of volume per time, the ventilation code for "business buildings" (6 air exchanges per hour, or 1 every 10 minutes) was selected as an average value for an average basement.

The building code specifies a lower Qa rate for smaller basements than for large basements. However, in order to treat the Qa rate as an independent parameter, it was not correlated with basement size. The ventilation parameter was developed by assuming that the smallest and the largest basements could achieve 6 air exchanges per hour. The smallest reasonable basement volume is 27 cubic meters (m^3) and the largest is 714 m^3. Therefore, the range in Qa was

determined by dividing the volume of a small basement (27 m^3) by 10 minutes (or 600 seconds) to get 45,000 cm^3/s, and the volume of a large basement (714 m^3) by 10 minutes to get 1,190,000 cm^3/s.

Because Qa is expected to vary between 45,000 and 1,190,000 cm^3/s, the distribution shape of this parameter is expected to be approximately triangular with a high frequency of mid-range values and a low frequency of values at the extremes. Therefore, a symmetrical triangular distribution was assumed. The minimum, maximum, and apex for this triangular distribution are 45,000, 1,190,000, and 617,500, respectively, where the apex is calculated as follows: (45,000 + 1,190,000)/2 = 617,500.

B.3.8.7 Time for Basement Air Exchange (Probabilistic)

The TAC for a basement is expressed as the number of days it takes for a single air exchange to occur. The time required to exchange the air in a basement is a function of the ventilation flow rate and the volume of the basement. Since the basement volume is a function of length and width, TAC is a function of three independent parameters: Qa, W, and L. The following equation was used to convert the units of Qa, L, and W to those of TAC.

$$\text{TAC (days/air change)} = \frac{D * L * W * 10^6}{Qa * 86{,}400} \quad (2)$$

TAC is, therefore, determined by the dimensions of the basement. Because of the dependencies among some of the basement parameters, they cannot be assigned independent distributions. By assigning distributions to the length, width, and ventilation flow rate, and then calculating TAC within the model code, these parameters will vary according to their joint probability distribution.

B.3.8.8 Basement Volume to Air Ratio (Probabilistic)

The VAR of a basement is determined by the dimensions of the basement. As with TAC, VAR is calculated directly from length, width, and ventilation flow rate. Because of the dependencies among some of the basement parameters, they cannot be assigned independent distributions. By

assigning distributions to L, W, and Qa, and then calculating VAR within the model code, these parameters will vary according to their joint probability distribution.

B.3.9 CHEMICAL-SPECIFIC PARAMETERS

Chemical-specific parameters are those parameters in the PPLV equations that vary according to the specific COC. Seven chemical-specific parameters are used in the PPLV equations to estimate vapor flux from COCs in subsurface soil chemicals for the open and enclosed space vapor models which are described in Appendix Section B.1. Of these parameters, two are fixed variables for each chemical, while the other five parameters are probabilistic. The seven chemical-specific parameters used in this analysis are as follows:

- Molecular weight—fixed
- Molecular diffusivity—fixed
- Fraction organic carbon in soils—probabilistic
- Fraction organic carbon in sediment—probabilistic
- Henry's Law constant—probabilistic
- Vapor pressure—probabilistic
- Soil water partition coefficient—probabilistic

Each of these parameters is described below.

B.3.9.1 Molecular Weight (Fixed)

Table B.3-32 lists molecular weights, which are fixed values, for the 27 COCs. Although molecular weights are listed for inorganic chemicals and the acetic acid compounds, these chemicals do not volatilize readily. Therefore, for the purposes of the vapor flux estimation, the molecular weight of these chemicals is considered to be zero.

B.3.9.2 Molecular Diffusivity (Fixed)

The molecular diffusivity values used in this analysis are summarized in Table B.3-33. Molecular diffusivity (Di) represents the chemical-specific diffusivity in air and is measured in cm^2/s.

While several diffusivity values were obtained from EPA (1988), no other values were identified in the general literature. Therefore, molecular diffusivity values for a number of COCs were calculated using Fuller's method (Perry and Chilton 1973) as shown in equation (1).

$$D_i = \frac{0.001T^{1.75}\left(\frac{1}{MW_i} + \frac{1}{MW_a}\right)^{1/2}}{P_{atm}\left[(\Sigma V_i)^{1/3} + (\Sigma V_a)^{1/3}\right]^2} \qquad (1)$$

where: D_i = Diffusivity of contaminant i in air (cm^2/s)

T = Temperature (degrees Kelvin [°K]; assumed to be 10 degrees Celsius [°C] (283 degrees K) in this evaluation)

MW_i = Molecular weight of contaminant i (grams per mole)

M_{Wa} = Molecular weight of air (grams per mole)

P_{atm} = Atmospheric pressure (atmosphere [atm])

ΣV_i = Molecular diffusion volumes of contaminant computed as the sum of the atomic diffusion volumes (square centimeters per mole [cm^2/mole]) minus 20.2 for each aromatic or heterocyclic ring. The diffusion volumes of the atoms as reported in EPA (1988) are as follows:

Carbo	= 16.5
Hydrogen	= 1.98
Oxygen	= 5.48
Nitrogen	= 5.69
Chlorine	= 19.5
Bromine	= 35.0
Fluorine	= 25.0
Sulfur	= 17.0

ΣVa = Molecular diffusion volumes of air computed as the sum of the atomic diffusion volumes (cubic centimeters per mole [cm^3/mole])

B.3.9.3 Fraction Organic Carbon in RMA Sediments (Probabilistic)

The F_{oc} of aquatic sediments is typically much higher than that found in terrestrial soils due to the sink effect of the lakes as well as the less oxygenated environment of the RMA lake sediments. Therefore, the percent of organic carbon of aquatic sediments and terrestrial soils have been determined separately. The F_{oc} distributions for RMA soils is described in Section B.3.9.4.

Sediment F_{oc} data collected at Ladora and Lower Derby lakes at RMA were used to develop an RMA-wide sediment F_{oc} distribution. Distributions were developed for each lake separately and for a third hypothetical lake representing intermediate F_{oc} conditions, which was used to characterize Upper Derby and Eastern Upper Derby lakes. The RMA-wide distribution was simulated as a combination of the F^{oc} distributions from the three lake types and in proportion to their contribution to the overall lake surface area at RMA. This combined distribution, shown in Figure B.3-18, is lognormal with a mean of 0.1205, standard deviation of 0.06612, log mean of -2.247, and log standard deviation of 0.5129. The sediment F_{oc} data compilation and the development of this distribution are described below.

B.3.9.3.1 Data Compilation

Data used to develop the sediment F_{oc} distribution are shown in Table B.3-34. These data include five samples from Lake Ladora and five samples from Lower Derby Lake. The samples were collected with an Eckman dredge during the September 1989 RIFS 6 aquatics investigation (EBASCO 1990b). The Eckman dredge can collect sediments deposited to a depth of 3 to 6 inches, avoiding underlying materials uncharacteristic of "pure" sediments. Although other sediment F_{oc} data were obtained from the earlier remedial investigation (RI), they were collected using a less accurate method, thus yielding divergent analytical results. Therefore, the percent organic carbon data for RMA lake sediments has been characterized based on the sediment samples collected during the RIFS 6 aquatic investigation.

B.3.9.3.2 Distribution Development

The classification of distribution family for sediment F_{oc} followed the general methods presented in Appendix B.3. The distribution was fit using a software program called STATGRAPHICS, from STSC, Inc. Because of the limited F_{oc} data available, a Kolmogorov-Smirnov goodness-of-fit test is not powerful enough to differentiate between fits to several varied distribution types. The shape of the distribution was instead based on both the data (e.g., skewness and outliers) and on simple, objective assumptions about the process underlying the data. No data points for the sediment F_{oc} parameter were considered to be possible outliers, so this statistical evaluation criteria was not required.

The single RMA-wide distribution of F_{oc} in sediments is a mixture of the subdistributions characteristic of each lake represented in proportion to the relative likelihood of their occurrence (Table B.3-35). In this case, the subdistributions are represented in proportion to total lake area contributed by each lake. The lakes were assumed to have relatively similar F_{oc} distributions. For example, because data were only available for Ladora and Lower Derby lakes, the smaller lakes grouped with Ladora and Lower Derby were assumed to have an F_{oc} distribution equal to that of Ladora and Lower Derby, respectively. Other smaller lakes in the region were not included in the analysis because of their small contributions to the total surface area of RMA lakes.

Distributions were estimated for Ladora and Lower Derby Lakes based on the respective F_{oc} data available for each. The data on F_{oc} for Ladora Lake showed no indications of skewness and so was fit with a normal distribution. A lognormal distribution was fit to the Lower Derby data because of its skewed tendency and proximity to zero. The distributions fit to the two data sets are given in Table B.3-35. These distributions overlap only slightly and are shown together in Figure B.3-19.

No F_{oc} data were available for Upper Derby, Eastern Upper Derby, Mary, and Rod and Gun Club Lakes. Therefore, F_{oc} distributions for these lakes were assigned based on their hydrological, vegetative, and sedimentary characteristics. Based on these characteristics, Rod and Gun Club Lakes and Lake Mary were judged to have F_{oc} distributions similar to Lake Ladora and were therefore assumed to have the same F_{oc} distribution as that fit to Ladora data. Upper and Eastern Upper Derby are intermittently flooded "lakes" having similar sedimentary textures to Lower Derby, but presumably higher F_{oc} due to the established vegetative cover. The sediment F_{oc} distribution for Upper and Eastern Upper Derby was assumed to be intermediate to that of Ladora and Lower Derby, so a normal distribution having a mean and standard deviation between the means and standard deviations was assigned for Ladora and Lower Derby. The following formulas were used:

$$\mu_{Intermed.} = \frac{\mu_{Ladora} + \mu_{LowerDerby}}{2} \quad (2)$$

$$\sigma_{Intermed.} = \sqrt{\frac{\sigma^2_{Ladora} + \sigma^2_{Lower\ Derby}}{2}} \quad (3)$$

where: $\mu_{Intermed.}$ = The mean of F_{oc} for Lakes Ladora and Lower Derby combined

$\sigma_{Intermed.}$ = The standard deviation calculated for Lakes Ladora and Lower Derby combined

The combined lognormal distribution for all lakes (Figure B.3-18) was fit to a simulated data set of 600 points created by sampling 600 x p points from each of the three lake distributions, where p is the corresponding proportion of total lake area (Table B.3-35). The appropriateness

of the lognormal distribution is indicated by the proximity of the data range to zero, and by the skewness coefficient of the simulated data (SK = 3.29).

The intent in developing the sediment F_{oc} distribution was to reflect a realistic range within lakes, and the fact that only two lakes were sampled for sediment F_{oc} contribute to the uncertainty regarding the sediment F_{oc} distribution. However, the assigned distribution is considered realistic for the conditions at RMA.

B.3.9.4 Fraction Organic Carbon in RMA Soils (Probabilistic)

The F_{oc} in soils at RMA varies according to both soil type and depth in the soil column. An RMA-wide horizontal distribution of F_{oc} was characterized by the combined distributions of the vertical median F_{oc} values. This combined data set was best fit by a lognormal distribution with the following distribution descriptors:

Mean (y) = -5.59

Standard Deviation (y) = .274

Where $y = \log_e F_{oc}$

Mean = 3.88×10^{-3}

Standard Deviation = 1.08×10^{-3}

95th Percentile = 5.86×10^{-3}

A description of how soil F_{oc} data were compiled and how this distribution was developed is provided below.

B.3.9.4.1 Data Compilation

RMA-specific data on F_{oc} used to develop a soil distribution were obtained from the CMP (see Appendix A), which was conducted by R.L. Stollar and Associates Inc (RLSA 1990). Although the data contained in the CMP were summarized from three sources (Helling 1971;

SCS 1974; Walsh and Associates 1988), the Walsh and Associates report provides higher quality data and so was used by R.L. Stollar and Associates, Inc. (RLSA 1990) to develop the ranges for the percent organic carbon in soil.

Walsh and Associates (1988) identified soil series and classifications at RMA and also collected data on the percent of organic carbon[1] at varying soil depths for each of these series/classifications. Specifically, six different soil series—Ascalon, Bresser, Nunn, Satanta, Truckton, Weld—and three soil classifications—Aquic Haplustolls, Petrocalcic Paleustolls, Typic Haplustolls—were identified, along with one soil category known as "disturbed land." The Bresser and Weld series and the disturbed land category comprise approximately 75 percent of the soil at RMA. The remaining 25 percent, listed in order from most to least prominent, includes Ascalon, Satanta, Truckton, Aquic Haplustolls, Nunn, Typic Haplustolls, and Petrocalcic Paleustolls. A map of the soil types and classifications at RMA is presented in Figure B.3-20.

The percent organic carbon for soils at RMA were compiled from the summary data contained in R.L. Stollar and Associates, Inc. (RLSA 1990). These data are presented in Table B.3-36 for each of the nine different soil series as well as for the disturbed land. The overall ranges for the percent organic carbon are summarized in Table B.3-37 in order of most- to least-prevalent soil series. F_{oc} decreases with increasing soil depth for each boring, as can be seen in these tables. All data on percent organic carbon were converted to the corresponding fraction prior to any statistical evaluations.

B.3.9.4.2 Distribution Development

The effect of the varying F_{oc} levels with depth was estimated by assuming all depths have a constant F_{oc} (e.g., the vertical mean or median F_{oc} for that soil column). An RMA-wide

[1] Data are reported as percent organic carbon consistent with the data source. Note that the fraction of organic carbon (percent organic carbon divided by 100) was used in all statistical evaluations and the risk characterization models.

distribution was then characterized as the horizontal variation in these vertical median F_{oc} values, taking into account the relative frequency of different soil types at RMA.

The F_{oc} distribution was fit using STATGRAPHICS. Both RMA-wide F_{ocsoil} distribution and the vertical F_{ocsoil} distributions were assumed to be lognormal, as indicated by a significant degree of positive skewness. Positive skewness was indicated by the standardized skewness coefficient and by the proximity of the data range to zero. A symmetrical distribution (e.g., normal), if fit to the data, would result in a significant probability of negative values, which are not meaningful.

Data were screened for validity, possible analytical or sampling errors, and appropriateness of environmental conditions (e.g., soil type) prior to distribution fitting. No data points for F_{oc} were considered to be possible outliers, so none was tested based on statistical criteria. The characterization of the vertical and horizontal variation in the soil column is discussed below.

Characterization of Vertical Variation

Because the vertical variation in the soil column is not incorporated into the model, a representative value, such as the mean or median of each boring, is required. The median was chosen as a representative value because vertical distributions for a given soil type are approximately lognormal. For lognormal populations, the median is generally used as a typical value in the population. In addition, the sample mean tends to be sensitive to the presence of extreme data points, making it an unreliable estimator of the true mean for lognormal populations, especially when sample sizes are small. The lognormal vertical distributions for each soil type were not heavily skewed; therefore, the mean and median are close in value.

The lognormality of the vertical variation within a soil type was assessed by combining all depths of all borings for a given soil type. Although this combined distribution represented some horizontal, boring-by-boring variation, this variation was relatively low; therefore, the lognormal

distributions were considered indicative of lognormality in the vertical F_{oc} distribution. All distributions were approximately lognormal and are presented Table B.3-38 for comparison.

Samples were taken from each boring to a depth of at least 45 feet except for one boring taken for the Petrocalcic Paleustolls soil. The median of this boring is consequently biased upward because of the lack of F_{oc} values in the lower soil column. However, this soil type constitutes only 0.1 percent of the area of RMA, so this boring did not significantly affect the analysis.

Characterization of Horizontal Variation

The vertical median F_{oc} levels vary locally (i.e., from boring to boring) and by soil type. The true distribution of the vertical medians for F_{oc} is a mixture of at least ten subdistributions, one per soil type, each with different means, variances, and, possibly, distribution shapes. These subdistributions must be combined into one RMA-wide distribution where each is represented in proportion to the relative likelihood of its occurrence. In this case, this likelihood is the proportion of total area contributed by each soil type. The proportion of total area contributed by each type is presented in Figure B.3-20. The proportions are summarized in Table B.3-38.

The data from all soil series were combined into one data set. To ensure that soil types are represented in the combined distribution according to their relative occurrence, the number of points (N_k) in the combined distribution for each soil type k should be proportional to the area of soil type k. The number of borings actually obtained for each soil type (N_k) were replicated an appropriate number of times until N_k samples were generated. For example, the 4 borings for the Bresser soil type were replicated 10 times so that the resulting 40 values could comprise 40 percent of the 100 values in the combined data set, which is roughly the same proportion (0.41) that the Bresser series contributes to RMA soils. The N_k given in Table B.3-38 were chosen because they require complete replication of the N_k samples. The combined data with replications were then fit with the lognormal distribution.

B.3.9.5 Henry's Law Constants (Probabilistic)

Henry's Law states that the solubility of a gas in a liquid is directly proportional to the equilibrium pressure of the gas over the solution. The Henry's Law constant (K_H) for a chemical is the constant used to display this linear relationship.

For most chemicals, the number of data points available for K_H was small (3 to 15). The estimated K_H distributions are summarized in Table B.3-39. For lognormal distributions, the mean and standard deviation of the log-transformed data is given in Table B.3-39, while the population mean and standard deviation (original unit) are given in Table B.3-40. For three chemicals (chloroacetic acid, dibromochloropropane, and dicyclopentadiene), no K_H data were available. K_H for distributions for these three COCs were extrapolated based on vapor pressure and solubility. Solubility distributions used for estimating these three K_H distributions are summarized in Table B.3-41. The compilation of data and distribution development for Henry's Law constants are presented below.

B.3.9.5.1 Data Compilation

K_H values were obtained using two methods. First, a literature search for K_H values was conducted. Second, for those chemicals with no K_H data in the literature, K_H was calculated based on the vapor pressure of the pure chemical over its solubility in water. All values for K_H identified from the literature search or calculated using vapor pressure and solubility are summarized in Table B.3-42. The process of K_H and solubility data compilation is described below.

K_H Literature Search

The comprehensive computer literature search for Henry's Law constants was conducted for all organic COCs (22 of the 27 COCs). Henry's Law constants were not compiled for the five inorganic COCs since the vapor inhalation pathways are not applicable to these COCs. The databases were searched using the following keywords/phrases: Henry's Law constant, Henry's

constant, and by both the chemical name and Chemical Abstract Service Registry Number (CAS#) of the COC. The Syracuse Research Corporation's Chemfate database and Chemical K_H Information System's Envirofate database were also accessed and searched for data on K_H. Dialog, a computer information service, was used to access the following kinds of databases: chemical abstracts, pollution abstracts, and the National Technical Information System (NTIS). References obtained from the computer search were screened by title; those articles appearing pertinent to the desired data were retrieved. Articles were then reviewed for K_H values. To ensure completeness of the literature search, an additional secondary reference search was conducted based on citations from key articles obtained from the above-listed databases.

Where ambiguity existed as to whether K_H values in the literature were experimental or calculated, the data were automatically assumed to be calculations. In cases where the same K_H value appeared in two or more different studies, each value was considered to be an individual data point, provided it could be verified that the origin of the values arose from separate studies. All duplicate K_H data originating from the same source were treated as only one data point regardless of how many times they may have been referenced by other articles. Data that could not be traced back to its primary reference were not used in developing the K_H range. To establish a basis for comparison, both experimentally measured and calculated K_H values were converted to a common unit of measurement, atmosphere cubic meter per mole (atm-m^3/mol).

Solubility Literature Search

Despite a comprehensive literature search, limited data were found for the following chemicals: chloroacetic acid, dibromochloropropane, dicyclopentadiene, and isodrin. Only one calculated K_H was found for chloroacetic acid and dibromochloropropane, and no data were found for dicyclopentadiene and isodrin. To obtain the most accurate representation of the K_H for each of these four chemicals, K_H values were calculated from solubility and vapor pressure data using the relationship described by Lyman et al. (1982). The Lyman relationship approximates the K_H to the ratio of the vapor pressure (V_p) of the pure chemical (V_P in atm) over the water solubility

of the chemical (SOL in moles per cubic meter, or mol/m^3). Vapor pressure distributions used to calculate K_H are described in Section B.3.9.6. Solubility distributions are described below.

All solubility values for COCs lacking K_H values are listed in Table B.3-43. Solubility data were obtained from a computer literature search using Chemfate, Dialog, and the Library of Medicine's Hazardous Substance Databank. References were screened by title and those articles pertinent to water solubility were retrieved. The data are summarized as cited by the literature (i.e., in the same units) together with their corresponding temperatures (where available) and reference sources. All solubility data found in the literature search were then converted to units of mol/m^3 for use in the PPLV model. Duplicate data that arose from the same study but that were cited by two or more sources were recorded as a single data point. If two identical values were reported for which the primary reference source was unclear, these data points were treated as being derived from the same study and listed as a single data point.

Only solubility data at temperatures between 5°C and 25°C were included in the data summary for this parameter. Multiple solubility values were pulled from the literature for chloroacetic acid and dibromochloropropane. A single solubility data point was found for dicyclopentadiene, and no solubility data were found for isodrin.

Screening and Weighting K_H Values

The process of gathering and screening data has a large effect on the distribution that results from the data analysis. In order to produce a data set that is collectively representative of the underlying distribution, data points that fell outside of the main body of values were screened based on the following criteria: the reliability of the study, the independence of the data (i.e., not from the same study), and the measurement of the values under an appropriate range of conditions (e.g., temperature and soil type).

In examining K_H data distributions, differences in empirical results can often be explained by the experimental method chosen. Unfortunately, there seems to be no clear consensus as to which experimental method is most accurate in measuring K_H. For this reason, all experimental methods were considered to be equally valid. However, in order to eliminate inaccurate data, the reliability of each value was assessed. Typically, in determining reliability, outliers are statistically evaluated by comparing them to a known data distribution. However, because the distribution family for K_H is unknown, outliers could not be statistically evaluated for exclusion, so no data were statistically rejected. In addition to evaluating the reliability of the data points, the experimental method was also examined for reliability. Values that arose from inappropriate or outdated experimental procedures were discarded. All other studies were considered acceptable and equally reliable.

Ideally, all reliable experimental methods available for estimating a parameter should be represented in equal numbers in the data set. If this is not the case, fitted distributions will be skewed toward a given technique because it was applied more often, not because it is more reliable. However, because differences in experimental technique are often not reported and are difficult to determine, values were included in the data set regardless of the method of determination.

Several data values are likely to be correlated if measured by the same experimenter using the same equipment conditions and experimental technique. If two or more K_H data values were given by the same researcher in the same study and were measured at the same temperature, they were considered to be correlated and replaced with a single datum equal to their mean. For K_H, individual measurements made at different temperatures within a specified range were included in the data set because it is desirable to include the variability due to temperature even if some correlation is present.

K_H varies significantly with temperature. Ideally, data on K_H should be measured for a range of soil temperatures, and then represented in a data set in rough proportion to the actual occurrence of these different soil temperatures at RMA. However, such accuracy is not possible due to the unavailability of data for different temperatures in the range considered likely to occur in RMA soils, i.e., 5 to 25°C. In addition, the high variability due to measurement error and other confounding factors made extrapolation to temperatures outside of those measured unreliable. Therefore all data measured in the above-referenced temperature range were included in the data set, while all data outside this range was discarded.

B.3.9.5.2 Development of Solubility Distributions

Solubility distributions used for estimating some K_H distributions are summarized in Table B.3-41. The rationale for fitting distributions for solubility to applicable COCs is discussed below.

Chloroacetic acid, dibromochloropropane, and dicyclopentadiene were all assigned solubility distributional shapes based on best professional judgment because of the limited amount of data available. In arriving at these distributions, data from compounds with similar structures to each of these chemicals were examined. Surprisingly, despite having different chemical structures, the data available from other compounds seemed to warrant assigning them similar distributional shape.

The four data points for chloroacetic acid were positively skewed and best professional judgment indicated that solubility was likely to be moderately positively skewed for the three chemicals in question. A moderate degree of positive skewness is difficult to represent with a lognormal distribution that cannot be shifted to span a given data range without changing shape considerably. Therefore, a positively skewed triangular distribution was fit to the data.

B.3.9.5.3 K_H Distribution Development

K_H distributions were developed from data except for those chemicals for which no K_H data were available. If no K_H data were available, K_H was estimated using the solubility distributions (discussed above) and vapor pressure data.

General Considerations for Distribution Development

For most chemicals, the K_H data provide enough information that the estimation of distributions is warranted. However, it should be noted that considerable uncertainty exists because the number of samples is so low and because the parameter is dependent on temperature. As described below, additional variability was incorporated into the distribution for some chemicals to reflect the uncertainty in estimating the distributional descriptors with low sample sizes.

The Kolmogorov-Smirnov goodness-of-fit test was used to select a distribution when the number of data points was at least 25 (i.e., $n < 25$). If a data set had 25 or fewer data points, the shape of distribution was chosen based on both the data (e.g., skewness) and on simple, objective assumptions about the underlying data. This approximate distribution is more realistic than that implied by fixing the parameter at a constant. Lognormality was assumed, regardless of skewness, when the data were sufficiently close to 0.0 so that the fit to a normal distribution would imply a significant chance for a negative K_H value (which is not meaningful). The assignment of a distribution family for K_H followed that generally used for other parameters (see Appendix B.3). No data points for the K_H parameter were identified as outliers, so this statistical evaluation criterion was not required.

A uniform triangular distribution was chosen to approximate the distribution of K_H for some chemicals for which the data points for K_H indicated a lack of central or skewed tendency in the data. The uniform triangular distribution is described in Appendix B.3.

If few data points were available (e.g., $n \leq 6$) so that there was an unacceptably high degree of uncertainty regarding a parameter distribution, the distribution was adjusted to incorporate the added uncertainty indicated by best professional judgment. Two methods were used to fit widened distributions depending on the skewness of the data.

For a normal distribution, the upper 75th confidence limit on the standard deviation was used instead of the maximum likelihood estimate, increasing the spread of the distribution. The conventional Chi-square-based confidence interval estimation of the standard deviation is described in the introduction to Appendix B.3.

In estimating lognormal distributions, the confidence interval method is not applicable because an increase in the standard deviation and/or the mean alters the shape and skewness of the distribution, making the new distributional shape arbitrary (not based on data). Lognormal distributions are particularly poorly estimated by low sample sizes. Therefore, if the data indicated a skewed tendency, a uniform triangular distribution was used to model the uncertainty about the K_H values. This distribution is expected to provide conservative (high) K_H values compared to the fitted lognormal distribution. The uniform triangular distribution results in a higher frequency of midrange to high K_H values and the exclusion of the infrequent extremely high values that would result from the highly skewed lognormal distribution.

K_H Distributional Approach

For most chemicals, the number of data points available for K_H was small (3 to 15). To aid in interpreting these small data sets, chemicals having similar properties are presented together. All of the distributions are expected to reflect a positive (conservative) bias because the data generally represent only the upper part of the temperature range (5°C to 25°C) considered to occur frequently at RMA. The potential bias is discussed for each chemical below.

Aldrin, Dieldrin, Endrin, and Isodrin: The number of K_H data for aldrin, dieldrin, and endrin were too few to adequately determine whether the underlying distributions had central or skewed tendencies. The data ranges were close to zero, so the data were fit with a right-tailed uniform triangular distribution. As described above, the distribution was assumed to be uniform between the data minimum and maximum and triangular from the data maximum out to an endpoint value, determined by assuming that one-sixth of the distribution lies in the triangular position. Because no data was available for isodrin, its distribution was assumed equal to that of aldrin, the compound most similar in structure to isodrin.

Most of the K_H data for aldrin and dieldrin were measured at 25°C, but one measurement at 20°C was taken for each chemical. All endrin data were measured at 25°C. These temperatures are in the upper range of those that frequently occur at RMA, so K_H values at the low end of the predicted temperature range are likely to be under-represented for each chemical. Although the variability of K_H may be underestimated based on the data, the distributions are expected to have a positive (conservative) bias.

Benzene and Toluene: Benzene data included nine values within a narrow range (5.00×10^{-3} to 5.55×10^{-3}) at the center of the distribution, with three values well outside this range. However, normality was not rejected at the .05 level by the Kolmogorov-Smirnov test goodness-of-fit (P = .36), indicating that the normal distribution provides a reasonable characterization of the data.

Toluene data was negatively skewed (SK = -1.7), and a visual comparison of histograms indicated that the Weibull distribution provided a better fit to the data than a normal distribution (the Kolmogorov-Smirnov goodness-to-fit test could not distinguish). As discussed previously, a triangular distribution was used to represent the Weibull distribution.

Most of the K_H data for benzene and toluene were measured at 25°C. Toluene was measured once at 20°C, while benzene was measured twice at 20°C and once at 10°C, so K_H values at the low end of the predicted temperature range are likely to be under-represented for each chemical. Although the variability of K_H may be underestimated based on the data, the distributions are expected to have a positive (conservative) bias.

Chloroform, 1,2-Dichloroethane, 1,1-Dichloroethylene, Methylene Chloride: Chloroform data appeared to be somewhat skewed to the left; however, the skewness coefficient (SK = -1.36) was not extreme, and the distance of the data range from zero indicated that a normal distribution was reasonable. Methylene chloride data too was not significantly skewed (SK = -.70), and so was fit with a normal distribution. 1,2-dichloroethane and 1,1-dichloroethylene data were fit with lognormal distributions to avoid the possibility of sampling negative values. The skewness of the data was slight for both 1,2-dichloroethane (SK = .24) and 1,1-dichloroethylene (SK = .65).

Most of the K_H data for these chemicals was measured at approximately 20°C to 25°C. Chloroform, 1,1-dichloroethylene, and methylene chloride each have one data point at approximately 10°C. Therefore K_H values at the low end of the predicted temperature range are likely to be under-represented for each chemical. Although the variability of K_H may be underestimated based on the data, the distributions are expected to have a positive (conservative) bias.

Carbon Tetrachloride, 1,1,2,2-Tetrachloroethane, Tetrachloroethylene: For carbon tetrachloride and 1,1,2,2-tetrachloroethane, the normal distribution was reasonable because the data were not significantly skewed (SK = -1.0) and were not close to zero. However, for 1,1,2,2-tetrachloroethane, the maximum likelihood estimate of the normal standard deviation was deemed by best professional judgment to be unrealistically low due to the low number of data points (n 5). Therefore, the 75th percentile method was used to estimate a larger standard deviation ($S^* = 1.44\ S^0$, where S^0 is the observed sample standard deviation). The 10 values for

tetrachloroethylene showed no indication of a central or skewed tendency. The data range was near zero and the data were fit with a right-tailed uniform triangular distribution.

Most of the K_H data for these chemicals was measured at 17.5 to 25°C. Carbon tetrachloride and tetrachloroethylene each have one data point at approximately 10°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be under-represented for these chemicals. Although the variability in K_H may be underestimated based on the data, the distribution is expected to have a positive (conservative) bias.

Chlorobenzene: K_H data for chlorobenzene were not significantly skewed (SK = -0.67) and were not close to zero, so the data were fit with a normal distribution. All of the K_H data for this chemical were measured at 20°C or 25°C, with most of the data points occurring at 25°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be underestimated for this chemical. Although the variability in K_H may be underestimated based on the data, the distribution is expected to have a positive (conservative) bias.

Trichloroethylene: K_H data for trichloroethylene were negatively skewed (SK = -1.84) and were best fit by a Weibull distribution. A triangular distribution was used to approximate the fitted Weibull distribution. Most of the K_H data for this chemical was measured at 17.5°C to 25°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be under-represented for this chemical. Although the variability in K_H may be underestimated based on the data, the distribution is expected to have a positive (conservative) bias.

DDE and DDT: The number of K_H data for DDE and DDT was too small to adequately determine whether the underlying distribution had central, skewed, or uniform tendencies. Best professional judgment indicated that the uncertainty in the measurement of these values implied a uniform likelihood of a K_H value in the data range. Therefore, the data were fit with a right-tailed uniform triangular distribution. All of the K_H data points to both chemicals were

measured at temperatures of approximately 25°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be under-represented for each chemical. Although the variability of K_H may be underestimated based on the data, the distributions are expected to have a positive (conservative) bias.

Chlordane: Chlordane data were significantly positively skewed (SK = 2.22), and so were fit with a lognormal distribution. All of the K_H data points for this chemical were measured at temperatures of approximately 25°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be under-represented for this chemical. Although the variability in K_H may be underestimated based on the data, the distribution is expected to have a positive (conservative) bias.

Hexachlorocyclopentadiene and Dicyclopentadiene: K_H data for hexachlorocyclopentadiene were fit with a lognormal distribution based on moderate skewness (SK = 1.06) and proximity of the data range to zero.

No K_H data were available for dicyclopentadiene. A method was developed to estimate the K_H distribution from vapor pressure and solubility distributions. However, these latter distributions are themselves estimated from very little data, leaving a large degree of uncertainty about the true distribution of K_H values. (The estimation of these distributions is discussed in the sections on solubility and vapor pressure.) The K_H distribution for dicyclopentadiene was estimated by sampling 200 points each from estimated distributions for vapor pressure and solubility, calculating 200 values for K_H, and then fitting a distribution to these 200 simulated K_H values. The 200 values for K_H were calculated as follows:

$$K_H = \frac{\text{vapor pressure}}{\text{solubility}} \qquad (4)$$

The simulated K_H data was best fit by a lognormal distribution. The Kolmogorov-Smirnov goodness-of-fit test did not reject lognormality at the 0.05 confidence level and is reliable at n = 200. However, the appropriateness of the fitted distribution is based on the appropriateness of the assumed distributions for vapor pressure and solubility, the formula for K_H, and the assumption that vapor pressure and solubility are independent for a given chemical.

All of the K_H data points for hexachlorocyclopentadiene were measured at 25°C. Therefore, K_H values at the low end of the predicted temperature range are likely to be under-represented for this chemical. Although the variability in K_H may be underestimated based on the data, the distribution is expected to have a positive (conservative) bias.

Dibromochloropropane: No K_H data were available for dibromochloropropane, so the K_H distribution was estimated from vapor pressure and solubility data in the manner described above. Due to the lack of data on K_H, vapor pressure, and solubility, there is a large degree of uncertainty regarding the true distribution of the K_H values. The simulated K_H distribution was flat-topped with a linearly decreasing positive tail, and was best fit by the uniform triangular distribution.

Chloroacetic Acid: The K_H distribution for chloroacetic acid was estimated from vapor pressure and solubility data in the manner described above. Due to the lack of data on K_H, vapor pressure, and solubility, there is a large degree of uncertainty regarding the true distribution of the K_H values. The simulated K_H data were best fit by a lognormal distribution. (The Kolmogorov-Smirnov test did not reject lognormality at the 0.05 level.)

B.3.9.6 Vapor Pressure (Probabilistic)

Vapor pressure is the pressure of the chemical vapor at equilibrium (i.e., the pressure when the rate of evaporation equals the rate of condensation). This parameter is used in the PPLV equations to evaluate inhalation exposures to volatile organic compounds.

Estimated vapor pressure distributions for COC are summarized in Table B.3-44. For lognormal distributions, the mean and standard deviation of the log-transformed data are shown in Table B.3-44, while the population mean and standard deviation (original units) are given in Table B.3-45. The data compilation and distribution development for the vapor pressure parameter are discussed below.

B.3.9.6.1 Data Compilation

Available V_p data are summarized for all organic COCs in Table B.3-46. Data in the tables are identified as either empirical or calculated. Vapor pressure data were found for all COCs with the exception of isodrin. Vapor pressure data were not summarized for metals since the vapor inhalation pathway is not applicable to these contaminants. Mercury, a metal that can have significant vapor pressure in the elemental form, is considered more likely to be complex in RMA soils as chloride or sulfate salts, so vapor pressure data were not summarized. The methods used to obtain and compile the vapor pressure data are discussed below.

To obtain vapor pressure data, a Chemfate database search was conducted for all organic COCs at RMA. The database Dialog was also searched. All Dialog references from previous parameter development (e.g., solubility, Henry's Law constant) were screened by title for vapor pressure data and all pertinent articles were retrieved. Last, all in-house articles (also from previous parameter development) were reviewed for vapor pressure data.

V_p data were recorded as cited in the literature source (i.e., in the same units) together with corresponding temperature data where available. Duplicate data arising from the same study that were cited by two or more sources were recorded as a single data point. If two identical values existed and the primary reference source was unclear, these values were assumed to be from the same study and were summarized as a single data point. All vapor pressure data found in literature search were converted to units of atm for use in the PPLV equations.

Screening and Weighting of Vapor Pressure Values

The process of gathering and screening data has a large effect on the type of distribution that results from the data analysis. To produce a data set that is collectively representative of the underlying distribution, data points falling outside of the predominance of values were screened using the following criteria: the reliability of the study, the independence of the data (i.e., not from the same study), and the measurement of the values under an appropriate range of conditions, such as temperature and soil type. These criteria are discussed below.

Extreme high and low vapor pressure values were reviewed on a case-by-case basis. Values arising from inappropriate, unreliable, or outdated experimental procedures were discarded. All other studies were considered acceptable and equally reliable. This equal consideration of all studies was applied because a nonequal weighting scheme, devised to account for differing reliability, could potentially introduce personal bias.

Ideally, the several experimental methods available for estimating a parameter should be represented in equal numbers in the data set if they are equally reliable methods. Otherwise, the fitted distribution will be skewed toward a given technique just because it was applied more often, not because it is more reliable. However, because differences in experimental technique are often not reported and are difficult to determine, values were included in the data set regardless of the method of determination.

Data values are likely to be correlated if measured by the same experimenter using the same equipment conditions and experimental technique. If two or more vapor pressure data values were given by the same researcher in the same study and measured at the same temperature, they were considered to be correlated and replaced with a single datum equal to their mean. An exception to this was made if the number of samples was low, in which case the potentially correlated points were included separately in the data set to increase the sample size. Vapor

pressure measurements in the same study for different temperatures within a defined range were included separately in the data set.

Vapor pressure varies significantly with temperature. Ideally, data on vapor pressure should be measured for a range of soil temperatures, and then represented in a data set in proportion to the actual occurrence of these different soil temperatures on RMA. However, such accuracy is not possible due to the lack of data on chemicals at different temperatures. Accordingly, best professional judgment was used to establish a defined range of temperatures that would be considered. The range of temperatures selected was 5 to 25°C. In addition, variability due to measurement error and other confounding factors precluded extrapolation of vapor pressure data to other temperatures in addition to those measured. Accordingly, data points measured at temperatures outside the above-referenced temperature range were excluded from the data set. In order to enhance the generally small data sets, vapor pressure values for which temperature was not reported were left in the data set if the value was well within the range of values reported in the defined temperature range. The inclusion of these data points with unknown temperatures was expected to enhance the estimation of vapor pressure distribution by increasing the number of samples.

B.3.9.6.2 Distribution Development

For most chemicals, the vapor pressure data provide enough information that the estimation of distributions is warranted. However, it should be noted that considerable uncertainty exists because the number of samples is so low and because the parameter is dependent on temperature. As discussed below, additional variability was incorporated into the distribution for some chemicals to reflect the uncertainty in estimating the distributional descriptors with low sample sizes.

General Distributional Approach

The assignment of a distribution family for vapor pressure followed that used in general for other parameters and is discussed in detail in the introduction to Appendix B.3. No data points for the vapor pressure parameter were considered to be possible outliers, so this statistical evaluation criterion was not required.

The fit of a distribution to a given data set can be statistically assessed only if the number of data points, n, is moderate to large. The Kolmogorov-Smirnov goodness-of-fit test was used to select a distribution when n was at least 25. In the more common case of a small data set, the power of this and other distribution statistical tests is very weak, often resulting in the acceptance of a distribution even if it is very different than the true distribution from which the data were sampled. Although there is a great deal of uncertainty inherent in such a case, the data indicate an approximate distribution. As discussed previously, this approximate distribution is more realistic than that implied by fixing the parameter at a constant. The following considerations affected the development of distributions for the vapor pressure parameter.

A uniform triangular distribution was chosen to approximate the distribution of vapor pressure for some chemicals for which this distribution is described in Appendix B, Section B.3.9.6. The data points for vapor pressure indicated a lack of central or skewed tendency in the data.

If few data points were available (fewer than six) so that there was an unacceptably high degree of uncertainty regarding a parameter distribution, the distribution was adjusted to incorporate the added uncertainty indicated by best professional judgment. Two methods were used to fit the widened distributions depending on the skewness of the data.

For a normal distribution, the upper 75th confidence limit on the standard deviation was used instead of the maximum likelihood estimate, increasing the spread of the distribution. The

conventional Chi-square-based confidence interval estimation of the standard deviation is described in Appendix B.3.

In estimating lognormal distributions, the confidence interval method is not applicable because an increase in the standard deviation and/or the mean alters the shape and skewness of the distribution, making the new distributional shape arbitrary (not based on data). Lognormal distributions are particularly poorly estimated by low sample sizes. Therefore, if the data indicated a skewed tendency, a uniform triangular distribution was used to model the uncertainty about the vapor pressure values. This distribution is expected to provide conservative (high) vapor pressure values compared to the fitted lognormal distribution. The uniform triangular distribution results in a higher frequency of midrange to high vapor pressure values and the exclusion of the infrequent extremely high values that would result from the highly skewed lognormal distribution.

Most of the distributions are expected to reflect a potential bias because the data generally represent only part of the range of temperatures (5°C to 25°C) considered to frequently occur at RMA. Potential bias is discussed for each chemical below. Generally the biases, if present, imply an overestimation of vapor pressure and are therefore conservative.

Specific Distributional Approach

For most chemicals, the number of data points available for vapor pressure was small (3 to 15). To aid in interpreting these small data sets, chemicals having similar properties are presented together.

Aldrin, Dieldrin, Endrin: Vapor pressure data for aldrin and dieldrin was best fit by a lognormal distribution according to the Kolmogorov-Smirnov goodness-of-fit test, as well as from visual comparison. One dieldrin data point was two orders of magnitude higher than the rest. No temperatures were referenced, so the data were excluded from the analysis. The four data points

for endrin vapor pressure did not indicate a central or skewed tendency, and a lognormal fit to the data was highly skewed, overstating the frequency of near-zero values and very large values, and understating the frequency of middle values. Best professional judgment indicated that vapor pressure values within the observed range are approximately equally likely and that it is reasonable that some positive skewness exists since this is indicated for aldrin and dieldrin. Therefore, a uniform triangular distribution was assigned to the vapor pressure data for endrin. No data were available for isodrin; therefore, its distribution was assumed to be equal to that of aldrin, the compound most similar in structure and activity to isodrin.

The data points for aldrin (n = 13), dieldrin (n = 24), and endrin (n = 4) were measured at temperatures of either 20°C or 25°C, with half or more of the values for each chemical corresponding to 20°C. These temperatures are in the upper range of those predicted to be frequent at RMA (5°C to 25°C), so the distribution may under-represent the frequency of vapor pressure values at low temperatures (i.e., low vapor pressure).

Benzene and Toluene: Benzene vapor pressure data was moderately negatively skewed (SK = -1.11), but since it was equally well fit by either a normal or negatively skewed Weibull distribution a normal distribution was assumed. Toluene vapor pressure data were strongly negatively skewed (SK = -2.03), and so was fit with a triangular distribution set to approximate the best-fitting Weibull distribution.

Approximately two-thirds of the benzene data points (n = 13) correspond to temperatures between 20°C and 25°C. The remaining data correspond to temperatures ranging from 10°C to 23°C. This range of temperatures appears to reasonably represent those observed on RMA, so the bias is expected to be small or negligible. Three-fourths of the toluene data points (n = 8) correspond to temperature of 25°C, while the remaining two data points correspond to 20°C and 12.5°C. Therefore, the variation in the toluene data may under-represent the frequency of V_p values at low and middle temperatures (i.e., low vapor pressure).

Chloroform, 1,2-Dichloroethane, 1,1-Dichloroethylene, Methylene Chloride: Data sets for chloroform, 1,2-dichloroethane, and 1,1-dichloroethylene were not significantly skewed (SK = 0.88, -0.98, and -1.13, respectively) and were fit with a normal distribution. For 1,1-dichloroethylene, the maximum likelihood estimate of the normal standard deviation was deemed by best professional judgment to be unrealistically low due to the low number of data points (n=3). Therefore, the 75th percentile method was used to estimate a larger standard deviation:

$$S^* = 1.86\ S^0 \qquad (5)$$

where: S^* = Estimated standard deviation

S^0 = The observed sample standard deviation

The data for methylene chloride was significantly negatively skewed (SK = -2.02) and a triangular distribution was set to approximate the best-fitting Weibull distribution.

The distributions of chloroform, methylene chloride, and 1,1-dichloroethylene were derived primarily from measurements at 20°C to 25°C, the upper end of the temperature range, so these distributions under-represent the vapor pressure values at lower temperatures. The distribution of 1,2-dichloroethane was derived from measurements at temperatures ranging from 5°C to 25°C, with nearly two-thirds of the measurements at 25°C, so the vapor pressure values at lower temperatures may be under-represented to a slight or moderate extent.

Carbon Tetrachloride, 1,1,2,2-Tetrachloroethane, Tetrachloroethylene: Although the data for carbon tetrachloride, 1,1,2,2-tetrachloroethane, and tetrachloroethylene were moderately or slightly negatively skewed (SK = -1.49, -0.2, and -1.57, respectively), the normal distribution fit slightly better that the Weibull distribution according to the Kolmogorov-Smirnov goodness-of-fit test. Therefore, normal distributions were assigned to these COCs.

The distributions of carbon tetrachloride and tetrachloroethylene were derived from measurement at temperatures ranging from 10°C to 25°C, with most values at 20°C and 25°C. Therefore, these distributions are expected to slightly under-represent low vapor pressure values. The distribution for 1,1,2,2- tetrachloroethane is derived entirely from values measured at temperatures of 20°C to 25°C and may under-represent the lower range of the vapor pressure distribution.

Chlorobenzene: Chlorobenzene vapor pressure data were significantly skewed (SK = -1.99), and so were fit with a triangular distribution set to approximate the best fitting Weibull distribution. This distribution was primarily derived from measurements at 25°C (n = 5), and so may under-represent the lower and middle ranges of the vapor pressure distribution.

Trichloroethylene: Trichloroethylene data were not significantly skewed (SK = 0.12) and were therefore fit with a normal distribution. This distribution was derived from measurement ranging from 17°C to 25°C, with most values at 20°C or larger. Therefore, vapor pressure values at low temperatures may be under-represented.

DDE and DDT: The four data points available for DDE did not indicate a strong skewness, so a normal distribution was fit. However the maximum likelihood estimate of the normal standard deviation was deemed by best professional judgment to be unrealistically low due to the low number of data points (n = 4). Therefore, the 75th percentile method was used to estimate a larger standard deviation:

$$S^* = 1.57\ S^0 \qquad (6)$$

where: S^* = Estimated standard deviation

S^0 = Observed sample standard deviation

The DDT vapor pressure data indicated a strong positive skewness (SK = 9.42, n=25), and so were fit with a lognormal distribution. The Kolmogorov-Smirnov goodness-of-fit test rejected

the fit of the lognormal distribution at the .05 level (the p value was 0.02); however, visual investigation of the fit indicated the lognormal distribution provides a reasonable characterization of the data.

These distributions are based on measurements at 20°C and 25°C, and so may under-represent the vapor pressure values at low temperatures. Most of the DDT measurements correspond to 20°C temperatures, so this distribution may also under-represent high vapor pressure values.

Chlordane: The five data points for chlordane vapor pressure indicated significant positive skewness (SK = 1.98), and so the data were fit with a lognormal distribution. The distribution was based on data measured at 25°C, and so may under-represent low values of vapor pressure.

Hexachlorocyclopentadiene and Dicyclopentadiene: The five data points for hexachlorocyclopentadiene were not skewed and were fit well by a normal distribution. However, the maximum likelihood estimate of the normal standard deviation was deemed by best professional judgment to be unrealistically low due to the low number of data. Therefore the 75th percentile method was used to estimate a larger standard deviation:

$$S^* = 1.44\ S^0 \qquad (7)$$

where: S^* = estimated standard deviation

S^0 = the observed sample standard deviation

Data for hexachlorocyclopentadiene corresponds to measurements at 25°C, and so the fitted distribution may under-represent low values of vapor pressure.

Only one data point was available for vapor pressure of dicyclopentadiene; therefore, the distribution shape was based on best professional judgment. Distributions for other chemicals have ranged from very positively skewed to negatively skewed. Because the distribution shape was uncertain, best professional judgment indicated that the distribution of vapor pressure values

should be considered uniform, within plus or minus an order of magnitude from the single data value. This single value was measured at 20°C.

Dibromochloropropane: One data point was available for dibromochloropropane vapor pressure, so the distribution shape was based on best professional judgment. Because direction of skewness was uncertain, the distribution of vapor pressure values were assumed to be uniformly distributed within plus or minus one order of magnitude from this point. This data point was measured at 21°C. The degree of bias could not be estimated based on this single data point.

Chloroacetic Acid: Only two data points were available for chloroacetic acid vapor pressure, so the distribution shape was based on best professional judgment. Because direction of skewness was uncertain, the distribution of vapor pressure values were assumed to be uniformly distributed within plus or minus one order of magnitude from the mean of the data points. The data points for chloroacetic acid were measured at 25°C, so the estimated uniform distribution may under-represent low- and middle-range vapor pressure values.

B.3.9.7 Soil-to-Water Partition Coefficients Normalized to Organic Carbon (Probabilistic)

A soil-to-water partition coefficient is a quantitative estimate of a chemical's affinity to adhere to soil. For organic COCs, soil-to-water K_{oc}s were developed. For inorganic COCs, K_{oc} data typically were not available, so distribution coefficients (K_ds) were used. The partition coefficient distributions are summarized for each COC in Table B.3-47. If lognormal distribution was assumed, $\log_{10} K_{oc}$ data were transformed to natural logarithms. A discussion of the data compilation and distribution development is provided below.

B.3.9.7.1 Data Compilation

Values for K_{oc} (organic COCs) and K_d (inorganic COCs) are summarized in Tables B.3-48 and B.3-49, respectively. The tables also include the source of the data and whether the data were empirical or derived from regression calculations. Despite a very comprehensive literature

search, limited data were found for chloroacetic acid, 1,1-dichloroethylene, and dibromochloropropane. No n-octanol-water partition coefficient (K_{ow}) or K_{oc} data were located for dicyclopentadiene, or isodrin. The process of compiling these data is discussed in this section.

Experimental K_{oc} values were available for only a small number of the 27 COCs. This was expected because of the high cost and experimental difficulties associated with direct K_{oc} measurements. Accordingly, K_{oc} values were determined by other means in order to obtain a well-developed range of values reflecting the true partitioning of the chemical as accurately as possible. The chosen method calculates K_{oc} from a more commonly measured physical property—K_{ow}.

A comprehensive computer literature search was run to obtain soil water partition coefficients for the 27 COCs. Dialog, a computer information service, was used to access the following kinds of computer databases: chemical abstracts, pollution abstracts, Compendex, and the National Technical Information System. In addition, Syracuse Research Corporation's Chemfate database as well as the Chemical Information System's Envirofate database were also accessed. Computer databases were searched using the following keywords and phrases: K_{ow}, K_{oc}, K_d, octanol-water partitioning coefficient, partition coefficient, and by both chemical name and CAS #.

A great deal of research has focused on establishing a direct relationship between K_{ow} and K_{oc} and in developing empirically based equations relating these two quantities. Numerous regressions equations have been developed. DiToro (1985) developed one of the best regression equations, which establishes a direct correlation between K_{ow} and K_{oc}:

$$\text{Log}(K_{oc}) = 0.00028 + 0.983\text{Log}(K_{ow}) \quad (8)$$

This equation was derived from a carefully screened database that eliminated questionable data and corrected for particle effects. Using this equation, all K_{ow} data found in the literature for the COCs were converted to the corresponding K_{oc} values. Other regression equations are available for estimating K_{oc}, but the DiToro equation (1985) is believed to be a more accurate predictor of K_{oc}.

All K_{ow} data (both experimental and calculated) were converted to K_{oc} values using DiToro's equation. Calculated K_{oc} values found in literature sources were not used since the vast majority of calculated K_{oc} values came directly from other regressions of K_{ow} data.

Weighting and Screening of K_{oc} Data

With the exception of the rejected outliers listed above, the K_{oc} data retrieved from the literature and that calculated from K_{ow} data were weighted equally in determining the K_{oc} distribution for each chemical. Each experimental K_{oc} value and each K_{oc} value calculated from K_{ow} data using DiToro's equation was treated as a single data point in the final K_{oc} range determination.

When ambiguity existed as to whether K_{oc} values were experimental or calculated, the data were automatically considered to represent calculated values. For those instances in which the same K_{ow} and K_{oc} values appeared in two or more different studies, each value was considered to be a unique data point, provided that it could be verified that the origin of the values arose from independent studies. All duplicate K_{ow} and K_{oc} data originating from the same source were treated as only a single data point regardless of how many times they may have been referenced by other articles. Data that could not be traced back to their primary reference source were retained, provided that the same data were not found elsewhere in literature from a primary source (in which case the primary study would be cited as the source of the data).

After all available K_{oc} values were compiled, the data were screened. All K_{oc} or K_{ow} data approximated from bioconcentration factors were removed from the final list of values. In

addition, data based on averages of K_{oc} or K_{ow} data quoted from a number of different studies and already included in the data set were also removed from consideration. Extremely high and low K_{oc} values (outliers) were reviewed on a case-by-case basis. Values arising from inappropriate experimental procedures or calculations were discarded. For example, a K_{ow} value for mercury cited in a study by Okouchi and Sasaki (1985) was rejected because the experimental procedure was based on the inappropriate assumption that K_{ow} could be measured similarly to other organic chemicals. This assumption produced a K_d value three orders of magnitude outside the range of other literature-retrieved values. Finally, outliers were excluded from the analysis if they differed from the other data by more than one $\log_{10}$ unit and came from questionable studies.

After obtaining all available K_{oc} data, including these calculated based on the K_{ow} regression of DiToro (1985), the draft K_{oc}/K_{ow} data packet was screened once more for possible outliers. Statistical analyses performed as part of the assignment of K_{oc} distribution functions indicated a few extreme data points that had significant leverage on the corresponding mean K_{oc} values (i.e., altered the mean log K_{oc} value by up to 0.5 log unit). Therefore, maximum and minimum data points that were extreme—i.e., greater than approximately one log unit from the next data point value—were reviewed. Original sources were checked; if the supporting experimental technique or the data source itself was questionable, the data were rejected. For example, several older EPA references contained undocumented values (i.e., the sources were not known). Other data were cited from secondary sources, which were not verifiable and which may have been developed from quantitative structure activity relationships. Other data appear to have been influenced by so-called partial effects. This screening resulted in the rejection of the following data:

Compound	Log K_{oc}	Reference
Aldrin	7.27	Briggs 1981
	2.96	Gosset et al. 1983
Chlordane	2.73	EPA 1981 EPA/600/2-82/001a
DDE	6.84	Mabey et al. 1982
DDT	3.99	Anliker et al. 1987
	3.91	Sabljic 1987; cite Garst et al. 1984
Dieldrin	6.09	Briggs 1981
	2.55	Gosset et al. 1983
	3.48	Mabey et al. 1982
Hexachlorocyclopentadiene	3.92	EPA (1981) EPA/600/2-82/001a

The K_{oc} values rejected here were developed from K_{ow} values and the DiToro equation. In each case, these values were noticeably divergent from the calculated means based on the balance of the K_{oc}/K_{ow} data for a particular COC, which supports a decision to reject the data.

Analysis of K_d Data

K_{oc} data typically were not available for the inorganic COCs. However, a limited database of K_ds and their corresponding Freundlich isotherm n values were retrieved from the literature. The Freundlich equation establishes a relationship showing that the amount of solute retained by the soil is equal to the distribution coefficient multiplied by the solute concentration in solution raised to the Freundlich isotherm n value:

$$S = K_d C^n$$

The distribution coefficient, K_d, is related to the K_{oc} by the following equation:

$$K_d = (K_{oc})(F_{oc}) \quad (9)$$

where: K_d = Distribution coefficient

K_{oc} = Soil-to-water partitioning coefficient normalized to organic carbon

F_{oc} = Fraction of organic carbon

Empirical K_d values were available for all metals. With the exception of arsenic and mercury, these data came from a single study (Butcher et al. 1989). In the Butcher et al. study, soil samples based on 11 soil types from seven different states were used to measure distribution coefficients for the metals. Since soil properties varied significantly from one soil type and location to another, a geometric mean was computed of the K_d and Freundlich isotherm n values across soil types for each of the metals. Although these geometric mean concentrations are not reported in the summary tables, the tables list the individual K_d values reported for each soil type.

B.3.9.7.2 Distribution Development

Distributions for K_{oc} were fit using STATGRAPHICs. Where few data points were available for a chemical-specific K_{oc}, a distribution could not be fit using statistical criteria such as the Kolmogorov-Smirnov goodness-of-fit test, alone. This fit test is not powerful enough in cases in which few data points are available to differentiate between fits to several varied distribution types, so the shape of the distribution was based on both the data (e.g., skewness) and on simple, objective assumptions about the underlying data. These assumptions are discussed below.

Lognormality was assumed, regardless of skewness, when the data were sufficiently close to zero such that the fit to a normal distribution would imply a significant chance for a negative K_{oc} (which is not meaningful). The assignment of a distribution family for K_{oc} followed that used in general for other parameters (see Appendix Section B.3.9.7) Therefore, all of the 27 COCs were assigned lognormal distributions. No data points for the K_{oc} parameter were considered to

be possible outliers based on statistical criteria, so this statistical evaluation criterion was not required.

To aid in interpreting the small data sets for some chemicals, these having similar properties and mean $\log_{10}$ (K_{oc}) values are presented together. The magnitude of the mean $\log_{10}$ (K_{oc}) value and the chemical groupings are correlated to the difficulty in measuring the K_{oc} experimentally. Therefore, the experimental measurement error reflected in the data for a given chemical should be roughly equivalent to that for other chemicals within the same group.

The log K_{oc} values of all chemicals fall within one of the following classes indicative of expected measurement difficulty:

Class Number	Log K_{oc} Range	Expected Measurement
1	>5.5	Difficult
2	3.5–5.5	Medium
3	2.5–3.5	Medium
4	1.2–2.5	Difficult
5	<1.2	Difficult

These classes were used as a basis for grouping chemicals with little or no K_{oc} data for the purpose of distribution fittings. Class designations for each COC are indicated below in parentheses. (NA denotes a class that is not applicable because of a lack of data.) A discussion of the distributions assigned to either individual chemicals or chemical classes follows.

For some chemicals (e.g., chloroacetic acid, 1,1-dichloroethylene, and hexachlorocyclopentadiene), the number of data points was extremely small (fewer than four). For others (e.g., dicyclopentadiene and isodrin), data were completely absent. In these cases, chemicals within the same group were assumed to have similar distributions of experimental error. In some cases, standard deviations were pooled or assumed to be equal to the standard deviation estimated for a chemical with a larger sample.

Aldrin (1-2), Isodrin (NA), Dieldrin (1-3), Endrin (2): K_{oc} data for aldrin and dieldrin were determined to be skewed to the right and/or relatively close to zero, so this group was assigned lognormal distributions. Lognormal distributions were estimated based on underlying chemical-specific data except in the case of isodrin, where the distribution was assigned based on the data for aldrin since both aldrin and isodrin are structurally similar and do not represent metabolites.

Benzene (3-4) and Toluene (3): Both K_{oc} distributions were skewed to the right (SK > 2.67), so a lognormal distribution was assigned to each chemical.

Chloroform (4), 1,2-Dichloroethane (4), 1,1-Dichloroethylene (4), Methylene Chloride (4): The K_{oc} distributions for this group were not significantly skewed (SK < 1.41). However, distributions were close to a value of zero, and so were assigned lognormal distributions. Because the number of data points for methylene chloride and 1,1-dichloroethylene were considered too low to estimate the log standard deviation, these chemicals were assigned the value obtained from pooling the standard deviations associated with chloroform and 1,2-dichloroethane.

Carbon Tetrachloride (3), 1,1,2,2-Tetrachloroethane (3), Tetrachloroethylene (3): The SK varied for this group (SK = 0.29, 2.17, and 1.08, respectively). The SK test did not reject normality for any chemical. However, the distributions were close to a value of zero, so a lognormal distribution was assigned to each chemical.

Chlorobenzene (3): The SK (1.23) was not significant; however, the data points were close to a value of zero. Therefore, a lognormal distribution was assigned to this chemical.

Trichloroethylene (3): The K_{oc} distribution was significantly skewed to the right (SK = 2.67), so a lognormal distribution was assigned to this chemical.

DDT (1-2) and DDE (1): Both K_{oc} distributions were highly skewed to the right (SK > 3.84), so a lognormal distribution was assigned to each chemical.

Chlordane (2-4): The K_{oc} distribution was not considered significantly skewed to the right according to the criteria (SK = 1.89). However, a normal distribution fit to the data implies a significant probability for negative values to occur. Because negative values are meaningless for K_{oc}, a lognormal distribution was assigned to this chemical.

Hexachlorocyclopentadiene (2) and Dicyclopentadiene (NA): The size of the data set (three data points) for hexachlorocyclopentadiene was inadequate to determine a distribution shape and a reasonably accurate estimate of the standard deviation, and K_{oc} estimates were not retrieved for dicyclopentadiene, so the mean for hexachlorocyclopentadiene was assumed for dicyclopentadiene. Chlordane, which has available K_{oc} data, was considered the chemical closest to this group; therefore, chlordane's lognormal distribution and standard deviation were assumed for both hexachlorocyclopentadiene and dicyclopentadiene.

Dibromochloropropane (3): Only a single K_{oc} value was available for dibromochloropropane. This value was used to estimate the mean. A lognormal distribution shape and standard deviation for dibromochloropropane were obtained from 1,1,2,2-tetrachloroethane, the closest chemical to dibromochloropropane in relation to physical/chemical properties.

Chloroacetic Acid: The sample size for chloroacetic acid was n = 1. The value for chloroacetic acid was used to estimate the mean for both distributions. A lognormal distribution and log standard deviation were assumed to follow those estimated for the chloroacetic acid partition coefficient in diethyl ether/water using the DiToro (1985) equation. The partitioning data for diethyl ether/water were converted to K_{oc} (Leo et al. 1971; Okouchi and Sasaki 1985). The partitioning data and the mean and standard deviation of the computed K_{oc} values are summarized below.

Log_{10} diethyl ether/water values = 0.41, 0.42, 0.39. 0.02. 0.37, 1.87.

Mean (Log_e K_{oc}) = 0.7295

Standard deviation (Log_e K_{oc}) = 0.3846

Inorganic COCs: Distributions for metals were fit for K_d values. K_d values for metals—arsenic, cadmium, chromium, lead, and mercury—were highly positively skewed, and so were assigned a lognormal distribution.

B.3.10 SOIL CHARACTERISTICS

This section provides information regarding the characteristics of the soil at RMA. These parameters are used to calculate vapor flux in the open and enclosed space vapor inhalation equations as described in Appendix B.1. Specifically, the temperature, porosity, density, and moisture of the soil at RMA soils are described below. Of these parameters, soil temperature is a fixed parameter. Probabilistic distributions are used for the soil porosity, density, and moisture.

B.3.10.1 Soil Temperature (Fixed)

Due to a lack of specific soil temperature data for RMA, the annual average air temperature of 9.9°C is used as an estimate of the annual average temperature for soil depths extending to the water table. This approach, presented in Ver Te Chow (1964), is based on the premise that the temperature of the soil column is dominated by the subsurface soil, which experiences only minor variations in temperature over the course of a year. The average temperature at nearby Stapleton International Airport is used as a close approximation of the annual average soil temperature at RMA. These data are summarized in Table B.3-50 for the years 1948 through 1987.

B.3.10.2 Total Porosity of RMA Soils (Probabilistic)

Direct porosity measurements of RMA soils are not available. Therefore, soil porosity for RMA was estimated using measured dry soil densities (Walsh and Associates 1988; SCS 1987). Total soil porosity was estimated deterministically using equation (1) (Vomicil 1965):

$$\textbf{Total Porosity} = 100\ [(\textbf{Particle Density} - \textbf{Soil Density})/\textbf{Particle Density}] \qquad (1)$$

where: Particle Density = 2.65 grams per cubic centimeter (g/cm^3)(typical density for mineral soils) (Brady 1974)

The total soil porosity data correspond to soil density data, so they are weighted according to the occurrence of the soil series at RMA. Because of this direct relationship, total porosity is not an independent probabilistic variable. This relationship has been incorporated in the uncertainty

analysis software such that for each value of soil density selected during the Latin Hypercube sampling routine, a corresponding total porosity value is calculated based on the relationship defined above. This results in a normal distribution of total porosity values with a mean of 0.45164 and a standard deviation of 0.06855.

The soil porosity distribution is derived from soil densities measured for depths from 0 to 6 feet. Thus, the porosity distribution is likely to be reasonably accurate for soils up to 6 feet deep. The mean of the soil porosity distribution (0.45165) also falls well within the ranges cited by Freeze and Cherry (1979) as reasonable for unconsolidated deposits such as those found at RMA. Thus, in the absence of soil density data for depths lower than 6 feet, the available bulk density data were chosen to represent all soil horizons.

Use of shallow-depth data could over- or underestimate density at greater depths. However, these values may be slightly more likely to underestimate than overestimate deeper-depth bulk soil densities. An underestimation of bulk density would result in an overestimation of soil porosity, which in turn, would result in an overestimation of risk. However, the magnitude of the over- or underestimation is likely to lie within the bounds of the probability distribution developed for bulk soil density, and is thus accounted for in the vapor model.

B.3.10.3 Density of RMA Soils (Probabilistic)

The soil density distribution is shown in Figure B.3-21. The distribution is somewhat bimodal yet relatively symmetrical, and so was fit with a normal distribution with a mean of 1.45315 and a standard deviation of 0.181662. The data compilation and development of this distribution are described below.

B.3.10.3.1 Data Compilation

The bulk density of the soil at RMA was not measured on a boring-by-boring basis during the CMP or the RI. However, Walsh (1988) and Soil Conservation Service (SCS) (1987) reported soil density data for seven soil series that correspond to the predominant soil series occurring at RMA. These data are summarized in Table B.3-51. The location of each density measurement was not recorded in either source, so the density data are only correlated with soil series.

B.3.10.3.2 Distribution Development

Soil density varies with soil type and, therefore, from site to site throughout RMA. Accordingly, the characterization of an RMA-wide distribution involves consideration of the specific distribution and the combination of distributions for each soil series. The soil series was known for each data point, so specific distributions for each series could be constructed. Representation of the uncertainties associated with soil density at each site cannot be addressed due to functional limitations associated with computer memory and the PPLV program.

The distribution of soil density is a mixture of at least six subdistributions corresponding to the different RMA soil series, each with a different mean, variance, and possible distribution shape. An overlay of all fitted distributions specific to each soil series indicated only small differences between soils. It is, therefore, considered reasonable to use a combined RMA-wide distribution for the soil density parameter. In the combined distribution, each subdistribution must be represented in proportion to the relative likelihood of its occurrence. In other words, the likelihood of occurrence represents the proportion of total area contributed by each soil series. The proportion of total area contributed by each series was estimated from the map depicting the occurrence of soils at RMA (Walsh and Associates 1988), and included in the documentation for the F_{oc} parameter (Section B.3.9).

The soil density distributions were fit using STATGRAPHICS. In fitting soil series-specific distributions for soil density, the Kolmogorov-Smirnov test was the single criterion used to select

a distribution family (if at least 20 data points were available). For those instances in which fewer than 20 data points were available, skewness and outliers were evaluated, as discussed in Appendix B.3. No data points for the soil density parameter were considered to be possible outliers, so this statistical evaluation criterion was not required.

Combined distributions can take on an endless variety of shapes and are too complex visually to derive analytically. A simple approach is to replicate the data of a given soil series so that when it is combined with data from all other series, it represents an appropriate fraction of the total number of data points. In this manner, the distribution shape, mean, and variance were maintained for each soil series data set. In constructing the distribution for the soil density parameter, an arbitrary sample size was selected such that each data set would be replicated with the fewest number of remaining data points. For the soil density parameter, a specific sample size of N = 712 was chosen. Specifically, each series (S) was replicated until there was a total of N_S data points, where N_S was determined by solving the following expression (equation 2):

$$\frac{N_S}{712} \approx f_s \qquad (2)$$

In this equation, f_S represents the fraction of the total RMA soil for soil series S as summarized in the F_{oc} discussion (Table B.3-52).

For some soil series, additional data points were randomly selected so that the number of points would approximately equal N_s. The distribution fit to the replicated set was checked against that fit to the original set and was found to be equivalent for each soil type.

The soil density distribution is shown in Figure B.3-21. The Kolmogorov-Smirnov test, with the original sample size assumed, indicated that normality should be rejected even at the 0.001 significance level. However, a bimodal distribution would not address the real discrepancy, which is soil- or site-dependent.

B.3.10.4 Soil Moisture Content of RMA Soils (Probabilistic)

The soil moisture distribution, shown in Figure B.3-22, is an exponential distribution with a mean of 0.07099. The data and methods used to develop the distribution are described below.

B.3.10.4.1 Data Compilation

All data on moisture content were obtained from CMP and RI data in the RMA database (D.P. Associates 1993). Approximately 25 percent of all soil samples in the database reported information on moisture content. These data were taken from soil samples at different depths and in all regions of RMA. Since the data are evenly distributed over the RMA study areas, and a single distribution is used for all of RMA, the site designations and depth data were not specifically considered in the development of a distribution for the soil moisture parameter.

B.3.10.4.2 Distribution Development

The data were transformed from grams of water per gram of soil to grams per cubic centimeter by multiplying by the mean RMA soil density of 1.45315 (see Section B.3.10.3). The resulting histogram, generated using SPLUS (from Statistical Sciences, Inc.), indicates that the exponential distribution is the only standard distribution that would reasonably fit the soil moisture data. The predominance of zero values precludes the fitting of a lognormal distribution since such values cannot be contained in a lognormal data set.

The fit to an exponential distribution was performed using a reduced data set because the actual number of data points (69,612) was too large for use in STATGRAPHICS. The reduced data set was contrived to precisely mimic the frequencies of the original data set, with the individual data values contributing to each histogram class being uniformly distributed within the class boundaries. The original and contrived data sets are compared in Figure B.3-22 (using contrived units). The fit of the contrived data set to the exponential distribution is shown in Figure B.3-23. The mean of the exponential distribution has a value of 0.07099.

For the purpose of fitting a distribution to the soil moisture data, it was assumed that soil moisture was independent of soil type and associated dependent variables such as soil density, total porosity, and fraction of organic content. In reality, there is likely to be some dependency on these variables, although other factors such as topography and vegetative cover lessen their importance. In developing a distribution for the soil moisture parameter, it is important to consider that moisture content can never be greater than the total porosity of the soil. This adds a very slight additional constraint to the distribution of the moisture content parameter.

The distributions for both the moisture content and the total soil porosity parameters are depicted in Figure B.3-24. As shown in the figure, the two distributions do not overlap significantly. However, there is a very small chance that a soil moisture sample will have a value as high as 0.49, and that a total porosity sample will have a value as low as 0.24, thereby defining the region of potential overlap. In the uncertainty analysis software, statistical sampling of each parameter is conducted independently, thereby minimizing the chance that the highest soil moisture values will correspond with the lowest total porosity values. In the event of such an occurrence, the soil moisture value is automatically set to the total porosity value.

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Table B.3-1 RME Parameter Importance Analysis: Percent Change in Cumulative Pathway Industrial Worker PPLV Resulting from a Two-Fold Increase in Each Parameter

	GENERIC PARAMETERS												CHEMICAL-SPECIFIC PARAMETERS			
	MTRX	SC	TE	DING	CSS	FR	DW	SX	IABS	DINH	BW	ABS	NON. DT. ING.	CAR DT. ING.	NON. DT. INH.	CAR. DT. INH.
Agent Products																
Benzothiazole	45.26	45.26	0	14.29	0.11	0.11	50	45.26	0.11	0.11	100	45.26	99.78		0.05	
Chloracetic Acid	45.26	45.26	0	14.29	0.11	0.11	50	45.26	0.11	0.11	100	45.26	99.78		0.05	
Metals																
Arsenic	23.73	23.73	50	39.32	3.92	3.92	50	23.73	3.92	3.92	100	23.73		92.15		2.08
Cadmium	2.22	2.22	50	4.51	48.19	48.19	50	2.22	48.19	48.19	100	2.22		86.93		3.62
Chromium	0.04	0.04	50	0.08	79.97	79.97	50	0.04	79.97	79.97	100	0.04		99.77		0.06
Copper	24.19	24.19	0	39.94	1.57	1.57	50	24.19	1.57	1.57	100	24.19	96.87		0.8	
Lead	24.24	24.24	0	39.99	1.35	1.35	50	24.24	1.35	1.35	100	24.24	97.3		0.69	
Mercury	24.22	24.22	0	39.97	1.44	1.44	50	24.22	1.44	1.44	100	24.22	97.12		0.74	
Zinc	22.94	22.94	0	22.94	7.58	7.58	50	22.94	7.58	7.58	100	22.94	84.83		4.28	
Semivolatile Organics																
Aldrin	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Chlordane	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
P-Chlorophenylmethyl Sulfoxide	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
P-Chlorophenylmethyl sulfone	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
P-Chlorophenylmethyl sufide	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
DDT	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
DDE	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Dibromochloropropane	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Dicyclopentadiene	34.91	34.91	0	10.05	26.03	26.03	50	34.91	26.03	26.03	100	34.91	47.93		21.36	
Dieldrin	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Endrin	45.26	45.26	50	14.69	0.11	011	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Hexachlorocyclopentadiene	37.49	37.49	0	11.10	21.60	21.60	50	37.49	21.60	21.60	100	37.49	56.81		15.97	
Isodrin	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26	99.78		0.05	

Table B.3-1 RME Parameter Importance Analysis: Percent Change in Cumulative Pathway Industrial Worker PPLV Resulting from a Two-Fold Increase in Each Parameter

	GENERIC PARAMETERS												CHEMICAL-SPECIFIC PARAMETERS			
	MTRX	SC	TE	DING	CSS	FR	DW	SX	IABS	DINH	BW	ABS	NON. DT. ING.	CAR. DT. ING.	NON. DT. INH.	CAR. DT. INH.
Supona	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.23	99.78		0.05	
Volatile Organics																
1,2-Dichloroethane	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
1,1-Dichloroethylene	45.23	45.23	0.11	14.68	0.22	0.22	50	45.23	0.22	0.22	100	45.26		99.56		0.11
Benzene	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Bicycloheptadiene	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26	99.78		0.05	
Carbon Tetrachloride	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Chlorobenzene	45.18	45.18	0	14.65	0.43	0.43	50	45.18	0.43	0.43	100	45.18	99.14		0.22	
Chloroform	45.25	45.25	50	14.69	0.14	0.14	50	45.25	0.14	0.14	100	45.25		99.71		0.07
Dimethyl Disulfide	45.26	45.26	0	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26	99.78		0.05	
Methyl Isobutyl Ketone	45.22	45.22	0	14.67	0.27	0.27	50	45.22	0.27	0.27	100	45.22	99.46		0.14	
Methylene Chloride	45.23	45.23	50	14.68	0.20	0.20	50	45.23	0.20	0.20	100	45.23		99.6		0.1
Tetrachloroethylene	45.28	45.28	50	14.70	0.01	0.01	50	45.28	0.01	0.01	100	45.28		99.99		0
1,1,2,2-Tetrachloroethane	45.26	45.26	50	14.69	0.11	0.11	50	45.26	0.11	0.11	100	45.26		99.78		0.05
Toluene	45.27	45.27	0	14.70	0.06	0.06	50	45.27	0.06	0.06	100	45.27	99.89		0.03	
Trichloroethylene	45.24	45.24	50	14.68	0.17	0.17	50	45.24	0.17	0.17	100	45.24		99.67		0.08

Parameter Key:

MTRX Soil Matrix Effect (also Soil Matrix Factor)
SC Soil Covering
TE Duration of Exposure
DING Soil Ingestion Rate
CSS Ambient Particulate Concentration (Also called Dust Loading Factor)
FR Fraction of Inhaled Particulates Retained
DW Exposure Frequency
SX Skin Surface Area
RME Reasonable Maximum Exposure
IABS Fraction of Inhaled Contaminants Absorbed or Inhalation Absorption
DINH Breathing Rate
BW Body Weight
ABS Oral Absorption Rate
NON.DT.ING Noncarcinogen Dose from Ingestion
CAR.DT.ING Carcinogen Dose from Ingestion
NON.DT.INH Noncarcinogen Dose from Inhalation
CAR.DT.INH Carcinogen Dose from Inhalation
DDE Dichlorodiphenyldichloroethene
DDT Dichlorodiphenyltrichloroethane

Table B.3-2 RME Parameter Importance Analysis: Percent Change in Cumulative Pathway Recreational Visitor PPLV Resulting from a Two-Fold Increase in Each Parameter

CHEMICAL	GENERIC PARAMETERS													CHEMICAL-SPECIFRC PARAMETERS							
	MTRX	SC	TE	DING.2	DING.6	DING.18	CSS	FR	DW	SX2	SX6	SX18	IABS	DING.2	DING.6	DINH.18	BW20	TM	ABS.	NON. DT. ING.	CAR. DT. ING.	NON. DT. INH.	CAR. DT. INH.
Agent Products																							
Benzothiazole	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
Chloroacetic Acid	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
Metals																							
Arsenic	14.27	14.27	50	0.47	2.04	42.81	1.95	1.95	50	0.45	0.62	12.16	1.95	0.47	2.04	42.81	100	1.95	14.27		96.10		1.00
Cadmium	2.26	2.26	50	0.07	0.29	9.43	46.34	46.34	50	0.06	0.09	1.89	46.34	2.77	3.07	41.23	100	46.34	2.26		7.32		76.00
Chromium	0.04	0.04	50	0.00	0.01	0.18	49.94	49.94	50	0.00	0.00	0.03	49.94	3.18	3.53	44.77	100	49.94	0.04		0.12		99.53
Copper	14.42	14.42	0	0.48	2.07	43.11	0.76	0.76	50	0.46	0.63	12.29	0.76	0.03	0.03	0.62	100	0.76	14.42	98.84		0.38	
Lead	14.43	14.43	0	0.02	0.02	0.53	0.65	0.65	50	0.46	0.63	12.30	0.65	0.48	2.07	43.13	100	0.65	14.43	98.70		0.33	
Mercury	14.43	14.43	0	0.48	2.07	43.13	0.70	0.70	50	0.46	0.63	12.30	0.70	0.48	2.07	43.13	100	0.70	14.43	98.61		0.35	
Zinc	14.01	14.01	0	0.46	2.00	42.28	3.92	3.92	50	0.45	0.61	11.93	3.92	0.13	0.15	3.21	100	3.92	14.01	92.16		2.08	
Semivolatile Organics																							
Aldrin	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
Chlordane	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16		99.84		0.04
P-Chlorophenylmethyl sulfide	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
P-Chlorophenylmethyl sulfone	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
P-Chlorophenylmethyl sulfoxide	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
DDT	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16		99.84		0.04
DDE	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16		99.84		0.04
Dibromochloropropane	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16		99.84		0.04
Dicyclopentadiene	32.14	32.14	0	0.14	0.60	17.74	22.25	22.25	50	1.30	1.78	28.51	22.25	0.93	1.04	18.86	100	22.25	32.14	55.50		16.7	
Dieldrin	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16		99.84		0.04
Endrin	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
Hexachlorocyclopentadiene	34.40	34.40	0	0.15	0.65	19.09	17.97	17.97	50	1.42	1.94	30.37	17.97	0.72	0.80	15.11	100	17.97	34.40	64.06		12.30	
Isodrin	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	
Supona	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0	0	0.07	100	0.08	40.16	99.84		0.04	

Table B.3-2 RME Parameter Importance Analysis: Percent Change in Cumulative Pathway Recreational Visitor PPLV Resulting from a Two-Fold Increase in Each Parameter

CHEMICAL	GENERIC PARAMETERS																	CHEMICAL-SPECIFIC PARAMETERS			
	MTRX	SC	TE	DING.2	DING.6	DING.18	CSS	FR	DW	SX2	SX6	SX18	IABS	DING.2	DING.6	DINH.18	BW20	TM	ABS.	NON. DT. ING.	CAR. DT. ING.	NON. DT. INH.	CAR. DT. INH.
Volatile Organics																							
1,2-Dichloroethane	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16		99.84		0.04
1,1-Dichloroethylene	40.14	40.14	50	0.19	0.83	23.17	0.16	0.16	50	1.81	2.46	35.8	0.16	0.01	0.01	0.13	100	0.16	40.14		99.67		0.08
Benzene	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16		99.84		0.04
Bicycloheptadiene	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16	99.84		0.04	
Carbon Tetrachloride	40.16	40.16	50	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16		99.84		0.04
Chlorobenzene	40.10	40.10	0	0.19	0.83	23.14	0.32	0.32	50	1.81	2.46	35.77	0.32	0.01	0.01	0.26	100	0.32	40.10	99.36		0.16	
Chloroform	40.15	40.15	50	0.19	0.83	23.18	0.11	0.11	50	1.81	2.47	35.82	0.11	0.00	0.00	0.09	100	0.11	40.15		99.79		0.05
Dimethyl Disulfide	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16	99.84		0.04	
Methyl Isobutyl Ketone	40.13	40.13	0	0.19	0.83	23.16	0.20	0.20	50	1.81	2.46	35.79	0.20	0.01	0.01	0.16	100	0.20	40.13	99.60		0.10	
Methylene Chloride	40.14	40.14	50	0.19	0.83	23.17	0.15	0.15	50	1.81	2.47	35.81	0.15	0.00	0.00	0.12	100	0.15	40.14				
Tetrachloroethylene	40.18	40.18	50	0.19	0.83	23.20	0.01	0.01	50	1.81	2.47	35.84	0.01	0.01	0.01	0.00	100	0.01	40.18		99.99		0.00
1,1,2,2-Tetrachloroethane	40.16	40.16	0	0.19	0.83	23.18	0.08	0.08	50	1.81	2.47	35.82	0.08	0.00	0.00	0.07	100	0.08	40.16		99.84		0.04
Toluene	40.17	40.17	50	0.19	0.83	23.19	0.04	0.04	50	1.81	2.47	35.83	0.04	0.00	0.00	0.03	100	0.04	40.17	99.62		0.02	
Trichloroethylene	40.15	40.15	0	0.19	0.83	23.18	0.12	0.12	50	1.81	2.47	35.81	0.12	0.01	0.01	0.10	100	0.12	40.15		99.75		0.06

Parameter Key:

MTRX	Soil Matrix Effect (also Soil Matrix Factor)
SC	Soil Covering
TE	Duration of Exposure
DING (2,6,18)	Soil Ingestion Rate for 3 Age Groups
CSS	Ambient Particulate Concentration (Also called Dust Loading Factor)
FR	Fraction of Inhaled Particulates Retained
DW	Exposure Frequency
SX (2,6,18)	Skin Surface Area for 3 Age Groups
IABS	Fraction of Inhaled Contaminants Absorbed
DDE	Dichlorodiphenyldichloroethene
DINH (2,6,18)	Breathing Rate for 3 Age Groups
BW20	Body Weight Averaged Over a Lifetime
ABS	Oral Absorption Rate
TM	Time of Exposure (hrs/day)
IABS	Inhalation Absorption
NON.DT.ING	Noncarcinogen Dose from Ingestion
CAR.DT.ING	Carcinogen Dose from Ingestion
NON.DT.INH	Noncarcinogen Dose from Inhalation
CAR.DT.INH	Carcinogen Dose from Inhalation
RME	Reasonable Maximum Exposure
DDT	Dichlorodiphenyltrichloroethane

Table B.3-3 Assigned Importance Categories for PPLV Parameters

PPLV Parameter	Importance Category	
	Industrial Worker	**Recreational Visitor**
Body Weight (BW)	I	I
Frequency of Exposure (DW)	I	I
Soil Matrix Factor (MTRX)	II	II
Skin Soil Covering (SC)	II	II
Skin Surface Area (SX)	II	II, IV
Exposure Duration (TE)	II	II
Soil Ingestion (SI)	II	II, IV
Dermal Absorption (ABS)	II	II
Dust Loading Factor (CSS)	III	III
Respiratory Deposition (FR)	III	III
Inhalation Absorption (IABS)	III	III
Breathing Rate (DINH/BR)	III	III, IV
Exposure Time (TM)	NA	III

I	Important for all contaminants
II	Important for the majority of contaminants
III	Not important for the majority of contaminants
IV	Not important for any contaminant

Table B.3-4 The Total Number of Hours per Year Spent on the Refuge and the Percentages of Time Spent in Different Types of Activities

Job Category	Total Hrs/Yr	% Time Indoors	% Time Middle (M) Exposure Activity; % Higher (H) Exp. Act. Soil depth: 0–2"	Soil depth: 0–12"	Soil depth:>12"
Engineering Equipment Operator/Crane/Tractor Operator; M: 1/3, MV: 1/1, CO: 2/5 (# Interviewed /# In Job Category)					
* M-B (Eng. Equip. Oper.)	1760	20	M: 34 H: 16	M: H: 17	M: H: 31
* MV-C (Eng. Equip. Oper.)	1816	10	M: 49 H:	M: H: 27	M: H: 20
* CO-L (Eng. Equip. Oper.)	1816	15	M: 26 H: 18	M: H: 19	M: H: 17
* CO-J (Tractor Oper.)	1786	10	M: 15 H: 63	M: H: 5	M: H: 9
Maintenance Mechanic/Worker; M: 1/2, MV: 1/1, CO: 1/3 (# Interviewed /# In Job Category)					
* M-A (Maintenance Mech.)	1840	10	M: 57 H: 34	M: H:	M: H: 1
* MV-F (Main. Mech.)	1920	25	M: 49 H: 4	M: H: 1	M: H: 2
* CO-I (Main. Mech.)	1880	25	M: 46 H:	M: H: 1	M: H: 6
Habitat Management Specialist/Wildlife Biologist; M:1/2, MV: 1/1, CO:1/1 (# Interviewed /# In Job Category)					
* M-F (Habitat Mgt. Specialist)	1786	50	M: 47 H:	M: 8 H:	M: H: 0.4
* MV-B (Wild. Biol.)	1680	60	M: 9 H: 24	M: H:	M: H:
* CO-F (Wild. Biol.)	1840	33	M: 39 H: 30	M: H: 16	M: H: 1
Biological Technician/Assistant Biologist; M: 1/1, MV: 1/1, CO: 1/1 (# Interviewed /# In Job Category)					
* M-H (Wild. Biol. Asst.)	1760	40	M: 40 H:	M: H: 2	M: H:
* MV-A (Bio. Tech.)	1904	30	M: 42 H: 56	M: 1 H: 6	M: 0.46 H:
* CO-C (Biol. Tech.)	1880	20	M: 34 H: 6	M: H: 24	M: H: 2
Work Supervisor/Maintenance Supervisor; M: 1/1, MV: 0/0, CO: 1/1 (# Interviewed /# In Job Category)					
* M-J (Work Supr.)	1780	20	M: 48 H: 4	M: H:	M: H: 12
* CO-K (Main. Supr.)	1610	25	M: 48 H:	M: H: 1	M: H: 2
Archeologist; M: 1/1, MV: 0/0, CO 0/0 (# Interviewed /# In Job Category)					
* M-C (Archaeologist)	1770	50	M: 100 H:	M: 2 H: 8	M: H: 5
Assistant Archeologist; M: 1/1 MV: 0/0 CO: 0/0 (# Interviewed /# In Job Category)					
* M-K (Asst. Arch.)	1920	50	M: 35 H: 19	M: H:	M: H:

Table B.3-4 The Total Number of Hours per Year Spent on the Refuge and the Percentages of Time Spent in Different Types of Activities

Job Category	Total Hrs/Yr	% Time Indoors	% Time Middle (M) Exposure Activity; % Higher (H) Exp. Act. Soil depth: 0–2"	Soil depth: 0–12"	Soil depth:>12"
Refuge Manager; M: 1/1, MV: 1/1, CO: 1/1 (# Interviewed /# In Job Category)					
M-D (Ref. Mgr.)	1316	90	M: 8 H:	M: 0.2 H:	M: 0.8 H:
MV-E (Ref. Mgr.)	1848	90	M: 14 H:	M: H: 0.2	M: H:
CO-G (Ref. Mgr.)	1656	60	M: 44 H:10	M: 0.3 H: 1	M: 7 H:
Assistant Refuge Manager/Deputy Manager; M: 1/1, MV: 0/0, CO: 1/1 (# Interviewed /# In Job Category)					
M-G (Asst. Ref. Mgr.)	1786	70	M: 29 H:	M: 2 H:	M: 6 H:
CO-B (Supr. Ref. Operations Spec.)*	1692	40	M: 43 H:	M: 0.3 H: 0.6	M: 9 H:
Refuge Operations Specialist; M: 0/0, MV: 1/2, CO: 0/0 (# Interviewed /# In Job Category)					
MV-D (Ref. Operations Spec.)	1864	85	M: 15 H:	M: H:	M: H:
Outdoor Recreation Planner; M: 1/1, MV: 1/3, CO: 1/2 (# Interviewed /# In Job Category)					
M-E (Outdoor Recreation Planner)	1728	50	M: 25 H:	M: H: 7	M: H: 10
MV-J (Outdoor Rec Planner)	1760	80	M: 19 H:	M: H:	M: H:
CO-D (Outdoor Recreation Planner	1790	90	M: 10 H:	M: H:	M: H:
Forester; M: 0/0, MV: 0/0, CO: 1/1 (# Interviewed /# In Job Category)					
CO-E (Forester)*	1740	50	M: 36 H:	M: H: 3	M: H:
Administrative Officer/Asst.; M: 0/0, MV: 0/1, CO: 1/1 (# Interviewed /# In Job Category)					
CO-A (Admin. Officer)	1692	70	M: 5 H:	M: H: 0.9	M: H:
Refuge Guide; M: 0/0, MV: 3/3, CO: 1/2 (# Interviewed /# In Job Category)					
MV-G (Ref. Guide)	1920	80	M: 14 H:	M: H:	M: H:
MV-H (Ref. Guide)	1920	80	M: 46 H:	M: H:	M: H:
MV-I Ref. Guide)	1824	80	M: 22 H:	M: H:	M: H:
CO-H (Ref. Guide)	1920	90	M: 6 H:	M: H: 0.6	M: H:

Table B.3-4 The Total Number of Hours per Year Spent on the Refuge and the Percentages of Time Spent in Different Types of Activities

Job Category Individuals	Total Hrs/Yr	% Time Indoors	% Time Middle Exposure Activity; % Higher Exp. Act. Soil depth: 0–2"		Soil depth: 0–12"		Soil depth: >12"	
Refuge Fire Management Officer; M: 1/1, MV: 0/0, CO: 0/0 (# Interviewed /# In Job Category)								
M-1 (Ref. Fire Mgt. Officer)*	1824	50	M: 29	H:	M: 0.4	H:	M: 2	H:

M = Malheur, Oregon; MV = Minnesota Valley, Minnesota; CO = Crab Orchard, Illinois
* Denotes a refuge worker in the subpopulation of biological and maintenance workers.

Table B.3-5 Normalized Proportions of the Time on the Refuge in Three General Types of Refuge Worker Activities: Combined Activities for Soil Depths 0- to 2-inches, 0- to 12-inches, or Greater Than 12 inches (Refuge Workers at Crab Orchard, Illinois; Malheur, Oregon; and Minnesota Valley, Minnesota)

Individuals	(Job Category)	% Time Indoors, Soil Depth		% Time Middle Exposure Activity (M) 0-2"		0-12"		% Higher Exp. Act (H) >12"		Lower	Ps Middle	Higher
*M-B	(Eng. Equip. Oper.)	Indoors	20.0	M: 34.0	H: 16.0	M: .0	H: 17.0	M: .0	H: 31.0	.1695	.2881	.5424
*MV-C	(Eng. Equip. Oper.)	Indoors	10.0	M: 49.0	H: .0	M: .0	H: 27.0	M: .0	H: 20.0	.0943	.4623	.4434
*CO-L	(Eng. Equip. Oper.)	Indoors	15.0	M: 26.0	H: 18.0	M: .0	H: 19.0	M: .0	H: 17.0	.1579	.2737	.5684
*CO-J	(Tractor Oper.)	Indoors	10.0	M: 15.0	H: 63.0	M: .0	H: 5.0	M: .0	H: 9.0	.0980	.1471	.7549
M-A	(Main. Mech)	Indoors	10.0	M: 57.0	H: 34.0	M: .0	H: .0	M: .0	H: 1.0	.0980	.5588	.3431
*MV-F	(Main. Mech)	Indoors	25.0	M: 49.0	H: 4.0	M: .0	H: 1.0	M: .0	H: 2.0	.3086	.6049	.0864
*C0-I	(Main. Mech)	Indoors	25.0	M: 46.0	H: .0	M: .0	H: 1.0	M: .0	H: 6.0	.3205	.5897	.0897
*M-F	(Habitat Mgt. Specialist)	Indoors	50.0	M: 47.0	H: .0	M: 8.0	H: .0	M: .0	H: .4	.4744	.5218	.0038
*MV-B	(Wild. Biol.)	Indoors	60.0	M: 9.0	H: 24.0	M: .0	H: .0	M: .0	H: .0	.6452	.0968	.2581
*CO-F	(Wild. Biol.)	Indoors	33.0	M: 39.0	H: 30.0	M: .0	H: 16.0	M: .0	H: 1.0	.2773	.3277	.3950
*M-N	(Wild. Biol. Asst.)	Indoors	40.0	M: 40.0	H: .0	M: .0	H: 2.0	M: .0	H: .0	.4878	.4878	.0244
*MV-A	(Bio. Tech)	Indoors	30.0	M: 42.0	H: 56.0	M: 1.0	H: 6.0	M: .4	H: .0	.2216	.3205	.4579
*CO-C	(Bio Tech.)	Indoors	20.0	M: 34.0	H: 6.0	M: .0	H: 24.0	M: .0	H: 2.0	.2326	.3953	.3721
*M-J	(Work Supr.)	Indoors	20.0	M: 48.0	H: 4.0	M: .0	H: .0	M: .0	H: 12.0	.2381	.5714	.1905
*CO-K	(Main. Supr.)	Indoors	25.0	M: 48.0	H: .0	M: .0	H: 1.0	M: .0	H: 2.0	.3289	.6316	.0395
*M-C	(Archaeologist)	Indoors	50.0	M: 100.0	H: .0	M: 2.0	H: 8.0	M: .0	H: 5.0	.3030	.6182	.0788
*M-K	(Asst. Arch.)	Indoors	50.0	M: 35.0	H: 19.0	M: .0	H: . 0	M: .0	H: .0	.4808	.3365	.1827
M-D	(Ref. Mgr.)	Indoors	90.0	M: 8.0	H: .0	M: .2	H: .0	M: .8	H: .0	.9091	.0909	.0000
MV-E	(Ref. Mgr.)	Indoors	90.0	M: 14.0	H: .0	M: .0	H: .2	M: .0	H: .0	.8637	.1344	.0019
CO-G	(Ref. Mgr.)	Indoors	60.0	M: 44.0	H: 10.0	M: .3	H: 1.0	M: 7.0	H: .0	.4906	.4195	.0899
M-G	(Asst. Ref. Mgr.)	Indoors	70.0	M: 29.0	H: .0	M: 2.0	H: .0	M: 6.0	H: .0	.6542	.3458	.0000
*CO-B	(Supr. Ref. Oper.)	Indoors	40.0	M: 43.0	H: .0	M: .3	H: .6	M: 9.0	H: .0	.4306	.5630	.0063
MV-D	(Ref. Operations Spec.)	Indoors	85.0	M: 15.0	H: .0	M: .0	H: .0	M: .0	H: 10.0	.8500	.1500	.0000
M-E	(Outdoor Rec. Planner)	Indoors	50.0	M: 25.0	H: .0	M: .0	H: 7.0	M: .0	H: .0	.5435	.2717	.1848
MV-J	(Outdoor Rec. Planner)	Indoors	80.0	M: 19.0	H: .0	M: .0	H: .0	M: .0	H: .0	.8081	.1919	.0000
CO-D	(Outdoor Rec. Planner)	Indoors	90.0	M: 10.0	H: .0	M: .0	H: .0	M: .0	H: .0	.9000	.1000	.0000
*CO-E	(Forester)	Indoors	50.0	M: 36.0	H: .0	M: .0	H: 3.0	M: .0	H: .0	.5618	.4045	.0337
CO-A	(Admin. Officer)	Indoors	70.0	M: 5.0	H: .0	M: .0	H: .9	M: .0	H: .0	.9223	.0659	.0119
MV-G	(Ref. Guide)	Indoors	80.0	M: 14.0	H: .0	M: .0	H: .0	M: .0	H: .0	.8511	.1489	.0000
MV-N	(Ref. Guide)	Indoors	80.0	M: 46.0	H: .0	M: .0	H: .0	M: .0	H: .0	.6349	.3651	.0000
MV-I	(Ref. Guide)	Indoors	80.0	M: 22.0	H: .0	M: .0	H: .0	M: .0	H: .0	.7843	.2157	.0000
CO-N	(Ref. Guide)	Indoors	90.0	M: 6.0	H: .0	M: .0	H: .6	M: .0	H: .0	.9317	.0621	.0062
*M-I	(Fire Mgt. Officer)	Indoors	50.0	M: 29.0	H: .0	M: .4	H: .0	M: 2.0	H: .0	.6143	.3857	.0000

M = Malheur, Oregon; MV = Minnesota Valley, Minnesota; CO = Crab Orchard, Illinois

* Denotes a refuge worker in the subpopulation of biological and maintenance workers.

Table B.3-6 Soil Ingestion Distributions

Exposed Population	Distribution	$\bar{y}$	Sy	M_x (mg/day)	Sx (mg/day)	50% (mg/day)	95% (mg/day)
Regulated/Casual Visitor							
<1 year	Fixed	—	—	1.0	—	—	—
1-7 years	Lognormal	3.970	0.8073	73.40	70.36	53	200
8 years-Adult	Lognormal	3.277	0.8073	36.70	35.18	26.5	100
Recreational Visitor							
<1 year	Fixed	—	—	1.0	—	—	—
1-7 years	Lognormal	3.970	0.8073	73.40	70.36	53	200
8 years-Adult	Lognormal	3.277	0.8073	36.70	35.18	26.5	100
Industrial Worker	Lognormal	2.565	0.8189	18.18	17.77	13	50
Commercial Worker	Lognormal	2.303	0.7258	13.02	10.84	10	33
Biological Worker	Lognormal	3.401	0.7673	40.26	36.05	30	106

$\bar{y}$ = log mean
Sy = log standard deviation
M_x = mean
Sx = standard deviation
- = not appliclable

Table B.3-7 Age-Specific Daily Soil Ingestion Rates Reported in Studies Using Tracer Methodologies

			Mean SIR (mg/d)						Median SIR (mg/d)					Variances							
Study	Age (Yrs)	N	Si	Ti	Al	Zr	LTM	Type	Si	Ti	Al	Zr	LTM	Si	Ti	Al	Zr	LTM	Type	Dist.	Comments
Davis et al. 1990	2–7(1)	104	82.4	246	38.9			Arth	59.3	81.3	24.3			12.2	120	14.4			SEM	unknown	A
Stanek et al. 1991														0.00397	0	0.0023	0.00132		(2)		
														0.00488	0.282	0.00563	0.00126		(3)		
	1–1.5	12							2	18	20	9								Lognormal	A
	1.5–2	9							–14	43	9	20								Lognormal	
	2–2.5	12							49	54	20	–5								Lognormal	
	2.5–3	12							47	23	35	13								Lognormal	
	3–3.5	7							82	64	39	29								Lognormal	
	3.5–4	7							106	264	41	39								Lognormal	
van Wijnen et al. 1990																					
	0–1	7					97.5	Geomean										1.66	GSD	Lognormal	B
	1–2	60					180	Geomean										3.12	GSD	Lognormal	
Day Care	2–3	96					142	Geomean										2.09	GSD	Lognormal	
	3–4	98					136	Geomean										1.91	GSD	Lognormal	
	4–5	14					126	Geomean										2.06	GSD	Lognormal	
Hospital	1–5	15					74	Geomean										2.34	GSD	Normal	
Binder et al. 1986	1–3(4)	59	184	1,834	181			Arth.	136	618	121			175	3,091	203			SD	Lognormal	B
Clausing et al. 1987																					
Nursery School	2–4	18(5)					105											67		Normal	B
Hospital	<4	6					49											22		Normal	
Calabrese et al. 1989	>18	6	5	377	77	22		Arth.	1	211	57	–4		55	518	65	141		SD	Normal	A

(1) Age Distribution of participants, age (%): 2(11); 3(15); 4(17); 5(21): 6(21); 7(15)
(2) Estimate of variance of soil ingestion between subjects.
(3) Estimate of variance within subjects (between weeks).
(4) Age distribution of participants (%): <1(2); 1-2(25); 2-3(73).
(5) Based on 27 samples taken from 18 children using the Limiting Tracer Method.
A SIR value(s) was adjusted for nonsoil sources.
Al aluminum
Arth arithmetic mean
B SIR value(s) was not adjusted for nonsoil sources.
Dist. distribution
Geomean geometric mean
GSD Geometric Standard Deviation
N numberr
LTM least tracer method
SEM Standard Error of the Mean
SD Arithmetic Standard Deviation
Si silicon
Ti titanium
yrs years
Zr zircon

Table B.3-8 Study-Specific Single-Year Age Classes Used in Assessing the Appropriateness of Pooling for Ages 0–17

Derived From	Age Class	Distribution Type	y^1	S_y	mean (mg/day)	50% (mg/day)	95% (mg/day)
Davis et al. 1990	2	Lognormal	4.052	1.14	107.1	57.54	168.0
Davis et al. 1990	3	Lognormal	3.682	1.022	67.03	39.72	91.04
Davis et al. 1990	4	Lognormal	4.097	0.7727	81.10	60.17	73.29
Davis et al. 1990	5	Lognormal	3.8807	0.9549	71.02	45.02	86.66
Davis et al. 1990	6-7	Lognormal	3.952	1.070	92.27	52.06	135.03
Stanek et al. 1991	1	Lognormal	2.853	1.273	39.00	17.34	75.58
Stanek et al. 1991	2	Lognormal	3.775	1.100	79.86	43.60	122.6
Stanek et al. 1991	3	Lognormal	4.096	1.039	103.0	60.07	143.5
van Wijnen et al.[3] 1990	infant	Lognormal	4.580	0.507	110.9	97.5	60.04
van Wijnen et al.[3] 1990	1	Lognormal	5.196	2.24	345.78	180.5	564.78
van Wijnen et al.[3] 1990	2	Lognormal	4.959	0.737	187.1	142.5	158.9
van Wijnen et al.[3] 1990	3	Lognormal	4.909	0.647	167.23	135.5	120.57
van Wijnen et al.[3] 1990	4	Lognormal	4.840	0.723	164.25	126.5	136.1

1 y = log e (soil ingestion) sy standard deviation
2 x = soil ingestion y mean
3 Based on data prior to correction for non-soil sources

Table B.3-9 Study-Specific Multiyear Class Distributions for Ages 0–17

Age Class	Distribution Type	y[1]	S_y	mean (mg/day)	50% (mg/day)	95% (mg/day)	References
Infant	Lognormal	3.887	0.5068	55.45	48.765	30.01	van Wijnen et al. 1990 (ages <1) (Corrected for background tracer ingestion)
1–7	Lognormal	3.874	1.057	84.18	48.14	120.76	Davis et al. 1990 (ages 2-7)
1–7	Lognormal	3.574	1.162	70.06	35.65	118.5	Stanek et al. 1991 (ages 1-3)
1–7	Lognormal	4.314	0.7885	102.0	74.73	94.69	van Wijnen et al. 1990 (ages 1-4)
1–7	Lognormal	4.281	0.7667	96.92	72.3	86.69	Clausing et al. 1987 (ages 2-4)

1 $y = \log_e$ (soil ingestion)
2 x = soil ingestion rate
y Mean
S_y Standard deviation

Table B.3-10 Exposed Skin Surface Area for RMA Populations[1]

Age Group (years)	Exposed Population Skin Surface Area (square centimeters)				
	Regulated/Casual Visitors	Recreational Visitors	Commercial Workers[2]	Industrial Workers[2]	Biological Worker[2]
0<1	1580	1940	N/A	N/A	N/A
1<2	1620	2160	N/A	N/A	N/A
2<3	1780	1780	N/A	N/A	N/A
3<4	2110	2110	N/A	N/A	N/A
4<5	2310	2310	N/A	N/A	N/A
5<6	2440	2440	N/A	N/A	N/A
6<7	2580	2580	N/A	N/A	N/A
7<8	2760	2760	N/A	N/A	N/A
8<9	2970	2970	N/A	N/A	N/A
9<10	3170	3170	N/A	N/A	N/A
10<11	3400	3400	N/A	N/A	N/A
11<12	3630	3630	N/A	N/A	N/A
12<13	3860	3860	N/A	N/A	N/A
13<14	3970	3970	N/A	N/A	N/A
14<15	4150	4160	N/A	N/A	N/A
15<16	4320	4320	N/A	N/A	N/A
16<17	4480	4480	N/A	N/A	N/A
17<18	4780	4780	N/A	N/A	N/A
>18	4790	4790	1550	3270	3270

1 Values were converted from square meters to square centimeters using a conversion factor of 10,000.
2 Only adults were evaluated for this exposed population.
N/A Denotes not applicable.

Table B.3-11 Surface Area Information by Age Groups[1]

Age Group (years)	Total Body Surface Area[2] (square meters)	Percentage of Total Body Surface Area				
		Head	Arms	Hands	Legs	Neck[3]
0<4	0.4641[4]	18.2	13.7	5.3	20.6	1.2
1<4	0.529[4]	16.5	13.0	5.7	23.1	1.2
2<3	0.591	14.2	11.8	5.3	23.2	1.2
3<4	0.656	13.6	14.4	6.1	26.9	1.2
4<5	0.718	13.8	14.0	5.7	27.8	1.2
5<6[4]	0.786[4]	13.4	13.5	5.2	27.5	1.2
6<7	0.854	13.1	13.1	4.7	27.1	1.2
7<8[4]	0.926[4]	12.6	12.7	4.9	27.7	1.2
8<9[4]	1.00[4]	12.3	12.5	5.1	28.0	1.2
9<10	1.06	12.0	12.3	5.3	28.2	1.2
10<11[4]	1.18[4]	11.1	12.8	5.3	29.2	1.2
11<12[4]	1.26	10.3	13.3	5.4	30.2	1.2
12<13	1.37	8.7	13.7	5.4	30.5	1.2
13<14	1.48	10.0	12.1	5.1	32.0	1.2
14<15[4]	1.58[4]	8.2	12.2	5.0	31.9	1.2
15<16[4]	1.64	8.0	12.7	5.0	32.6	1.2
16<17	1.68	8.0	13.1	5.1	33.5	1.2
17<18	1.72	7.6	17.5	5.1	30.8	1.2
>18	1.82	7.2	14.3	5.0	32.7	1.2

1 Data in this table were obtained or calculated from data in EPA (1985b, Tables 3-6, 3-7, 3-8, 3-10, 3-11, 3-12). Data represent the basis from which surface areas for specific body parts were derived (see Table B.3-12).

2 Total body surface area in square meters was calculated by taking the arithmetic mean of the 50th percentile total body surface area in square meters for males and females (EPA 1985b, Table 3-9).

3 Value was based on percent total surface area for neck as calculated by Popendorf's Anatomical Model as presented on page 18 in EPA (1985b, Table 3-4).

4 No data points were available for these age groups, so surface area estimates were derived by interpolation using linear regression.

Table B.3-12 Skin Surface Area for Specified Body Parts[1]

Age Group (years)	Total Body Surface Area[2] (square meters)	Body Parts Surface Area (square meters)				
		Head	Arms[3]	Hands	Legs[3]	Neck
0<1	0.464[4]	0.084	0.0381	0.025	0.0571	0.006
1<2	0.528[4]	0.087	0.0412	0.030	0.0732	0.006
2<3	0.591	0.084	0.0418	0.031	0.0822	0.007
3<4	0.656	0.089	0.0567	0.040	0.106	0.008
4<5	0.718	0.099	0.0606	0.041	0.1120	0.009
5<6	0.786	0.106[5]	0.0639[5]	0.041[5]	0.130[5]	0.009
6<7	0.854	0.112	0.0672	0.040	0.139	0.010
7<8	0.926	0.117	0.0708[5]	0.046[5]	0.154[5]	0.011
8<9	1.00	0.123	0.075[5]	0.051[5]	0.169[5]	0.012
9<10	1.06	0.130[6]	0.0786	0.056	0.184	0.013
10<11	1.18	0.130[6]	0.090[5]	0.0622[5]	0.206[5]	0.014
11<12	1.26	0.130[6]	0.101[5]	0.068[5]	0.229[5]	0.015
12<13	1.37	0.130[6]	0.113	0.074	0.251	0.016
13<14	1.48	0.130[6]	0.107	0.075	0.283	0.018
14<15	1.58	0.130[6]	0.116[5]	0.079[5]	0.302[5]	0.190
15<16	1.64	0.130[6]	0.124[5]	0.082[5]	0.320[5]	0.200
16<17	1.68	0.130[6]	0.132	0.085	0.338	0.020
17<18	1.72	0.130[6]	0.180	0.088	0.317	0.021
>18	1.82[7]	0.130[6]	0.156[7]	0.090[7]	0.356[7]	0.022

Note: Data in this table were either taken directly from or calculated from data presented in EPA (1985b).

1 Represents an average of the 50th percentile male and female total surface areas (EPA 1985b, Tables 3-5, 3-6, 3-10, 3-11).
2 Specific body part surface areas were calculated for ages 0 to 18 years using the total body surface area and percent of total surface area for each part as presented in Table B.3-11.
3 Values given represent 60 percent of the total surface area for arms and legs assumed to be exposed while wearing short-sleeve shirts or short pants.
4 Interpolated using linear regression.
5 Calculated by linear interpolation of the closest bordering values.
6 Value represents average head surface area for ages 9 years to adult. This average was calculated and assigned to all ages 9 years through adult since the available data were too variable to detect a trend. No correction for hats and hair coverage was conducted.
7 Empirical data obtained from EPA (1985b).

Table B.3-13 Probabilistic Distributions for Soil Covering by Exposed Population

Exposed Population age Group[1]	Qualitative SC Rating	Reference	Sample Size	Type of Study (ages in years)	Estimated Distribution for SC	mean μ	Standard Deviation Ó	Log Mean y	Log Standard Deviation S_y
Regulated Casual-Infants (0 to <1)	very low	Judgment[2]	NA	NA	normal	0.02	0.006	NA	NA
Regulated Casual-Toddler (1 to <7)	medium	Lepow et al. (1975)	22	playground sample (2-6)	lognormal	0.51	0.83	-1.3	1.1
Regulated Casual-Children Adolescent(s) (7 to <18)	low	Que Hee et al. (1985)	[3]	soil application (small adult)	lognormal	0.20	0.10	-1.7	0.49
Regulated Casual (18 to <75)	low	Que Hee et al. (1985)	[3]	soil application (small adult)	lognormal	0.20	0.10	-1.7	0.49
Recreational-Infant (0 to <1)	very low	Judgment[2]		NA	normal	0.02	0.006	NA	NA
Recreational-Toddler (1 to <7)	medium	Lepow et al. (1975)	22	playground sample (2-6)	lognormal	0.51	0.83	-1.3	1.1
Recreational-Children Adolescent (7 to <18)	high	Roels et al. (1980)	[4]	playground sample (9-14)	normal	0.86	0.28	NA	NA
Recreational-Adult (18 to <75)	medium	Driver et al. (1989)	[3]	soil application (adult)	lognormal	0.57	0.22	-0.63	0.37
Commercial-Adult (18 to <75)	very low	Hawley (1985)	NA	theoretical (adult)	normal	0.0546	0.014[2]	NA	NA
Industrial-Adult (18 to <75)	medium-high	Judgment[2]		NA	lognormal	0.52	0.257	-0.77	0.47
Biological Worker (18 to <75)	low to high	Hawley (1985) Que Hee et al. (1985) Driver et al.(1989) Roels et al. (1980)	NA [3] [3] [4]	theoretical (adult) soil application (small adult) soil application (adult) playground sample (9-14)	normal[5]	0.41	0.20	-1.0	0.47

1 Infants (0 to <1 years), Toddlers (1 to <7 years), Children Adolescents (7 to <18 years), Adults (18 to <75 years)
2 Estimation included judgment by EBASCO
3 Experimental application of soil was replicated several times on the same set of hands
4 Different individuals sampled; however, the sample size was not reported
5 Biological worker SC distribution is a time-weighted average value based on the four reference studies
NA Not applicable
SC Soil Covering

Table B.3-14 Summary of Dust/Soil Adherence Values

Soil Adherence (mg/cm^2)	Size Fraction of Soil (in microns)	Age Group	Reference
0.51	-	Children	Lepow et al. (1975)
0.86	-	Adolescent	Derived from Roels et al. (1980)
0.170	<44	Adolescent	Derived from Que Hee et al. (1985)
0.173	44-149	Adolescent	
0.197	149-177	Adolescent	
0.183	177-246	Adolescent	
0.0644	246-392	Adolescent	
0.384	392-833	Adolescent	
1.40	<150	Adult Male	Driver et al. (1989)
0.95	<250	Adult Male	
0.58	Unsieved	Adult Male	
0.88	<150[3]	Adult Male	
0.48	Unsieved[3]	Adult Male	
1.4 (potting soil)	-	Adult	Harger (1979)
2.8 (kaolin)	-	Adult	
3.5[4]	-	Adult	Hawley (1985)
1.8[5]		Adult	
0.56[6]		Adult	

1 Soil adherence = weight of soil sample/percent of skin surface area in milligrams per square centimeter (mg/cm^2).
2 Derived by Sedman (1989) using data from Roels et al. (1980).
3 Soils of high and low organic content were studied to determine the influence of organic matter on soil adherence. Soil adherence values were not found to be significantly different, so the average was taken.
4 Outdoor yardwork exposure scenario assuming a 50 µm coating of soil on hands and forearms.
5 Attic exposure scenario assuming a 50 µm coating of dust on hand and forearms.
6 Ordinary living space exposure assuming dust exposure on hands.

Table B.3-15 Summary of Oral and Dermal Soil Absorption Estimates

Chemical	Species (N)	Oral % ABS	Reference	Species (N)	Dermal % ABS	Reference
Aldrin	Rat (10)	44[2]	MRI 1991	Human	1.0*	Feldman and Maibach 1974
Arsenic	Rabbit	42[3]	Griffin & Turck 1991	NA	NA	NA
Benzene	Rat (12)	61.4[4,5] 60.5[3,4]	Turkall et al. 1988 Abdel-Rahman and Turkall 1988	Rat (12)	54.7[4,5]	Abdel-Rahman and Turkall 1988
Cadmium	ND	ND	ND	NA	NA	NA
Carbon Tetrachloride	ND	ND	ND	ND	ND	ND
Chlordane	ND	ND	ND	Monkey (4) Human (NA)	4.2 0.34	Wester et al. 1992 Wester et al. 1992
Chloroacetic Acid	ND	ND	ND	ND	ND	ND
Chlorobenzene	ND	ND	ND	ND	ND	ND
Chloroform	ND	ND	ND	ND	ND	ND
Chromium	ND	ND	ND	NA	NA	NA
Dicyclopentadiene	ND	ND	ND	ND	ND	ND
DDE	ND	ND	ND	Monkey (4)	3.3	Wester et al. 1990
DDT	ND	ND	ND	Human (NA)	1.0[8]	Wester et al. 1990
Dibromochloropropane	ND	ND	ND	ND	ND	ND
1,1-Dichloroethylene	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND
Dieldrin	Rat (10)	78[2]	MRI 1991	Human	2.0*	Feldman and Maibach 1974
Endrin	ND	ND	ND	ND	ND	ND
Hexachlorocyclopentadiene	ND	ND	ND	ND	ND	ND

Table B.3-15 Summary of Oral and Dermal Soil Absorption Estimates

Chemical	Species (N)	Oral % ABS	Reference	Species (N)	Dermal % ABS	Reference
Isodrin	ND	ND	ND	ND	ND	ND
Lead	[6]	30[6]	EPA 1991b	NA	NA	NA
Mercury	Mice (35)	9.1[7]	Revis et al. 1990	NA	NA	NA
Methylene Chloride	ND	ND	ND	ND	ND	ND
PCB	Rat (12)	82[8]	Fries et al. 1989	ND	ND	ND
PCE	ND	ND	ND	ND	ND	ND
TCE	ND	ND	ND	ND	ND	ND
1,1,2,2-Tetrachloroethylene	ND	ND	ND	ND	ND	ND
Toluene	Rat (12)	75.7[4,5]	Turkall et al. 1991	Rat (12)	84.4[4,5]	Skowronski et al. 1989

1 RAF values were not developed for metals for the dermal pathway.
2 Percent absorption equals portion of administered compound recovered in feces. Only high dose groups were considered.
3 Represents an average of oral absorption of arsenic at low (0.46 mg/kg) and low (4.64 mg/kg) doses.
4 Percent absorption value represents a total excretion (primarily from urine) excluding expired breath.
5 Average of total percent ABS from sandy and clay soil types.
6 An absorption value for lead from a soil matrix of 30% is reported by EPA (1991b). EPA indicates this value is based on empirical data that addresses speciation. Details of this research were not available.
7 Represents an average of percent absorption determined for mercury present in feces from soil samples at varying dose levels detected in floodplain soil along East Fork Popular Creek.
8 PCBs are not COCs at RMA; however, associated data were considered in evaluating dermal RAFs for Group A chemicals. The oral % ABS represents an average of total urine and body fat percent ABS (feces minus percent parent compound from 2,2,5-trichlorobiphenyl, 2,2,4,5,5-pentachlorobiphenyl administered in various soil types and dose levels).
9 Value derived from in vitro data.

ABS Absorption
ND Denotes no data available.
NA Denotes not applicable.
* %ABS based on pure compound (12-hour value cited).

Table B.3-16 Chemical Classification Scheme for Bioavailability Parameter

A	B	C[1]
DDT	Carbon Tetrachloride	Arsenic
DDE	Chlorobenzene	Lead
Aldrin	Chloroform	Mercury
Chlordane	Dibromochloropropane	Cadmium
Dicyclopentadiene	1,2-Dichloroethane	Chromium
Dieldrin	1,1-Dichloroethylene	
Endrin	1,1,2,2-Tetrachloroethane	
Isodrin	Tetrachloroethylene	
Hexachlorocyclopentadiene	Toluene	
	Trichloroethylene	
	Benzene	
	Methylene Chloride	
	Chloroacetic acid	

1 For metals, oral RAFs were determined on an individual basis; dermal pathway RAFs were not developed.

Table B.3-17 Summary Data and Assigned Uniform Distributions for Oral RAF for COCs

Group	Chemical	Summary % ABS Data[1] Soil	RfD	CPF	Assigned Mean Soil % ABS Soil	Est. Mean RAF RfD	CPF	Dist. (Min, Max)[2] RfD	CPF
A	DDT	ND	ND	ND	61	NE	NE	0.61,1.0	0.61,1.0
	DDE	ND	ND	ND	61	NE	NE	0.61,1.0	0.61,1.0
	Aldrin	44	96.8	96.8	44	0.45	0.45	0.25,0.65	0.25,0.65
	Chlordane	ND	ND	ND	61	NE	NE	0.61,1.0	0.61,1.0
	DCPD	ND	ND	NA	61	NA	NA	0.61,1.0	NA
	Dieldrin	78	98	98	78	0.80	0.80	0.60,1.0	0.60,1.0
	Endrin	ND	ND	NA	61	NA	NA	0.61,1.0	NA
	Isodrin	ND	ND	NA	61	NA	NA	0.61,1.0	NA
	HCCPD	ND	ND	NA	61	NA	NA	0.61,1.0	NA
B	Carbon Tetrachloride	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	Chlorobenzene	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	Chloroform	ND	ND	96[3] 89[3]	68	NE	0.74	0.68,1.0	0.54,0.94
	DBCP	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	1,2-Dichloroethane	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	1,1-Dichloroethylene	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	1,1,2,2-Tetrachloroethane	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	Tetrachloroethylene	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	Toluene	75.7	ND	NA	75.7	NE	NA	0.76,1.0	NA
	Trichloroethylene	ND	ND	93	68	NE	0.73	0.68,1.0	0.53,0.93
	Benzene	61.4 60.5	ND	ND	61	NE	NE	0.61,1.0	0.61,1.0
	Methylene Chloride	ND	ND	ND	68	NE	NE	0.68,1.0	0.68,1.0
	Chloroacetic Acid	ND	ND	NA	68	NE	NA	0.68,1.0	NA
C	Arsenic	42	ND	ND	42	NE	NE	0.42,1.0	0.42,1.0
	Lead	30	ND	NA	ND	NE	NA	0.30,1.0	NA
	Mercury	9.1	ND	NA	9.1	NE	NA	0.09,1.0	NA
	Cadmium	ND	ND	NA	ND	NE	NA	1.0	NA
	Chromium	ND	ND	NA	ND	NE	NA	1.0	NA

1 RfD and CPF refer to absorption from critical toxicity studies.

2 Upperbound distributions values of 1.0 imply uncertainty in critical toxicity study absorption due to a lack of data.

3 Mean used to determine RAF.

ND No data.

NE Not estimated.

NA Not applicable.

Table B.3-18 Absorption Estimates (Percentages) for Organic COCs From Media Administered in the Critical Toxicity Study

Chemical	RfD	CPF	Reference
Aldrin	96.8[1]	96.8[1]	MRI 1991
Benzene	ND	ND	
Carbon Tetrachloride	ND	ND	
Chlordane	ND	ND	
Chloroacetic Acid	ND	NA	
Chlorobenzene	ND	ND	
Chloroform	ND	96[2] 89[3]	Brown et al. 1974 Taylor et al. 1974
DDE	ND	ND	
DDT	ND	ND	
DBCP	ND	ND	
1,2-Dichloroethane	ND	ND	
1,1-Dichloroethene	ND	ND	
DCPD	ND	NA	
Dieldrin	98[1]	98[1]	MRI 1991
Endrin	ND	NA	
HCCPD	38[4]	NA	Lawrence and Dorough 1982
Isodrin	ND	NA	
Methylene Chloride	ND	ND	
Aldrin	96.8[1]	96.8[1]	MRI 1991
1,1,2,2-Tetrachloroethane	ND	ND	
Tetrachloroethylene	ND	ND	
Toluene	ND	NA	
Trichloroethylene	ND	93[5]	Prout et al. 1985 Dekant et al. 1984

1 Represents parent compound in feces minus administered compound following high dose of aldrin/dieldrin in diet (MRI 1991).
2 Represents the average of percent total recovery of radioactivity in excreta and tissues of mice.
3 Represents the average of percent of administered radioactivity in the feces and urine after oral administration of radiolabelled chloroform.
4 Value represents percentage radioactivity in biliary excretions (13.5 percent) and urine.
5 Average percentage absorption values from Prout et al. (1985) and Dekant et al. (1984).

NA Denotes Not Applicable
ND Denotes No Data Available

Table B.3-19 Summary Data and Assigned Uniform Distributions for Dermal RAF for COCs

		Summary % ABS Data				Assigned Mean % ABS		Dist. (Min, Max)[1]	
Group	Chemical	Soil	Pure	RfD	CPF	Soil	Pure	RfD	CPF
A	DDT	3.3 1.0	NE	ND	ND	2.2	A	0.002,0.042	0.002,0.042
	DDE	ND	NE	ND	ND	2.2	NA	0.002,0.042	0.002,0.042
	Aldrin	ND	1.0	96.8	96.8	NE	1.0	0.00062,0.0052	0.00062,0.0052
	Chlordane	4.2,0.34	6.0[2]	ND	ND	2.27	NA	0.003,0.043	0.003,0.043
	DCPD	ND	ND	ND	NA	2.2	NA	0.002,0.042	NA
	Dieldrin	ND	2.0	98	98	NE	2.0	0.0012,0.01	0.0012,0.01
	Endrin	ND	NE	ND	NA	2.2	NA	0.002,0.042	NA
	Isodrin	ND	NE	ND	NA	2.2	NA	0.002,0.042	NA
	HCCPD	ND	NE	38	NA	2.2	NA	0.038,0.078	NA
B	Carbon Tetrachloride	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	Chlorobenzene	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	Chloroform	ND	NE	ND	96[3] 89[3]	69	NA	0.69,1.0	0.55,0.95
	DBCP	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	1,2-Dichloroethane	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	1,1-Dichloroethylene	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	Methylene Chloride	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	1,1,2,2-Tetrachloroethane	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	Tetrachloroethylene	ND	NE	ND	ND	69	NA	0.69,1.0	0.69,1.0
	Toluene	82.4	NE	ND	NA	82.4	NA	0.82,1.0	NA
	Trichloroethylene	ND	NE	ND	93	69	NA	0.69,1.0	0.54,0.94
	Benzene	54.7	NE	ND	ND	54.7	NA	0.55,1.0	0.55,1.0
	Chloroacetic Acid	ND	NE	ND	NA	69	NA	0.69,1.0	NA

		Summary % ABS Data				Assigned Mean % ABS		Dist. (Min, Max)[1]	
Group	Chemical	Soil	Pure	RfD	CPF	Soil	Pure	RfD	CPF
C	Arsenic[4]	NA	NE	ND	ND	NE	NA	NA	NA
	Lead[4]	NA	NE	ND	NA	NE	NA	NA	NA
	Mercury[4]	NA	NE	ND	NA	NE	NA	NA	NA
	Cadmium[4]	NA	NE	ND	NA	NE	NA	NA	NA
	Chromium[4]	NA	NE	ND	NA	NE	NA	NA	NA

1 Dermal RAF distributions for Group A and B chemicals were estimated using the approach illustrated in Figure B.3-13. Upperbound distribution values of 1.0 imply uncertainty in critical toxicity study absorption due to lack of data.
2 Percent absorption based on acetone vehicle.
3 Mean used to determine RAF.
4 Metals treated qualitatively.
ND No data.
NE Not estimated.
NA Not applicable.

Table B.3-20 Time-Weighted Average Breathing Rates for Exposed Populations (m^3/hr)

Age	Regulated/ Casual (BR)	Recreational (BR)	Commercial (DINH and RB)	Industrial (DINH and RB)	Biological/ Maintenance Worker (DINH)
Infants	0.23	0.23	NA	NA	NA
1-2	0.67	0.67	NA	NA	NA
2-3	0.86	0.86	NA	NA	NA
3-4	1.0	1.0	NA	NA	NA
4-5	1.2	1.9	NA	NA	NA
5-6	1.4	2.2	NA	NA	NA
6-7	1.6	2.7	NA	NA	NA
7-8	1.8	3.1	NA	NA	NA
8-9	2.0	3.2	NA	NA	NA
9-10	2.1	3.6	NA	NA	NA
10-11	1.6	3.0	NA	NA	NA
11-12	1.5	3.0	NA	NA	NA
12-13	1.4	3.2	NA	NA	NA
13-14	1.5	3.7	NA	NA	NA
14-15	1.5	4.0	NA	NA	NA
15-16	1.5	4.0	NA	NA	NA
16-17	1.6	4.5	NA	NA	NA
17-18	1.4	4.7	NA	NA	NA
18-75	1.3	3.6	0.83	2.1	2.1

BR Breathing rate for the regulated/casual visitor.

DINH Breathing rate for the commercial and industrial worker.

RB Breathing Rate for the commerical and industrail worker in an enclosed basement space.

NA Not Applicable.

Table B.3-21 Age-Specific Breathing Rates for Designated Activity Level (m^3/hr)[1,2]

Age	Resting	Light	Moderate	Heavy	Very Heavy[3]
0-1	0.05	0.41[3]	0.49[3]	0.85[3]	NA
1-2	0.11[3]	0.55[3]	0.79[3]	1.2[3]	NA
2-3	0.19[3]	0.61[3]	1.1[3]	1.6[3]	NA
3-4	0.25[3]	0.68[3]	1.4[3]	2.2	NA
4-5	0.32[3]	0.75[3]	1.7[3]	2.1	2.8
5-6	0.39	0.83	2.0	2.3	3.1
6-7	0.40[3]	0.89[3]	2.3[3]	3.0	4.0
7-8	0.41[3]	0.96[3]	2.6[3]	3.5	4.6
8-9	0.42[3]	1.0[3]	2.9[3]	3.5	4.7
9-10	0.43	1.0	3.2	3.9	5.3
10-11	0.68[3]	1.2	2.0	3.9	4.6
11-12	0.92	1.1[3]	1.8	4.2	4.6
12-13	0.56	0.98	1.9	4.4	5.1
13-14	0.87	1.0[3]	2.0	5.3	5.9
14-15	0.52	0.98[3]	2.0	5.9	6.6
15-16	0.92	0.94[3]	2.0[3]	5.9	6.4
16-17	0.44	0.89[3]	2.9	6.0	7.2
17-18	0.59[3]	0.85[3]	2.0[3]	7.3	8.0
Adult (18-75)	0.54	0.66	2.0	3.8	

NA Not applicable.

1 Breathing rates were derived from data in EPA (1985b, Table 4-5) by taking the arithmetic mean of the male and female (when available) ventilation rates for each age group and activity level.

2 Conversion of breathing rates expressed as l/min to m^3/hr was conducted using a conversion of 0.001 m^3/liter x 60 min/hr.

3 Breathing rates were not available for these data points; therefore, they were derived by linear regression.

Table B.3-22 Projected Activity Types and Assigned Ventilation Rate Categories for RMA Populations

	Activity[1]	Hours	Level
Regulated/Casual Visitor	Picnicking	2	Light-Moderate
	Birdwatching	2	Light-Moderate
	Photography	2	Light-Moderate
	Hiking (nature walking)	2	Light-Moderate
	Catch and Release Fishing	2	Light-Moderate
	Sightseeing	2	Light-Moderate
Recreational Visitor	Bicycling	2	Moderate-Heavy
	Outdoor Games	2	Moderate-Heavy
	Jogging/Running	2	Moderate-Very Heavy
	Hiking	2	Moderate
Commercial Worker	Office Activities Retail	8.0[3]	Light (88% or 7 hrs), Moderate (12% or 1 hr)
Industrial Worker	Construction Grounds maintenance Warehouse operators	8.0[4]	Light (25% or 2 hrs), Moderate (50% or 4 hrs), and Heavy (25% or 2 hrs)
Biological/ Maintenance Worker	[6]	8.0[5]	Light (25% or 2 hrs), Moderate (2.5% or 5 hrs), and Heavy (12.5% or 1 hr)

1 Projected activities were assumed based on the final Human Health Exposure Assessment report (EBASCO 1990a).

2 No hourly assignment is made for these activities and populations. Individuals are assumed to engage in one or more of these activities during their daily exposure at the RMA (see discussion on time-dependent variables in Appendix A.1.18).

3 The commercial worker was assumed to spend 7 hours at a light ventilation rate and 1 hour at a moderate ventilation rate. One hour of this activity is expected to occur in a basement. Where greater than 8 hours per day are possible, the same percentage of time in light and moderate levels was assumed.

4 The industrial worker was assumed to spend 2 hours at a light ventilation rate, 4 hours at a moderate ventilation rate, and 2 hours at a heavy ventilation rate. Seven hours are assumed to be spent outdoors. One hour of this activity is expected to occur in a basement. Where greater than 8 hours per day are possible, the same proportions were maintained.

5 The biological/maintenance worker is expected to spend 8 hours per work day as follows: 2 hours at a light activity level, 5 hours at a moderate activity level, and 1 hour at a heavy activity level. Where greater than 8 hours per day are possible, the same proportions were maintained.

6 See Appendix B.2 for details of activities.

Table B.3-23 Projected Time-Weighted Breathing Rates (m^3/hr) for the Regulated and Casual Visitor

Age	Resting	Light	Moderate	High	TWA-BR
0–1[1]	0.05	0.41	NA	NA	0.23
1–2	NA	0.55	0.79	NA	0.67
2–3	NA	0.61	1.1	NA	0.86
3–4	NA	0.68	1.4	NA	1.0
4–5	NA	0.75	1.7	NA	1.2
5–6	NA	0.83	2.0	NA	1.4
6–7	NA	0.89	2.3	NA	1.6
7–8	NA	0.96	2.6	NA	1.8
8–9	NA	1.0	2.9	NA	2.0
9–10	NA	1.0	3.2	NA	2.1
10–11	NA	1.2	2.0	NA	1.6
11–12	NA	1.1	1.8	NA	1.5
12–13	NA	0.98	1.9	NA	1.4
13–14	NA	1.0	2.0	NA	1.5
14–15	NA	0.98	2.0	NA	1.5
15–16	NA	0.94	2.0	NA	1.5
16–17	NA	0.89	2.9	NA	1.9
17–18	NA	0.85	2.0	NA	1.4
18–75	NA	0.66	2.0	NA	1.3

[1] A TWA-BR was calculated for infants assuming 50 percent of their time would be spent resting and 50 percent at a light activity level.

NA Not Applicable.

Table B.3-24 Projected Time-Weighted Average Breathing Rates (m^3/hr) for the Recreational Visitor

Age	Moderate	Heavy	Very Heavy	Moderate/ Heavy[1]	Moderate/ Very Heavy	TWA-BR
0–1	NA	NA	NA	NA	NA	0.23[2]
1–2	NA	NA	NA	NA	NA	0.67[2]
2–3	NA	NA	NA	NA	NA	0.86[2]
3–4	NA	NA	NA	NA	NA	1.0[2]
4–5	1.7	2.1	2.8	1.9	2.3	2.1
5–6	2.0	2.3	3.1	2.2	2.6	2.4
6–7	2.3	3.0	4.0	2.7	3.2	3.0
7–8	2.6	3.6	4.6	3.1	3.6	3.4
8–9	2.9	3.5	4.7	3.2	3.8	3.5
9–10	3.2	3.9	5.3	3.6	4.3	4.0
10–11	2.0	3.8	4.6	2.9	3.3	3.1
11–12	1.8	4.2	4.6	3.0	3.2	3.1
12–13	1.9	4.4	5.1	3.2	3.5	3.4
13–14	2.0	5.3	5.9	3.7	4.0	3.8
14–15	2.0	5.9	6.6	4.0	4.3	4.2
15–16	2.0	5.9	6.4	4.0	4.2	4.1
16–17	2.9	6.0	7.2	4.5	5.1	4.8
17–18	2.0	7.3	8.0	4.7	5.0	4.9
18–75	2.0	3.8		2.9	4.4[3]	3.6

[1] The prorated activity level for biking and outdoor games were assumed to be different for each individual, so an average of the moderate and heavy breathing rates for bicycling and outdoor games were used to calculate the TWA-BR. In addition, heavy breathing rates were assigned to ages 4–18 for jogging/running.

[2] TWA-BRs for these age groups were assumed to be the same as the Regulated/Casual Visitor as presented in Table B.3.23.

[3] An average of moderate-severe breathing rates for running/jogging was used to calculate TWA-BR for adults.

NA Not Applicable.

Table B.3-25 Fraction of Total Respiratory Deposition

Particle Size (μm)		Fraction of Total Deposition
0 to 2.5		
	0.25	0.30
	0.50	0.23
	0.75	0.28
	1.00	0.53
	1.25	0.68
	1.50	0.78
	1.75	0.85
	2.00	0.89
	2.25	0.92
	2.50	0.95
	$\bar{x}$ =	0.64 (64%)
2.5 to 15		
	3.0	0.97
	4.0	1
	5.0	1
	6.0	1
	7.0	1
	8.0	1
	9.0	1
	10.0	1
	11.0	1
	12.0	1
	13.0	1
	14.0	1
	15.0	1
	$\bar{x}$ =	0.99 (99%)

$\bar{x}$ Arithmetic average
μm Microns
% Percent

Table B.3-26 Summary of Dust Loading Factor (CSS) Distributions by Land-Use Scenario ($\mu g/m^3$)

Land Use	Distribution Assigned	$\hat{\mu}_x$	$\hat{\sigma}$	$\overline{y}$	S_y
Regulated/ Casual Visitor	Lognormal	23.65	13.53	3.022	0.532
Recreational Visitor	Lognormal	23.65	13.53	3.022	0.532
Commercial Worker	Lognormal	5.464	3.505	1.526	0.587
Industrial Worker	Lognormal	23.65	13.53	3.022	0.532
Biological/ Maintenance Worker	Lognormal	56.21	32.88	3.882	0.5425

$\hat{\mu}_x$ = mean

$\hat{\sigma}$ = standard deviation

S_y = standard deviation of log-transformed data

$\overline{y}$ = log CSS

$\mu g/m^3$ = micrograms per cubic meter

Table B.3-27 Body Weight of Adults (kilograms)[1,2,3]

Age	Men		Women		Combined Men and Women	
	Mean	(Standard Error of Mean)	Mean	(Standard Error of Mean)	Mean	(Standard Error of Mean)
18<25	70.9	(0.56)	57.1	(0.48)	64.0	(0.48)
25<35	76.7	(0.50)	59.9	(0.32)	68.3	(0.32)
35<45	78.9	(0.58)	62.4	(0.45)	70.65	(0.45)
45<55	78.1	(0.50)	64.4	(0.80)	71.25	(0.80)
55<65	76.8	(0.57)	64.4	(0.47)	70.6	(0.47)
65<75	73.2	(0.50)	63.8	(0.50)	68.5	(0.50)
18<35	73.8	(0.42)	58.7	(0.23)	66.25	(0.23)
35<55	78.5	(0.32)	63.3	(0.44)	70.9	(0.44)
55<75	75.6	(0.40)	64.2	(0.30)	69.9	(0.30)
18<75	75.9	(0.24)	61.5	(0.23)	68.7	(0.23)

1 Source: EPA (1989a, Table 5A-1, 5A-2). Data represents body weights of male and female adults.

2 Values represent 50th percentile body weights.

3 Standard error of the mean (SEM) = $\sqrt{SEM^2_{males} + SEM^2_{females}}$

< Denotes less than.

Table B.3-28 Body Weight of Children (kilograms)[1,2,3]

Age	Male		Female		Combined Male and Female	
	Mean	(Standard Error of Mean)	Mean	(Standard Error of Mean)	Mean	(Standard Error of Mean)
0<1	9.2	(0.16)	8.5	(0.09)	8.9	(0.09)
1<2	11.5	(0.12)	10.5	(0.08)	11.0	(0.08)
2<3	13.4	(0.07)	12.6	(0.03)	13.0	(0.03)
3<4	15.3	(0.10)	14.6	(0.15)	15.0	(0.15)
4<5	17.4	(0.10)	16.4	(0.27)	16.9	(0.27)
5<6	19.3	(0.12)	18.8	(0.17)	19.1	(0.17)
6<7	21.9	(0.10)	21.0	(0.83)	21.5	(0.83)
7<8	24.4	(0.30)	23.5	(0.43)	24.0	(0.43)
8<9	27.3	(0.69)	27.3	(0.81)	27.3	(0.81)
9<10	29.7	(0.88)	29.6	(0.45)	29.7	(0.45)
10<11	34.5	(0.44)	34.3	(0.80)	34.4	(0.80)
11<12	36.4	(1.42)	40.0	(1.74)	38.2	(1.74)
12<13	42.1	(1.44)	45.2	(2.01)	43.7	(2.01)
13<14	47.7	(1.07)	48.6	(0.96)	48.2	(0.96)
14<15	55.5	(0.99)	52.8	(0.51)	54.1	(0.51)
15<16	60.2	(0.80)	53.9	(0.77)	57.1	(0.77)
16<17	63.6	(0.58)	55.3	(0.51)	59.5	(0.51)
17<18	65.7	(0.67)	58.3	(1.08)	62.0	(1.08)

1 Source: EPA (1989a, Table 5A-3, 5A-4). Data represent body weights of male and female children.

2 Values represent 50th percentile body weights.

3 Standard error of the mean (SEM) = $\sqrt{SEM^2_{males} + SEM^2_{females}}$

< Denotes less than.

Table B.3-29 Summary of Data Sources for PPLV Direct and Indirect Equation Parameters, Time-Dependent Variables

Population	TM (hrs/days)	DW (days/yr)	TE (yrs/lifetime)
Regulated/Casual Visitor	National U.S. Bureau Outdoor Recreation (1972) Walsh (1986) Regional National Park Service (1984) National Sporting Goods Assoc. (1989) Specific to RMA Estimates of Visitors to Alternative Recreational Surface Uses Proposed for RMA (THK 1990)	Regional 1988 Visitors Survey; DPOR (1989) National Park Service (1984)	Regional Residential Energy Use Survey; PSCo (1989)
Recreational Visitor	National U.S. Bureau Outdoor Recreation (1972) Walsh and Associates (1988) Regional National Sporting Goods Assoc. (1989) National Park Service (1984) Specific to RMA Estimates of Visitations to Alternative Recreational Surface Uses Proposed for RMA (THK 1990)	Neighborhood National Sporting Goods Assoc. (1989)	Regional Residential Energy Use Survey: PSCo (1989)
Commercial Industrial Worker	EPA Exposure Factors Handbook, 1989a General Literature	Denver Specific MSEC (1981-1990)	Denver Specific MSEC (1981-1990) National Bureau of the Census (1987) Bureau of Labor Statistics (1990)
Biological/Maintenance Worker	Assumed 8 hours/day	National Wildlife Refuge Survey (Appendix B.2)	National Wildlife Refuge Survey (Appendix B.2)

Table B.3-30 Summary of Probabilistic Distributions for Time-Dependent Exposure Parameters

Exposed Population	Parameter	Distribution	Mean	Standard Deviation	50th Percentile	95th Percentile
Regulated/ Casual Visitor	Exposure Time (hours/day)	Lognormal	2.5	2.1	1.9	6.3
	Exposure Frequency (days/year)	Lognormal	34.9	22.4	29.6	76.1
	Exposure Duration (years/lifetime)	Lognormal	10.1	15.7	5.5	33.8
Recreational Visitor	Exposure Time (hours/day)	Lognormal	1.8	1.7	1.38	4.96
	Exposure Frequency (days/year)	Lognormal	63.14	67.02	43.3	181
	Exposure Duration (years/lifetime)	Lognormal	10.1	15.7	5.5	33.8
Commercial/ Industrial Worker	Exposure Time (hours/day)	Normal	7.4	3.3	7.4	12.8
	Exposure Frequency (days/year)	Normal	236.0	2.8	236.0	241.0
	Exposure Duration (years/lifetime)	Lognormal	4.4	7.0	2.3	14.8
Biological/ Maintenance Worker	Exposure Time (hours/day)	Fixed	8			
	Exposure Frequency (day/year)	Normal	225	10.23	225	242
	Exposure Duration (year\lifetime)	Normal[1]	7.18	7.0	7.18	18.7

[1] Truncated at 25th percentile

Table B.3-31 TM*DW*TE Probability Distributions in Hours/Lifetime[1]

Percentile	Neighborhood Regulated/Casual Visitor[2]	Neighborhood Recreational Visitor[2]	Commercial/ Industrial Worker[3]	Biological/ Maintenance Worker[3]
99	8,823.00	13,730.80	87,688.4	43,853.82
95	3,271.50	4,581.76	34,468.6	37,512.14
90	1,929.36	2,554.61	18,295.9	29,571.89
85	1,350.91	1,722.22	14,166.2	26,891.52
80	1,017.26	1,258.34	10,400.1	23,080.63
75	797.86	961.79	9,506.3	20,864.77
70	640.51	734.30	8,087.0	19,595.74
65	523.25	603.10	6,242.2	18,316.56
60	431.83	487.68	4,822.2	16,273.6
55	358.77	397.53	4,242.7	14,411.80
50	298.87	324.57	3,583.0	13,216.85
45	248.81	265.00	3,133.4	11,533.60
40	206.84	216.01	2,605.5	10,201.40
35	170.70	174.67	2,313.6	8,165.10
30	139.45	139.66	2,086.7	6,280.71

1/ The distributions in Table B.3-30 result in these distributions for hours per lifetime, which are derived from data provided in Section B.3.7.
2/ Percentiles for Regulated/Casual and Recreational Visitors calculated analytically.
3/ Percentiles for Commercial/Industrial and Biological/Maintenance Workers obtained through simulation.

Table B.3-31 TM*DW*TE Probability Distributions in Hours/Lifetime[1]

Percentile	Neighborhood Regulated/Casual Visitor[2]	Neighborhood Recreational Visitor[2]	Commercial/ Industrial Worker[3]	Biological/ Maintenance Worker[3]
25	111.95	109.53	1,631.5	4,546.83
20	87.81	83.72	1,192.0	2,543.84
15	66.12	61.17	880.6	2,399.28
10	48.36	43.28	772.2	2,290.08
5	27.30	22.99	473.1	2,194.40
0	1.84	1.16	69.5	281.53

1/ The distributions in Table B.3-30 result in these distributions for hours per lifetime, which are derived from data provided in Section B.3.7.
2/ Percentiles for Regulated/Casual and Recreational Visitors calculated analytically.
3/ Percentiles for Commercial/Industrial and Biological/Maintenance Workers obtained through simulation.

Chemical	Molecular Weight (g/mol)	Reference
Aldrin	364.93	1
Arsenic	74.92	1
Benzene	78.11	1
Cadmium	112.41	1
Carbon Tetrachloride	153.84	1
Chlordane	409.80	1
Chloroacetic Acid	94.50	1
Chlorobenzene	112.56	1
Chloroform	119.39	1
Chromium	52.00	1
DDE	318.02	1
DDT	354.50	1
Dibromochloropropane	236.36	1
1,2-Dichloroethane	98.96	1
1,1-Dichloroethylene	96.95	1
Dicyclopentadiene	132.20	2
Hexachlorocyclopentadiene	273.00	2
Isodrin	364.90	3
Lead	207.20	1
Mercury	200.59	1
Methylene Chloride	84.94	1
1,1,2,2-Tetrachloroethane	167.86	1
Tetrachloroethylene	165.85	1
Toluene	92.13	1
Trichloroethylene	131.40	1
Dieldrin	380.93	1
Endrin	380.93	1

1 The Merck Index (1989)
2 Verschueren (1977)
3 RTECS (1987)
DDE dichlorodiphenyldichloroethene
DDT dichlorodiphenyltrichloroethane
g/mol grams per mole

Table B.3-33 Summary of Chemical-Specific Molecular Diffusivity Values

Chemical	Molecular Diffusivity (cm^2/s)	Reference
Aldrin	0.0407*	EBASCO 1990a (Vol. 5)
Arsenic	ND	–
Benzene	0.0819	EPA 1988[1]
Cadmium	NA	–
Carbon Tetrachloride	0.0750	EPA 1988
Chlordane	0.0404*	EBASCO 1990a (Vol. 5)
Chloroacetic Acid	ND	–
Chlorobenzene	0.0676	EPA 1988
Chloroform	0.0834	EPA 1988
Chromium (VI)	NA	–
Dibromochloropropane	0.0600*	EBASCO 1990a (Vol. 5)
DDE	0.0440*	EBASCO 1990a (Vol. 5)
DDT	0.0423*	EBASCO 1990a (Vol. 5)
1,2-Dichloroethane	0.0856	EPA 1988
1,1-Dichloroethylene	0.0744	EPA 1988
Dicyclopentadiene	0.0562*	EBASCO 1990a (Vol. 5)
Dieldrin	0.0416*	EBASCO 1990a (Vol. 5)
Endrin	0.0416*	EBASCO 1990a (Vol. 5)
Hexachlorocyclopentadiene	0.0522*	EBASCO 1990a (Vol. 5)
Isodrin	0.0407*	EBASCO 1990a (Vol. 5)
Lead	NA	–
Mercury	NA	–
Methylene chloride	0.0958*	EBASCO 1990a (Vol. 5)
1,1,2,2-Tetrachloroethane	0.00798*	EBASCO 1990a (Vol. 5)
Tetrachloroethylene	0.0697	EPA 1988
Toluene	0.0736	EPA 1988
Trichloroethylene	0.0749	EPA 1988

* Calculated by Fuller's method
1 Data reported are for 10°C, the temperature assumed for RMA soils.
$cm^{2/s}$ square centimeters per second
DDE Dichlorodiphenyldichloroethene
DDT Dichlorodiphenyltrichloroethane
NA Not applicable
ND No data

Table B.3-34 Summary of the Percent Organic Carbon for RMA Lake Sediments

Sample Number	Percent Organic Carbon[1]
Lake Ladora	
B5075001	19.9%
B5075002	11.4%
B5075003	12.8%
B5075004	16.4%
B5075005	22.2%
Lower Derby Lake	
B5085001	5.9%
B5085002	4.6%
B5085003	4.7%
B5085004	11.3%
B5085005	7.3%

1 Data are reported as percent organic carbon consistent with the data source. Note that the fraction of organic carbon has been used in statistical evaluations and in the Risk Characterization.

Table B.3-35 Fitted Distributions for F_{oc}

Lakes of Similar F_{oc} Distribution	Proportion of Total Lake Area (p)	Distribution Family	Mean	Standard Deviation	P Value[1]
Lower Derby	0.38	Lognormal	0.06734	0.02300	1
Ladora, Lake Mary, and Rod and Gun Club	0.34	Normal	0.1645	0.05602	1
Upper Derby and Eastern Upper Derby	0.28	Normal	0.1159	0.03323	NA

1 Probability of error if the distribution is rejected.

Depth (Inches)	Percent Organic Carbon
Petrocalcic Paleustoll (Pedon No. 36–32)	
0–7	0.7
7–23	0.6
23–33	0.8
33+	Horizon cemented by calcium carbonate
Typic Haplustoll (Pedon No. 23D)	
0–5	0.9
5–12	0.6
12–27	0.4
27–42	0.2
42–60	0.2
Typic Haplustoll (Pedon No. 77)	
0–9	0.5
9–19	0.3
19–30	0.3
30–40	0.3
40–52	0.2
52–67	0.2
Typic Haplustoll (Pedon No. 33)	
0–6	0.4
6–16	0.2
16–29	0.2
29–39	0.1
39–60	0.1

Depth (Inches)	Percent Organic Carbon
Nunn (Pedon No. 17)	
0–8	1.1
8–14	0.5
14–27	0.3
27–33	0.3
33–47	0.3
47–69	0.2
Aquic Haplustoll (Pedon Nos. 2–15)	
0–15	1.1
15–24	0.3
24–34	0.4
34–60	0.3
Aquic Haplustoll (Pedon No. 83C)	
0–12	0.9
12–29	0.7
19–27	0.4
27–39	0.2
39–60	0.2
Aquic Haplustoll (Pedon No. 46)	
0–6	1.5
6–11	0.5
11–16	0.5
16–41	0.4
41–46	0.2

Depth (Inches)	Percent Organic Carbon
Truckton (Pedon No. 78A)	
0–8	0.9
8–15	0.5
15–43	0.5
43–60	0.5
Truckton (Pedon No. 2–1)	
0–16	0.4
16–26	0.3
26–37	0.3
37–46	0.2
46–60	0.1
Truckton (Pedon No. 1–40)	
0–6	0.7
6–16	0.4
16–24	0.3
24–60	0.1
Satanta (Pedon 1–39)	
0–6	1.7
6–19	0.4
19–44	0.4
44–54	0.2
54–60	0.1

Depth (Inches)	Percent Organic Carbon
Satanta (Pedon No. 16)	
0–6	0.8
6–9	0.5
9–24	0.5
24–39	0.2
39–52	0.1
52–58	0.2
58–62	0.2
Satanta #36-12 (Pedon No. 36–12)	
0–8	0.8
8–18	0.7
18–36	0.4
36–50	0.3
50–57	0.3
Satanta (Pedon No. 73C)	
0–8	1.4
8–19	0.5
19–36	0.6
36–45	0.4
45–53	0.5
53–60	0.3
Satanta (Pedon No. 1–38)	
0–7	1.2
7–14	0.7
4–23	0.5
3–44	0.3
44–60	0.1

Depth (Inches)	Percent Organic Carbon
Ascalon (Pedon No. 6–31)	
0–7	0.9
7–19	0.5
10–31	0.2
31–48	0.2
48–58	0.3
Ascalon (Pedon No. 36–17)	
0–11	0.6
11–25	0.5
25–47	0.2
47–59	0.1
Ascalon (Pedon No. 25)	
0–5	0.8
5–14	0.3
14–22	0.4
22–45	0.3
45–59	<0.1
59–67	0.1
Ascalon (Pedon No. 79)	
0–7	0.6
7–24	0.4
24–44	0.2
44–67	0.1

Depth (Inches)	Percent Organic Carbon
Satanta (disturbed) (Pedon No. 1–43)	
0–21	0.7
21–25	0.4
25–36	0.5
36–47	0.3
47–59	0.2
Truckton (disturbed) (Pedon No. 2–37)	
0–4	0.5
4–10	0.3
10–25	0.2
25–49	0.2
49–60	0.1
Bresser (disturbed) (Pedon No. 1–46)	
0–17	0.3
17–23	0.3
23–30	0.3
30–46	0.1
46–59	0.1
Weld (Pedon No. 12)	
0–9	0.9
9–21	0.5
21–39	0.3
39–58	0.2
58–63	0.4

Depth (Inches)	Percent Organic Carbon
Weld (Pedon No. 11)	
0–4	1.7
14–12	0.6
2–20	0.4
20–31	0.3
31–57	0.2
57–70	0.2
Bresser (Pedon No. 6–30)	
0–9	0.6
9–22	0.4
22–47	0.1
47–60	0.2
Bresser (Pedon No. 2–34)	
0–7	0.5
7–18	0.4
18–25	0.3
25–55	0.2
55–61	0.1
Bresser (Pedon No. 73D)	
0–8	0.7
8–16	0.5
16–26	0.6
26–37	0.3
37–45	0.4
45–60	0.2

Depth (Inches)	Percent Organic Carbon
Bresser (Pedon No. 1–41)	
0–8	0.7
8–24	0.4
24–46	0.1
46–50	0.2
50–60	0.2

Table B.3-37 Summary of Percent Organic Carbon by Soil Series/Classification [1]

Soil Series/Classification	Percent Organic Carbon
Bresser	0.10–0.70
Weld	0.20–1.7
Disturbed Land	0.10–0.70
Ascalon	<0.10–0.90
Satanta	0.10–1.7
Truckton	0.10–0.90
Aquic Haplustoll	0.20–1.5
Nunn	0.20–1.1
Typic Haplustoll	0.10–0.90
Petrocalcic Palaustoll	0.60–0.80

1 Soils series and classifications listed above are in order from most to least prominent by area at RMA. The Bresser and Weld soil series and the Disturbed Land category comprise approximately 75 percent of RMA soils.

Table B.3-38 Parameters for the Lognormal F_{α} Distribution

Soil Series Classification		Proportion of Arsenal Soil	Number of Borings (N_k)	Number Represented in Combined Distribution (N_k)
1.	Bresser	.416	4	40
2.	Weld	.184	2	18
3.	Disturbed Land	.135	3	15
4.	Ascalon	.111	4	12
5.	Santana	.0396	5	4
6.	Truckton	.0405	3	4
7.	Aquic Haplustoll	.0405	3	4
8.	Nunn	.022	1	2
9.	Typic Hyplustoll	.00796	3	1
10.	Petrocalcic Paleustoll	.00133	1	0

Table B.3-39 Summary of K_H Distribution Assignments for the COCs

Contaminant	n	Distribution Assigned	Distribution Parameters[1] a	b	c	P Value[2]
Aldrin	6	Uniform-Triangular	1.44E-05	4.96E-04	6.89E-04	-
Isodrin	-	Uniform-Triangular[3]	1.44E-05	4.96E-04	6.89E-04	-
Dieldrin	8	Uniform-Triangular	4.57E-10	5.8E-05	8.12E-05	-
Endrin	3	Uniform-Triangular	4.0E-07	7.52E-06	1.04E-05	-
Toluene	11	Triangular	5.10E-03	6.55E-03	7.10E-03	0.19
Benzene	12	Normal	5.33E-03	1.06E-03	N/A	0.07
Chloroform	11	Normal	3.10E-03	6.78E-04	N/A	1.0
1,2-Dichloroethane	7	Lognormal	-5.75	0.313	N/A	1.0
1,1-Dichloroethylene	7	Lognormal	-4.21	0.384	N/A	1.0
Methylene Chloride	10	Normal	2.36E-03	7.22E-04	N/A	1.0
Carbon Tetrachloride	11	Normal	0.0237	7.27E-03	N/A	1.0
1,1,2,2-Tetrachloroethane	5	Normal	4.15E-04	8.60E-05	N/A	1.0
Tetrachloroethylene	10	Uniform-Triangular	2.87E-03	0.0287	0.0390	-
Chlorobenzene	10	Normal	3.63E-03	4.93E-04	N/A	1.0
Trichlorethylene	9	Triangular	3.7E-03	0.010	0.014	1.0

Table B.3-39 Summary of K_H Distribution Assignments for the COCs

Contaminant	n	Distribution Assigned	Distribution Parameters[1] a	b	c	P Value[2]
DDT	5	Uniform-Triangular	8.30E-06	5.23E-05	6.99E-05	–
DDE	3	Uniform-Triangular	2.10E-05	1.20E-03	1.67E-03	–
Chlordane	5	Lognormal	-9.04	1.30	N/A	0.52
Hexachlorocyclopentadiene	5	Lognormal	-3.86	0.373	N/A	1.0
Dicyclopentadiene		Lognormal[4]	-3.41	0.990	N/A	–
Dibromochloropropane	–	Uniform-Triangular[4]	1.74E-05	1.08E-03	1.51E-03	–
Chloroacetic acid	–	Lognormal[4]	-18.6	0.922	N/A	–

1 Distribution parameters differ for the following distributions and are given below:

	a	b	c
Normal	Mean	Standard deviation	N/A
Lognormal	Mean (y) ($y = \log_e K_H$)	Standard deviation (y)	N/A
Uniform-triangular (one tailed)	Lower limit uniform	Upper limit uniform	Upper limit triangular
Triangular	Lower limit	Apex	Upper limit

2 Probability of error if distribution is rejected.

3 Assumed based on structural similarity to another chemical.

4 Derived using K_H = vapor pressure/aqueous solubility.

Table B.3-40 Mean and Standard Deviation of Lognormal K_H Distributions

Contaminant	Distribution Assigned	Mean	Standard Deviation
1,2-Dichloroethane	Lognormal	3.34E-3	1.07E-3
1,1-Dichloroethylene	Lognormal	1.60E-2	6.37E-3
Chlordane	Lognormal	2.76E-4	5.80E-4
Hexachlorocyclopentadiene	Lognormal	2.26E-2	8.73E-3
Dicyclopentadiene	Lognormal	5.39E-2	6.96E-2
Chloroacetic acid	Lognormal	1.37E-8	1.77E-8

Table B.3-41 Summary of Solubility Distribution on Assignments for Three Contaminants of Concern

Contaminant	n	Distribution Assigned	Distribution Parameters [1] a	b	c
Chloroacetic Acid	4	Triangular	8.82E+03	2.85E+04	10.7E+04
Dibromochloropropane	3	Triangular	5.96	7.13	11.82
Dicyclopentadiene	1	Triangular	0.275	1.40	5.90

1 Parameters for Triangular Distribution

a	b	c
Lower limit	Apex	Upper limit

Henry's Law Constant	Converted Henry's Law Constant (atm·m³/mol)	Reference Temperature (°C)	Reference
Aldrin			
3.20E-04 atm · m³/mol	3.20E-04	25	SRC (1988)
4.96E-04 atm · m³/mol	4.96E-04	25	EPA/600/2-82/001a EPA (1981)
1.60E-05 atm · m³/mol	1.60E-05	25	Mabey et al. (1982)
2.8E-3 KPa · m³/mol	2.76E-05	25	Mackay & Shiu (1981)
1.44E-05 atm · m³/mol	1.44E-05	25	Mackay & Leinonen (1975)
1.42 Pa · m³/mol *	4.96E-04	20	Warner et al. (1987a)
Benzene			
5.55E-03 atm · m³/mol *	5.55E-03	25	Mackay et al. (1979)
5.50E-03 atm · m³/mol	5.50E-03	25	Mackay & Leinonen (1975)
2.67E-03 atm · m³/mol	2.67E-03	10	Mackay & Leinonen (1975)
4.39E-03 atm · m³/mol	4.39E-03	20	Mackay & Yeun (1983)
2.24E-01 unitless	5.48E-03	25	Nirmalakhandan & Speece (1988)
5.55E-03 atm · m³/mol	5.55E-03	25	EPA (1981)
5.50E-03 atm · m³/mol	5.50E-03	25	Mabey et al. (1982)
0.306 unitless *	7.36E-03	20	Yurteri et al. (1987)
5.5E-01 KPa · m³/mol	5.43E-03	25	Mackay & Shiu (1981)
5.49E-03 atm · m³/mol	5.49E-03	25	Mackay et al. (1979)
5.48E-03 atm · m³/mol	5.48E-03	25	Warner et al. (1987a)
5.55E-03 atm · m³/mol *	5.55E-03	25	Warner et al. (1987a)
Carbon Tetrachloride			
2.3E+0 KPa · m³/mol	2.30E-02	20	Mackay & Shiu (1981)
2.37E-02 atm · m³/mol *	2.27E-02	20	Mackay & Yeun (1983)
1.32E-02 atm · m³/mol *	1.32E-02	10	Gosset (1987)
2.11E-02 atm · m³/mol *	2.11E-02	17.5	Gosset (1987)
3.04E-02 atm · m³/mol *	3.04E-02	24.8	Gosset (1987)
4.60E-02 atm · m³/mol *	4.60E-02	34.6	Gosset (1987)
3.02E-02 atm · m³/mol	3.02E-02	25	EPA (1981)
0.936 unitless *	2.25E-02	20	Yurteri et al. (1987)
5.9E+07 dyne · cm/g *	8.96E-03	24	Chiou et al. (1980)
1.22 unitless	2.99E-02	25	Munz & Roberts (1987)
2.86E-02 atm · m³/mol	2.86E-02	25	Warner et al. (1987a)
3.02E-02 atm · m³/mol *	3.02E-02	25	Warner et al. (1987a)

* Denotes empirical data (i.e., not calculated)

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
Chlordane			
0.055 unitless *	1.34E-03	23	Atlas et al. (1982)
0.036 unitless *	8.75E-04	23	Atlas et al. (1982)
4.80E-05 atm · m^3/mol	4.80E-05	25	EPA (1981)
9.64 Pa · m^3/mol*	9.52E-05	25	Mackay et al. (1986)
9.40E-05 atm · m^3/mol	9.40E-05	25	Mackay et al. (1986)
4.80E-05 atm · m^3/mol *	4.80E-05	25	Warner et al. (1987a)
Chloroacetic Acid			
8.90E-08 atm · m^3/mol	8.90E-08	Not given	SRC (1988)
1.40E-09 atm · m^3/mol	1.40E-09		Solubility calculation[1]
Chlorobenzene			
2.61E-03 atm · m^3/mol	2.61E-03	20	Mackay & Yeun (1983)
3.60E-03 atm · m^3/mol	3.60E-03	20-25	Mabey et al. (1982)
3.93E-03 atm · m^3/mol	3.93E-03	25	EPA (1981)
0.131 unitless *	3.15E-03	20	Yurteri et al. (1987)
0.182 unitless	4.45E-03	25	Nirmalakhandan & Speece (1988)
0.35 KPa · m^3/mol	3.46E-03	25	Mackay et al. (1979)
3.71E-03 atm · m^3/mol	3.79E-03	25	Mackay et al. (1979)
3.77E-03 atm · m^3/mol *	3.77E-03	25	Mackay et al. (1979)
3.70E-03 atm · m^3/mol	3.70E-03	25	Warner et al. (1987a)
3.93E-03 atm · m^3/mol *	3.93E-03	25	Warner et al. (1987a)

* Denotes empirical data (i.e., not calculated)

[1] References for solubility in Table B.3-43. References for vapor pressure in separate packet.

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
Chloroform			
2.88E-03 atm · m^3/mol	8E-03	20	Mabey et al. (1982)
1.50E-03 atm · m^3/mol *	1.50E-03	9.6	Gosset (1987)
2.46E-03 atm · m^3/mol *	2.46E-03	17.5	Gosset (1987)
3.67E-03 atm · m^3/mol *	3.67E-03	24.8	Gosset (1987)
5.63E-03 atm · m^3/mol *	5.63E-03	34.6	Gosset (1987)
3.39E-03 atm · m^3/mol	3.39E-03	25	EPA (1981)
0.283 KPa · m^3/mol *	2.79E-03	20	Mackay & Shiu (1981)
0.387 KPa · m^3/mol	3.82E-03	20	Mackay & Shiu (1981) cite: Dilling (1977)
3.23E-03 atm · m^3/mol	3.23E-03	25	Warner et al. (1987a)
3.39E-03 atm · m^3/mol *	3.39E-03	25	Warner et al. (1987a)
0.322 KPa · m^3/mol *	3.18E-03	25	Dilling (1977)
1.54E-01 unitless	3.77E-03	25	Munz & Roberts (1987)
Dibromochloropropane			
1.47E-04 atm · m^3/mol	1.47E-04	C	SRC (1988)
1.22E-04 atm · m^3/mol	1.22E-04	C	Solubility calculation
DDE			
2.10E-05 atm · m^3/mol	2.10E-05	25	SRC (1988)
2.34E-05 atm · m^3/mol	2.34E-05	25	EPA (1981)
6.80E-05 atm · m^3/mol	6.80E-05	25-30	Mabey et al. (1982)
0.05 unitless *	1.20E-03	23	Atlas, et al. (1982)
DDT			
8.30E-06 atm · m^3/mol	8.30E-06	25	SRC (1988)
1.58E-05 atm · m^3/mol	1.58E-05	25	Mabey et al. (1982)
3.89E-05 atm · m^3/mol	3.89E-05	25	Mackay & Leinonen (1975)
1.31 Pa · m^3/mol *	1.29E-05	25	Mackay et al. (1986)
5.3E-03 KPa · m^3/mol	5.23E-05	25	Edwards (1966)

* Denotes empirical data (i.e., not calculated)
[1] References for solubility in Table B.3-43. References for vapor pressure in Table B.3-46.

Table B.3-42 Henry's Law Constant (K_H) Data

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
1,2-Dichloroethane			
5.37E-02 atm · m^3/mol	1.31E-03	25	Nirmalakhanda & Speece (1988)
9.14E-04 atm · m^3/mol	9.14E-04	20	Mabey et al. (1982)
0.11 KPa · m^3/mol	1.09E-03	25	Mackay & Shiu (1981) cite: Dilling (1977)
8.3E-06 dyne · cm/g *	8.11E-04	24	Chiou et al. (1980)
1.35E-03 atm · m^3/mol	1.35E-03	25	Warner et al. (1987a)
1.10E-03 atm · m^3/mol *	1.10E-03	25	Warner et al. (1987a)
0.04 unitless *	9.79E-04	25	Dilling (1977)
1,1-Dichloroethylene			
1.27E-02 atm · m^3/mol *	1.27E-02	10	Gosset (1987)
1.91E-02 atm · m^3/mol *	1.91E-02	17.5	Gosset (1987)
2.61E-02 atm · m^3/mol *	2.61E-02	24.8	Gosset (1987)
3.66E-02 atm · m^3/mol *	3.66E-02	34.6	Gosset (1987)
1.50E-02 atm · m^3/mol	1.50E-02	25	EPA (1981)
3.089 unitless *	7.43E-03	20	Yurteri et al. (1987)
1.51E-02 atm · m^3/mol	1.51E-02	20	Warner et al. (1987a)
1.50E-02 atm · m^3/mol *	1.50E-02	20	Warner et al. (1987a)
Dicyclopentadiene			
1.53E-03 atm · m^3/mol	1.53E-03	---	Solubility Calculation[1]
Dieldrin			
1.51E-05 atm · m^3/mol	1.51E-05	25	SRC (1988)
2.00E-07 atm · m^3/mol	2.00E-07	25	Mackay & Leinonen (1975)
7.8E-01 Pa · m^3/mol	7.70E-06	25	Mackay et al. (1986)
5.80E-05 atm · m^3/mol	5.80E-05	25	EPA (1981)
4.57E-10 atm · m^3/mol	4.57E-10	20-25	Mabey et al. (1982)
1.1E-03 KPa · m^3/mol	1.09E-05	25	Mackay & Shiu, 1981
2.90E-05 atm · m^3/mol	2.90E-05	20	Slater & Spedding (1981) cite:
5.77E-05 atm · m^3/mol *	5.77E-05	25	Mackay et al. (1979)
			Warner et al. (1987a)

* Denotes empirical data (i.e., not calculated)

[1] References for solubility in Table B.3-43. References for vapor pressure in Table B.3-46.

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
Endrin			
7.52E-06 atm · m^3/mol	7.52E-06	25	SRC (1988)
5.00E-07 atm · m^3/mol	5.00E-07	25	EPA (1981)
4.00E-07 atm · m^3/mol	4.00E-07	25	Mabey et al. (1982)
Hexachlorocyclopentadiene			
1.64E-02 atm · m^3/mol	1.64E-02	25	EPA (1981)
1.60E-02 atm · m^3/mol	1.60E-02	25	Mabey et al. (1982)
2.70E-02 atm · m^3/mol	2.70E-02	25	Wolfe et al. (1982)
3.62E-02 atm · m^3/mol	3.62E-02	25	Warner et al. (1987a)
1.64E-02 atm · m^3/mol *	1.64E-02	25	Warner et al. (1987a)
Isodrin			
No data			
Methylene Chloride			
3.19E-03 atm · m^3/mol	3.19E-03	25	EPA (1981)
2.03E-03 atm · m^3/mol	2.03E-03	20-25	Mabey et al. (1982)
2.19E-03 atm · m^3/mol *	2.19E-03	24.8	Gosset (1987)
3.26E-03 atm · m^3/mol *	3.26E-03	34.6	Gosset (1987)
1.31E-03 atm · m^3/mol *	1.31E-03	17.5	Gosset (1987)
1.15E-03 atm · m^3/mol *	1.15E-03	9.6	Gosset (1987)
9.33E-02 unitless	2.28E-03	25	Nirmalakhandan & Speece (1988)
0.256 KPa · m^3/mol	2.53E-03	25	Mackay & Shiu (1981)
0.272 KPa · m^3/mol *	2.69E-03	25	Dilling (1977)
3.04E-03 atm · m^3/mol	3.04E-03	25	Warner et al. (1987a)
3.19E-03 atm · m^3/mol *	3.19E-03	25	Warner et al. (1987a)

* Denotes empirical data (i.e., not calculated)

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
1,1,2,2- Tetrachloroethane			
3.80E-04 atm · m^3/mol	3.80E-04	20	Mabey et al. (1982)
1.82E-02 unitless	4.55E-04	25	Nirmalakhandan & Speece (1988)
4.32E-04 atm · m^3/mol	4.32E-04	25	EPA 1981
4.8E-02 KPa · m^3/mol	4.79E-04	25	Mackay & Shiu (1981)
2.0E+06 dyne · cm/g	3.31E-04	24	Chiou et al. (1980)
Tetrachloroethylene			
2.87E-02 atm · m^3/mol	2.87E-02	25	EPA (1981)
5.01E-01 unitless	1.23E-02	25	Nirmalakhandan & Speece (1988)
6.82E-03 atm · m^3/mol *	6.82E-03	9.6	Gosset (1987)
1.17E-02 atm · m^3/mol *	1.17E-02	17.5	Gosset (1987)
1.77E-02 atm · m^3/mol *	1.77E-02	24.8	Gosset (1987)
2.82E-02 atm · m^3/mol *	2.82E-02	34.6	Gosset (1987)
0.535 unitless *	1.29E-02	20	Yurteri et al. (1987a)
2.85E-02 atm · m^3/mol	2.85E-02	25	Warner et al. (1987a)
2.87E-02 atm · m^3/mol *	2.87E-02	25	Warner et al. (1987a)
2.1E+07 dyne · cm/g *	3.44E-03	24.5	Chiou et al. (1980)
7.46E-01 unitless	1.84E-02	25	Munz & Roberts (1987)
Toluene			
6.66E-03 atm · m^3/mol	6.66E-03	20-25	Mabey et al. (1982)
5.93E-03 atm · m^3/mol	5.93E-03	25	EPA 1981
6.68E-03 atm · m^3/mol	6.68E-03	25	Mackay & Leinonen (1975)
5.18E-03 atm · m^3/mol	5.18E-03	20	Mackay & Yeun (1983)
0.244 unitless *	5.87E-03	25	Yurteri et al. (1987)
0.670 KPa · m^3/mol	6.61E-03	25	Mackay & Shiu (1981) cite: Mackay et al. (1979)
6.66E-03 atm · m^3/mol	6.66E-03	25	Mackay et al (1979)
6.64E-03 atm · m^3/mol *	6.64E-03	25	Mackay et al (1979)
6.44E-03 atm · m^3/mol	6.44E-03	25	Warner et al. (1987a)
5.93E-03 atm · m^3/mol *	5.93E-03	25	Warner et al. (1987a)
2.75E-01 unitless	6.74E-03	25	Nirmalakhandan & Speece (1988)

* Denotes empirical data (i.e., not calculated)

Henry's Law Constant	Converted Henry's Law Constant (atm · m^3/mol)	Reference Temperature (°C)	Reference
Trichloroethylene			
4.79E-01 unitless	1.17E-02	25	Nirmalakhandan & Speece (1988)
3.78E-03 atm · m^3/mol *	3.78E-03	10	Gosset (1987)
6.32E-03 atm · m^3/mol *	6.32E-03	18	Gosset (1987)
9.58E-03 atm · m^3/mol *	9.58E-03	25	Gosset (1987)
1.49E-02 atm · m^3/mol *	1.49E-02	35	Gosset (1987)
1.17E-02 atm · m^3/mol	1.17E-02	25	EPA 1981
0.43 unitless *	1.03E-02	20	Yurteri et al. (1987a)
1.17E-02 atm · m^3/mol	1.17E-02	25	Warner et al. (1987a)
1.17E-02 atm · m^3/mol *	1.17E-02	25	Warner et al. (1987a)
4.17E-01 unitless	1.02E-02	25	Munz & Roberts (1987)

* Denotes empirical data (i.e., not calculated)

Solubility	Solubility Adjusted for Specific Gravity (mol/m^3)	Reference Temperature (°C)	Reference
Chloroacetic Acid			
0.614E-07 mg/l *	9.13E+04	25	Freiter (1978)
88.0 g/100 g of sat. sol. *	1.31E+04	20	Freiter (1978)
85.8 g/100 g of sat. sol.*	1.28E+04	25	Seidell (1941)
90.0 g/100 g of sat. sol. *	1.34E+04	25	Seidell (1941)
86.0 g/100 g of sat. sol. *	1.28E+04	30	Seidell (1941)
88.2 g/100 g of sat. sol. *	1.31E+04	30	Seidell (1941)
92.2 g/100 g of sat. sol. *	1.37E+04	30	Seidell (1941)
Dicyclopentadiene			
0.020 lb/100 lb H_2O	1.29	20	U.S. Coast Guard CHRIS - Haz. Chem. Data (84-84)
Dibromochloropropane			
0.1230E04 mg/l *	5.20E+00	25	Wilson et al. (1981)
700 ppm	2.96E+00	---	Burlinson et al. (1982)
1,000 ppm	4.23E+00	---	Gunther et al. (1968)

* Denotes empirical data (i.e., not calculated)

Table B.3-44 Summary of Vapor Pressure Distribution Assignments for Contaminants of Concern

Contaminant	n	Distribution Assigned	Distribution Parameters[1] a	b	c	P Value[2]
Aldrin	13	Lognormal[4]	-17.4	1.22	N/A	1.0
Isodrin	---	Lognormal[3,4]	-17.4	1.22	N/A	--
Dieldrin	24	Lognormal[4]	-20.4	1.35	N/A	0.30
Endrin	4	Uniform-Triangular	2.63E-10	3.95E-09	5.42E-09	--
Toluene	8	Triangular	1.90E-02	3.50E-02	4.30E-02	0.04
Benzene	13	Normal	1.07E-01	2.70E-02	N/A	.46
Chloroform	9	Normal	2.41E-01	4.10E-02	N/A	1.0
1,2-Dichlorocthane	14	Normal	8.25E-02	2.40E-02	N/A	1.0
1,1-Dichloroethylene	3	Normal	7.63E-01	7.06E-02[sv]	N/A	1.0
Methylene Chloride	8	Triangular	3.00E-01	5.40E-01	0.650	0.42
Carbon Tetrachloride	19	Normal	1.24E-01	2.13E-02	N/A	0.312
1,1,2,2-Tetrachloroethane	6	Normal	7.25E-03	1.73E-03[sv]	N/A	1.0
Tetrachloroethylene	9	Normal	2.07E-02	4.56E-03	N/A	1.0
Chlorobenzene	5	Triangular	1.25E-02	1.55E-02	1.73E-02	0.17
Trichlorethylene	12	Normal	8.26E-02	1.22E-02	N/A	1.0
DDT	25	Lognormal[4]	-21.8	8.33E-01	N/A	0.04
DDE	4	Normal	8.69E-09	1.20E-09[5]	N/A	1.0

Table B.3-44 Summary of Vapor Pressure Distribution Assignments for Contaminants of Concern

Contaminant	n	Distribution Assigned	Distribution Parameters[1] a	b	c	P Value[2]
Chlordane	5	Lognormal[4]	-17.0	1.70	N/A	1.0
Hexachlorocyclopentadiene	5	Normal	1.07E-04	2.50E-05[5]	N/A	1.0
Dicyclopentadiene	1	Uniform	1.84E-04	1.84E-02	N/A	--
Dibromochloropropane	1	Uniform	1.05E-04	1.05E-02	N/A	--
Chloroacetic acid	2	Uniform	8.56E-06	8.56E-04	N/A	--

[1] Distribution parameters vary for the following distributions and are given below:

	a	b	c	
Normal	Mean	Standard deviation	N/A
Lognormal	Mean (y) ($y = \log_e V_p$)	Standard deviation (y)	N/A
Uniform-triangular (one tailed)	Lower limit uniform	Upper limit uniform	Upper limit triangular
Triangular	Lower limit	Apex	Upper limit

[2] Probability of error if distribution is rejected.
[3] Assumed based on similarity in structure and activity to another chemical.
[4] The mean and standard deviation for lognormal distributions is given in Table 25.
[5] Upper 75th confidence limit of standard deviation.
DDE Dichlorodiphenyldichloroethene
DDT Dichlorodiphenyltrichloroethane

Table B.3-45 Mean and Standard Deviation of Lognormal Vapor Pressure Distributions

Contaminant	Distribution Assigned	Mean	Standard Deviation
Aldrin	Lognormal	5.84 E-08 atm	1.08 E-07 atm
Isodrin	Lognormal	5.84 E-08 atm	1.08 E-07 atm
Dieldrin	Lognormal	3.43 E-09 atm	7.81 E-09 atm
DDT	Lognormal	4.82 E-10 atm	4.82 E-10 atm
Chlordane	Lognormal	1.76 E-07 atm	7.24 E-07 atm

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
Aldrin			
0.23E-04 Torr *	3.03E-08	20	SRC (1988) cite: Kilzer et al. (1979)
0.6E-05 Torr *	7.90E-09	25	SRC (1988) cite: Kilzer et al. (1979)
1.2E-04 mm Hg	1.58E-07	25	SRC (1988) cite: Grayson et al. (1982)
4.9E-05 mm Hg	6.45 E-08	25	Haque & Freed (1975) cite: Lichtenstein et al. (1971)
6.0E-06 mm Hg	7.90E-09	25	MacKay & Leinonen (1975)
7.99E-07 KPa	7.89E-09	25	MacKay & Shiu (1981) cite: Edwards (1966)
0.00712 Pa *	7.03E-08	20	Suntio et al. (1988) cite: Kim (1985)
0.00923 Pa *	9.11E-08	20	Suntio et al. (1988) cite: Kim (1985)
0.00308 Pa	3.04E-08	20	Suntio et al. (1988) cite: Porter et al. (1964)
0.00001 Pa	9.87E-11	20	Suntio et al. (1988) cite: Worthing (1983)
0.000707 Pa	6.98E-09	20	Suntio et al. (1988) cite: Worthing (1983)
0.01 Pa	9.87E-08	20	Suntio et al. (1988) cite: Raw (1970)
0.0042 Pa *	4.14E-08	20	Suntio et al. (1988) cite: Seiber et al. (1981)
4.87E-05 mm Hg	6.41E-08	30	Zweig (1964) cite: Porter et al. (1964)
7.48E-05 mm Hg	9.84E-08	40	Zweig (1964) cite: Porter et al. (1964)
1.03E-04 mm Hg	1.36E-07	50	Zweig (1964) cite: Porter et al. (1964)
0.008 Pa	7.90E-08	25	Suntio et al. (1988) cite: Gunther (1971)
0.001 Pa	9.87E-09	20	Suntio et al. (1988) cite: Dobbs & Call (1982)
Benzene			
0.95E+02 Torr *	0.13	25	SRC (1988) cite: ThiBodeaux (1981)
0.4553E+02 Torr	0.06	10	SRC (1988) cite: Zwolinski et al. (1971)
0.9518E+02 Torr	0.13	25	SRC (1988) cite: Zwolinski et al. (1971)
0.1828E+03 Torr	0.24	40	SRC (1988) cite: Zwolinski et al. (1971)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
95.2 mm Hg	0.13	25	SRC (1988) cite: Boublik et al. (1984
87.5 mm Hg	0.12	24	Chiou, Kile & Malcom (1988) cite: Weast, RC (1972)
100 Torr	0.13	26	Callahan et al. (1979) cite: Howard & Durkin (1974)
45.5 Torr	0.06	10	Callahan et al. (1979) cite: MacKay & Leinonen (1975)
0.1 atm*	0.1	20	MacKay & Yeun (1983)
1.21E+04 Pa	0.12	23	Politszki et al. (1982) cite: Schmidt-Bleek (1982)
0.125 atm	0.125	25	MacKay, Shiu, & Sutherland (1979) cite: Downing et al. (1955)
57.41 mm Hg *	0.076	15	Boublik et al. (1973) cite: Willingham et al. (1945)
67.22 mm Hg *	0.088	17	Boublik et al. (1973) cite: Willingham et al. 1945
77.28 mm Hg *	0.102	21	Boublik et al. (1973) cite: Willingham et al. (1945)
87.75 mm Hg *	0.115	23	Boublik et al. (1973) cite: Willingham et al. (1945)
103.64 mm Hg *	0.136	27	Boublik et al. (1973) cite: Willingham et al. (1945)
124.67 mm Hg *	0.164	31	Boublik et al. (1973) cite: Willingham et al. (1945)
149.43 mm Hg *	0.197	35	Boublik et al. (1973) cite: Willingham et al. (1945)
175.89 mm Hg *	0.231	39	Boublik et al. (1973) cite: Willingham et al. (1945)
217.16 mm Hg *	0.286	44	Boublik et al. (1973) cite: Willingham et al. (1945)
261.75 mm Hg *	0.344	49	Boublik et al. (1973) cite: Willingham et al. (1945)
324.93 mm Hg *	0.428	55	Boublik et al. (1973) cite: Willingham et al. (1945)
402.42 mm Hg *	0.530	61	Boublik et al. (1973) cite: Willingham et al. (1945)
500.69 mm Hg *	0.66	67	Boublik et al. (1973) cite: Willingham et al. (1945)
627.93 mm Hg *	0.826	74	Boublik et al. (1973) cite: Willingham et al. (1945)
732.07 mm Hg *	0.963	79	Boublik et al. (1973) cite: Willingham et al. (1945)
744.04 mm Hg *	0.979	79	Boublik et al. (1973) cite: Willingham et al. (1945)
755.23 mm Hg *	0.994	80	Boublik et al. (1973) cite: Willingham et al. (1945)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
767.94 mm Hg *	1.01	80	Boublik et al. (1973) cite: Willingham et al. (1945)
779.34 mm Hg *	1.02	80	Boublik et al. (1973) cite: Willingham et al. (1945)
Carbon Tetrachloride			
0.115E+03 Torr *	0.15	25	SRC (1988) cite: Rogers (1981)
0.52E+02 Torr *	0.068	10	SRC (1988) cite: Gallant (1966)
0.109E+03 Torr *	0.14	25	SRC (1988) cite: Gallant (1966)
0.199E+03 Torr *	0.26	40	SRC (1988) cite: Gallant (1966)
115 mm Hg	0.15	25	SRC (1988) cite: Boublik et al. (1984)
103 mm Hg	0.14	24	Chiou, Kile, & Malcom (1988) cite: Weast et al. (1972)
90 Torr	0.12	20	EPA (1981)
0.118 atm *	0.118	20	Mackay & Yeun (1983)
113 mm Hg	0.15	25	Popendorf (1984)
15.06 KPa	0.15	25	MacKay & Shiu (1981) cite: Dilling (1977)
12.13 KPa	0.12	20	MacKay & Shiu (1981) cite: Neely (1976)
12 KPa	0.12	20	MacKay & Shiu (1981) cite: McConnel et al. (1975)
9.92 mm Hg	0.013	-20	Miller (1967) cite: Hardie et al. (1964)
33.1 mm Hg	0.044	0	Miller (1967) cite: Hardie et al. (1964)
89.6 mm Hg	0.12	20	Miller (1967) cite: Hardie et al. (1964)
139.6 mm Hg	0.18	30	Miller (1967) cite: Hardie et.al. (1964)
309 mm Hg	0.41	50	Miller (1967) cite: Hardie et al. (1964)
1462 mm Hg	1.92	100	Miller (1967) cite: Hardie et al. (1964)
91 mm Hg	0.12	NA	Love & Eilers (1982) cite: Warner (1980), Dilling (1977)
90.6 mm Hg *	0.12	20	Boublik et al. (1973) cite: Hildebrand et al. (1959)

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NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
189.1 mm Hg *	0.25	37	Boublik et al. (1973) cite: Hildebrand et al. (1959)
69.08 mm Hg *	0.091	14	Boublik et al. (1973) cite: Boublik (1960)
78.2 mm Hg *	0.103	17	Boublik et al. (1973) cite: Boublik (1960)
89.08 mm Hg *	0.117	19	Boublik et al. (1973) cite: Boublik (1960)
98.7 mm Hg *	0.13	22	Boublik et al. (1973) cite: Boublik (1960)
115.3 mm Hg *	0.152	25	Boublik et al. (1973) cite: Boublik (1960)
136.9 mm Hg *	0.18	29	Boublik et al. (1973) cite: Boublik (1960)
164.2 mm Hg *	0.216	33	Boublik et al. (1973) cite: Boublik (1960)
189.5 mm Hg *	0.249	37	Boublik et al. (1973) cite: Boublik (1960)
231.5 mm Hg *	0.305	42	Boublik et al. (1973) cite: Boublik (1960)
281.6 mm Hg *	0.371	47	Boublik et al. (1973) cite: Boublik (1960)
91 mm Hg	0.12	20	Boublik et al. (1973) cite: Neely (1976)
Chlordane			
9.8E-06mm Hg	1.28E-08	25	SRC (1988) cite: Worthing et al. (1983)
1E-05mm Hg	1.32E-08	25	Spencer (1973)
61 mPa	6.02E-07	25	Worthing et al. (1983)
0.0079 Pa	7.80E-08	NA	Suntio et al. (1988)
0.00133 Pa	1.31E-08	25	Suntio et al. (1988) cite: Martin (1972)
Chloroacetic Acid			
6.51E-01 Torr *	8.57E-05	25	SRC (1988) cite: Freiter (1978)
0.065 mm Hg	8.55E-05	25	SRC (1988) cite: Freiter (1978)
1 mm Hg	1.316E-03	43	NLM Haz Sub Databank cite: Patty et al. (1963)
31.06 mm Hg *	4.09E-02	104	Boublik et al. (1973) cite: McDonald et al. (1959)
31.01 mm Hg	4.08E-02	104	Boublik et al. (1973) cite: McDonald et al. (1959)

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NA Denotes data not available.

Table B.3-46 Vapor Pressure Data for Chemicals of Concern

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
50.07 mm Hg *	6.59E-02	115	Boublik et al. (1973) cite: McDonald et al. (1959)
50.1 mm Hg	6.59E-02	115	Boublik et al. (1973) cite: McDonald et al. (1959)
90.78 mm Hg *	1.19E-01	128	Boublik et al. (1973) cite: McDonald et al. (1959)
90.87 mm Hg	1.20E-01	128	Boublik et al. (1973) cite: McDonald et al. (1959)
189 mm Hg *	2.49E-01	147	Boublik et al. (1973) cite: McDonald et al. (1959)
188.81 mm Hg	2.48E-01	147	Boublik et al. (1973) cite: McDonald et al. (1959)
389.40 mm Hg *	5.12E-01	168	Boublik et al. (1973) cite: McDonald et al. (1959)
389.63 mm Hg	5.13E-01	168	Boublik et al. (1973) cite: McDonald et al. (1959)
729.10 mm Hg *	9.59E-01	188	Boublik et al. (1973) cite: McDonald et al. (1959)
729.22 mm Hg *	9.60E-01	188	Boublik et al. (1973) cite: McDonald et al. (1959)
766.30 mm Hg *	1.01E-01	189	Boublik et al. (1973) cite: McDonald et al. (1959)
785.60 mm Hg *	1.03	190	Boublik et al. (1973) cite: McDonald et al. (1959)
765.47 mm Hg	1.01	189	Boublik et al. (1973) cite: McDonald et al. (1959)
786.19 mm Hg	1.03	190	Boublik et al. (1973) cite: McDonald et al. (1959)
Chlorobenzene			
1.2E+01mm Hg	0.016	25	Branson et al. (1978)
0.012 atm	0.012	20	MacKay et al. (1986)
1.581 KPa	0.016	25	MacKay & Shiu (1981) cite: Weast et al. (1972-1973)
1.59 KPa	0.016	25	MacKay & Shiu (1981) cite: Boublik et al. 1973
0.0156	0.0156	25	MacKay, Shiu & Sutherland (1979) cite: Weast et al. (1972-73)
Chloroform			
200 mm Hg	0.26	25	Haque & Freed (1975) cite: Dilling et al. (1975)

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NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
150 Torr	0.20	20	EPA (1981)
150.5 Torr	0.20	20	Callahan et al. (1979) cite: Pearson & McConnel (1975)
195 mm Hg	0.26	25	Popendorf (1984)
19.60 mm Hg	0.026	-20	Miller (1967) cite: Hardie et al. (1964)
61.0 mm Hg	0.080	0	Miller (1967) cite: Hardie et al. (1964)
159.6 mm Hg	0.210	20	Miller (1967) cite: Hardie et al. (1964)
246.0 mm Hg	0.32	30	Miller (1967) cite: Hardie et al. (1984)
526.0 mm Hg	0.69	50	Miller (1967) cite: Hardie et al. (1964)
192 mm Hg	0.25	NA	Dilling (1977)
0.208 atm	0.208	20	Munz & Roberts (1987) cite: Jordon (1954)
260E-03 atm	0.260	25	Warner et al. (1987b) cite: ISHOW Database
246 mm Hg	0.324	20	Neely (1976)
Dibromochloropropane			
0.8 mm Hg	1.05E-03	21	NLM Haz Sub Database cite: Merck (1983)
DDE			
6.0E-06 mm Hg	7.90E-09	25	SRC (1988) cite: Bidleman (1984)
6.5E-06 mm Hg	8.55E-09	20	EPA (1981)
0.000865 Pa *	8.54E-09	30	Suntio et al. (1988) cite: Spencer & Cliath (1972)
0.00173 Pa *	1.71E-08	30	Suntio et al. (1988) cite: Westcott & Bidleman (1981)
0.000867 Pa	8.56E-09	20	Westcott et al. (1981) cite: Spencer (1975)
7.4E-06 mm Hg	9.74E-09	25	Westcott et al. (1981)
DDT			

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NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
0.00002 Pa	1.97E-10	20	Suntio et al. (1988) cite: Metcalf (1972)
0.0000203 Pa *	2E-10	20	Suntio et al. (1988) cite: Spencer & Cliath (1972)
0.000058 Pa *	5.72E-10	25	Suntio et al. (1988) cite: Jaber et al. (1982)
0.00002533 Pa	2.5E-10	25	Suntio et al. (1988) cite: Martin (1972)
0.0000227 Pa	2.24E-10	20	Suntio et al. (1988) cite: Hartley (1969)
0.0000201 Pa *	1.98E-10	25	Suntio et al. (1988) cite: Jaber et al. (1982)
0.0000293 Pa *	2.9E-10	20	Suntio et al. (1988) cite: Rothman (1980)
0.0000247 Pa *	2.44E-10	20	Suntio et al. (1988) cite: Dickinson (1956)
0.000647 Pa *	6.39E-9	20	Suntio et al. (1988) cite: Kuhn & Mussini (1949)
0.00002 Pa *	1.97E-10	20	Suntio et al. (1988) cite: Balsan (1947)
0.0000253 Pa	2.5E-10	20	Suntio et al. (1988) cite: Melnikov (1971)
0.00002 Pa	1.97E-10	20	Suntio et al. (1988) cite: Miskas (1964)
0.0000133 Pa	1.31E-10	20	Suntio et al. (1988) cite: Quellette & King (1977)
0.0000253 Pa	2.5E-10	20	Suntio et al. (1988) cite: Worthing (1983)
0.0000253 Pa	2.5E-10	20	Suntio et al. (1988) cite: Raw (1970)
0.0000253 Pa	2.5E-10	20	Suntio et al. (1988) cite: Hartley & Grambryce (1980)
0.0000431 Pa *	3.29E-10	20	Suntio et al. (1988) cite: Dobbs & Cull (1982)
0.0000333 Pa	3.29E-10	20	Suntio et al. (1988) cite: Atkins et al. (1971)
0.00015 Pa *	1.48E-09	20	Suntio et al. (1988) cite: Sieber et al. (1981)
2.0E-05 Pa	1.97E-10	NA	Dobbs et al. (1982)
4.3E-05 Pa	4.24E-10	NA	Dickinson et al. (1955) cite: Balson (1947)
2.2E-07 Torr *	2.90E-10	20	Rothman (1980)
4.3E-07 Torr *	5.66E-10	25	Rothman (1980)
9.3E-07 Torr *	1.22E-09	30	Rothman (1980)
4.0E-06 Torr *	5.26E-09	40	Rothman (1980)
1.5E-05 Torr *	1.97E-08	50	Rothman (1980)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
4.8E-05 Torr *	6.32E-08	60	Rothman (1980)
1.5E-04 Torr*	1.97E-07	70	Rothman (1980)
4.5E-04 Torr*	5.92E-07	80	Rothman (1980)
1.46E-04 mm Hg *	1.92E-07	71	Dickinson (1955)
1.94E-04 mm Hg *	2.55E-07	71	Dickinson (1955)
2.05E-04 mm Hg *	2.70E-07	71	Dickinson (1955)
2.03E-04 mm Hg *	2.67E-07	71	Dickinson (1955)
1.98E-04 mm Hg *	2.61E-07	71	Dickinson (1955)
2.01E-04 mm Hg *	2.65E-07	71	Dickinson (1955)
2.23E-04 mm Hg *	2.93E-07	71	Dickinson (1955)
2.17E-04 mm Hg *	2.86E-07	71	Dickinson (1955)
1.94E-04 mm Hg *	2.55-07	71	Dickinson (1955) cite: Balson (1947)
8.0E-04 mm Hg *	1.05E-06	71	Dickinson (1955) cite: Kuhn & Muassini (1949)
1.48E-05 mm Hg *	1.95E-08	50	Dickinson (1955)
1.52E-05 mm Hg *	2.E-08	50	Dickinson (1955)
5.33E-05 mm Hg *	7.01E-08	60	Dickinson (1955)
5.25E-05 mm Hg *	6.91E-08	60	Dickinson (1955)
5.4E-05 mm Hg *	7.11E-08	60	Dickinson (1955)
6.04E-04 mm Hg *	7.95E-07	80	Dickinson (1955)
5.75E-04 mm Hg *	7.57E-07	80	Dickinson (1955)
5.91E-04 mm Hg *	7.78E-07	80	Dickinson (1955)
5.7E-04 mm Hg *	7.5E-07	80	Dickinson (1955)
1.53E-03 mm Hg *	2.01E-06	88	Dickinson (1955)
1.45E-03 mm Hg *	1.91E-06	88	Dickinson (1955)
1.65E-03 mm Hg *	2.17E-06	90	Dickinson (1955)
1.76E-03 mm Hg *	2.32E-06	90	Dickinson (1955)
1.7E-07 mm Hg	2.24E-10	20	Hartley (1969)
1.4E-05 Torr *	1.84E-08	30	Westcott et al. (1981)

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NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
1.3E-05 Torr *	1.71E-08	30	Westcott et al. (1981)
6.5E-06 Torr *	8.55E-04	30	Westcott et al. (1981) cite: Spencer et al. (1972)
7.26E-07 mm Hg	9.55E-10	30	Westcott et al. (1981) cite: Spencer et al. (1972)
1.5E-07 mm Hg	1.97E-10	20	Clayton et al. (1981)
1,2-Dichloroethane			
0.39E+02 Torr *	0.051	10	SRC (1988) cite: Gallant et al. (1966)
0.82E+02 Torr *	0.11	25	SRC (1988) cite: Gallant et al. (1966)
0.155E+03 Torr *	0.20	40	SRC (1988) cite: Gallant et al. (1966)
78.9 mm Hg	0.1	25	SRC (1988) cite: Daubert et al. (1985)
79 mm Hg	0.1	25	Popendorf (1984)
10.93 KPa	0.11	25	MacKay & Shiu (1981) cite: Dilling (1977)
8.52 KPa	0.084	25	MacKay & Shiu (1981) cite: McConnel et al. (1975)
8.4 KPa	0.083	25	MacKay & Shiu (1981) cite: Pearson et al. (1975)
8.93 KPa	0.088	25	MacKay & Shiu (1981) cite: Neeling (1976)
82 mm Hg	0.11	NA	Dilling (1977) cite: McConnell (1975)
21 mm Hg *	0.028	0	Boublik et al. (1973) cite: Pearson et al. (1929)
28.2 mm Hg *	0.037	5	Boublik et al. (1973) cite: Pearson et al. (1929)
36.7 mm Hg *	0.048	10	Boublik et al. (1973) cite: Pearson et al. (1929)
49.1 mm Hg *	0.065	16	Boublik et al. (1973) cite: Pearson et al. (1929)
62.1 mm Hg *	0.0817	20	Boublik et al. (1973) cite: Pearson et al. (1929)
79.8 mm Hg *	0.105	25	Boublik et al. (1973) cite: Pearson et al. (1929)
100.9 mm Hg *	0.133	30	Boublik et al. (1973) cite: Pearson et al. (1929)
126.3 mm Hg *	0.166	35	Boublik et al. (1973) cite: Pearson et al. (1929)
153.2 mm Hg*	0.202	40	Boublik et al. (1973) cite: Pearson et al. (1929)
67 mm Hg	0.088	20	Neely (1976)

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NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
1,1-Dichloroethylene			
600 mm Hg	0.79	25	SRC (1988) cite: Boublik et al. (1989)
591 Torr	0.78	25	EPA (1981)
7.34E+04	0.72	23	Schmidt-Bleek (1982)
Dicyclopentadiene			
1.4 Torr	1.84E-03	20	NLM Haz sub databank cite: Clayton et al. (1981)
Dieldrin			
0.000024 Pa	2.37E-10	25	Suntio et al. (1988) cite: Melnikov (1971)
0.0000237 Pa	2.34E-10	20	Suntio et al. (1988) cite: Quellete & King (1977)
0.0004 Pa	3.95E-09	20	Suntio et al. (1988) cite: Worthing et al. (1983)
0.000104 Pa	1.03E-09	25	Suntio et al. (1988) cite: Spencer (1982)
0.000413 Pa	4.08E-09	20	Suntio et al. (1988) cite: Raw (1970)
0.00089 Pa	8.78E-09	20	Suntio et al. (1988) cite: Seibert et al. (1981)
0.019 Pa	1.88E-07	NA	Suntio et al. (1988)
5.89E-06 mm Hg	7.75E-09	25	SRC (1988) cite: Grayson (1982)
1.4E-06 mm Hg	1.84E-09	25	Haque & Freed (1975) cite: Lichtonstein et al. (1982)
1E-07 mm Hg	1.316E-10	25	MacKay & Leinonen (1975) cite: MacKay et al. (1975)
1.3 mPa	1.28E-08	30	Nash (1983) cite: MacKay, Spencer, & Clieth (1974)
1.78E-07 Torr	2.34E-10	20	Staples et al. (1983) cite: Maybey et al. (1981)
1.6E-06mm Hg	2.11E-09	30	Spencer, Farmer, & Cliath (1973) cite: Spencer et al. (1969)
6.59E-07 KPa	6.50 E-09	25	MacKay & Shiu (1981) cite: Edwards (1966)
3.47E-07 KPa	3.42E-09	20	MacKay & Shiu (1981) cite: Edwards (1966)
3.87E-07 KPa	3.81E-09	20	MacKay & Shiu (1981) cite: Atkings et al. (1971)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Table B.3-46 Vapor Pressure Data for Chemicals of Concern

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
2.53E-07 KPa •	2.50E-09	20	MacKay & Shiu (1981) cite: Zimmerlietali (1974)
1.04E-07 KPa •	1.03E-09	20	MacKay & Shiu (1981) cite: Ponter (1964)
2.67E-08 KPa	2.64E-10	20	MacKay & Shiu (1981) cite: Harris et al. (1964)
2.37E-08 KPa	2.34E-10	20	MacKay & Shiu (1981) cite: Weil et al. (1974)
0.000373 Pa •	3.68E-09	20	Suntio et al. (1988) cite: Spencer (1969)
0.000387 Pa	3.82E-09	20	Suntio et al. (1988) cite Alkins & Eggleton (1971)
0.000413 Pa •	4.08E-09	20	Suntio et al. (1988) cite: Phillips (1971)
2.6E-06 mm Hg	3.42E-09	20	Spencer et al. (1969)
9.9E-06 mm Hg	1.303E-08	30	Spencer et al. (1969)
35.1E-06 mm Hg	4.62E-08	40	Spencer et al. (1969)
10.1E-06 mm Hg	1.33E-08	30	Spencer et al. (1969)
33.9E-06 mm Hg	4.46E-08	40	Spencer et al. (1969)
1.43E-06 mm Hg •	1.88E-09	30	Spencer et al. (1969) cite: Porter (1964)
2.74E-06 mm Hg •	3.61E-09	40	Spencer et al. (1969) cite: Porter (1964)
2.2E-06 mm Hg •	2.90E-09	20	Spencer et al. (1969) cite: Porter (1964)
10.2E-06 mm Hg	1.34E-08	30	Spencer et al. (1969)
35.4E-06 mm Hg	4.66E-08	40	Spencer et al. (1969)
7.78E-07 mm Hg	1.02E-09	25	Spencer (1973)
1.8E-07 mm Hg	2.37E-10	25	Melnikov et al. (1971)
Endrin			
3.0E-06 mm Hg	3.95E-09	20	SRC (1988) cite: Nash et al. (1983)
2.0E-07 mm Hg	2.63E-10	25	Haque & Freed (1975)
0.4 m Pa	3.95E-09	20	Nash (1983) cite: Gueckel et al. (1983)
0.0000267 Pa	2.64E-10	25	Suntio et al. (1988) cite: Martin (1972)
0.0015 Pa	1.48E-08	NA	Suntio et al. (1988)

• Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
Hexachlorocyclopentadiene			
0.63E-01 mm Torr *	8.29E-05	25	SRC (1988) cite: Bell et al. (1978)
0.81E-01 Torr *	1.07E-04	25	SRC (1988) cite: Kilzer et al. (1979)
0.80E-01 Torr *	1.07E-04	25	SRC (1988) cite: Wolfe et al. (1983)
0.1 mm Hg	1.32E-04	25	SRC (1988) cite: Atalla et al. (1981)
0.08 mm Hg	1.05E-04	25	Clayton et al. (1981)
1 mm Hg	1.32E-03	60	Clayton et al. (1981)
Isodrin			
No Data Available			
Methylene Chloride			
0.225E+03 Torr *	0.3	10	SRC (1988) cite: Gallant (1966)
0.409E+03 Torr *	0.54	25	SRC (1988) cite: Gallant (1966)
0.76E+03 Torr *	1	40	SRC (1988) cite: Gallant (1966)
435 mm Hg	0.57	25	MacKay & Shiu (1981) cite: Boublik et al. (1984)
426 mm Hg	0.56	25	Haque & Freed (1975) cite: Dilling et al. (1973
362.4 Torr	0.48	20	Callahan et al. (1979) cite: Pearson & McConnell (1975)
431 mm Hg	0.58	25	Popendorf (1984)
438 mm Hg	0.58	NA	Dilling (1977) Cite: Syverud et al. (1969
349 mm Hg	0.459	20	Neely (1976)
1,1,2,2-Tetrachloroethane			
5 Torr	6.58E-03	20	EPA (1981)
6 mm Hg	7.9E-03	25	Popendorf (1984)
0.867 KPa	8.56E-03	25	MacKay & Shiu (1981) cite: Dilling (1977)
0.647 KPa	6.39E-03	20	MacKay & Shiu (1981) cite: Neely (1976)
6.5 mm Hg	8.55E-03	NA	Dilling (1977) cite: Hardie (1964), Stull (1944)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
4.2 mm Hg	5.53E-03	25	Suntio et al. (1988) cite: Mathews et al. (1950)
5 mm Hg	6.58E-03	30	Suntio et al. (1988) cite: Mathews et al. (1950)
8.1 mm Hg	0.0107	35	Suntio et al. (1988) cite: Mathews et al. (1950)
11.2 mm Hg	0.0147	40	Suntio et al. (1988) cite: Mathews et al. (1950)
15 mm Hg	0.0197	45	Suntio et al. (1988) cite: Mathews et al. (1950)
20.1 mm Hg	0.0265	50	Suntio et al. (1988) cite: Mathews et al. (1950)
Tetrachloroethylene			
0.81E+01 Torr	0.011	10	SRC (1988) cite: Gallant (1966)
0.186E+02 Torr	0.024	25	SRC (1988) cite: Gallant (1966)
0.4E+02 Torr	0.053	40	SRC (1988) cite: Gallant (1966)
18.55 mm Hg	0.024	25	SRC (1988) cite: Daubert et al. (1985)
19 mm Hg	0.025	25	Haque & Freed (1975) cite: Dilling et al. (1973)
17.7 mm Hg	0.023	24	Weast et al. (1972)
14 Torr	0.018	20	EPA (1981)
1.84E-02 atm	1.84E-02	20	Munz & Roberts (1987) cite: Boublik (1984)
18.6 mm Hg	0.024	NA	Dilling (1977)
1 mm Hg	1.32E-03	-20	Miller (1967)
4 mm Hg	5.26E-03	0	Miller (1967)
14.2 mm Hg	0.019	20	Miller (1967)
25 mm Hg	0.033	30	Miller (1967)
67 mm Hg	0.088	50	Miller (1967)
438.5 mm Hg	0.58	100	Miller (1967)
Trichloroethylene			
74 mm Hg	0.097	25	Haque & Freed (1975) cite: Dilling et al. (1973)
71 mm Hg	0.093	24	Chiou, Kile, & Malcom (1988) cite: Weast et al. (1972)
94 mm Hg	0.12	30	EPA (1985a)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
57.9 Torr	0.076	20	EPA (1981)
5.4 mm Hg	7.11E-03	-20	Miller (1967) cite: Hardie et al. (1964)
20.1 mm Hg	0.026	0	Miller (1967) cite: Hardie et al. (1964)
57.8 mm Hg	0.076	20	Miller (1967) cite: Hardie et al. (1964)
94 mm Hg	0.12	30	Miller (1967) cite: Hardie et al. (1964)
212 mm Hg	0.28	50	Miller (1967) cite: Hardie et al. (1964)
1119 mm Hg	1.47	100	Miller (1967) cite: Hardie et al. (1964)
8.45E+03 Pa	0.083	22	Politszki et al. (1982) cite: Schmidt-Bleek (1982)
59 mm Hg	0.078	20	Dilling (1977)
23 mm Hg	0.03	1	Dilling (1977)
97.8E-03 atm	0.0978	25	Warner et al. (1987b) cite: ISHOW Database (1979)
77 Torr	1.01E-01	25	Clayton et al. (1981)
46.8 mm Hg *	0.0616	18	Boublik et al. (1973) cite: McDonald et al. (1944)
54.2 mm Hg *	0.0713	20	Boublik et al. (1973) cite: McDonald et al. (1944)
56.3 mm Hg *	0.0741	21	Boublik et al. (1973) cite: McDonald et al. (1944)
66.1 mm Hg *	0.0821	24	Boublik et al. (1973) cite: McDonald et al. (1944)
71.6 mm Hg *	0.094	26	Boublik et al. (1973) cite: McDonald et al. (1944)
77.4 mm Hg *	0.101	27	Boublik et al. (1973) cite: McDonald et al. (1944)
90 mm Hg *	0.18	31	Boublik et al. (1973) cite: McDonald et al. (1944)
93.2 mm Hg *	0.123	31	Boublik et al. (1973) cite: McDonald et al. (1944)
107.2 mm Hg *	0.141	34	Boublik et al. (1973) cite: McDonald et al. (1944)
129.8 mm Hg *	0.171	38	Boublik et al. (1973) cite: McDonald et al. (1944)
135.2 mm Hg *	0.178	39	Boublik et al. (1973) cite: McDonald et al. (1944)
154.10 mm Hg *	0.203	42	Boublik et al. (1973) cite: McDonald et al. (1944)
168.20 mm Hg *	0.221	44	Boublik et al. (1973) cite: McDonald et al. (1944)
182.40 mm Hg *	0.24	46	Boublik et al. (1973) cite: McDonald et al. (1944)

Toluene

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
28.4 mm Hg	0.037	25	MacKay and Leinonen (1975)
0.029 atm *	0.029	20	MacKay and Yeun (1983)
28 mm Hg	0.037	25	Popendorf (1984)
3.8 KPa	0.038	25	Zwolinski et al. (1971)
3.65E+03 Pa	0.036	24	Politszki et al. (1982)
37.4E-03 atm	0.0374	25	Warner et al. (1987b)
47.68 mm Hg *	0.0627	35	Boublik et al. (1973) cite: Willingham et al. (1945)
57.41 mm Hg *	0.0756	39	Boublik et al. (1973) cite: Willingham et al. (1945)
67.22 mm Hg *	0.0885	42	Boublik et al. (1973) cite: Willingham et al. (1945)
77.28 mm Hg *	0.102	46	Boublik et al. (1973) cite: Willingham et al. (1945)
87.75 mm Hg *	0.115	49	Boublik et al. (1973) cite: Willingham et al. (1945)
103.64 mm Hg *	0.136	52	Boublik et al. (1973) cite: Willingham et al. (1945)
124.67 mm Hg *	0.164	57	Boublik et al. (1973) cite: Willingham et al. (1945)
149.43 mm Hg *	0.197	62	Boublik et al. (1973) cite: Willingham et al. (1945)
175.69 mm Hg *	0.231	66	Boublik et al. (1973) cite: Willingham et al. (1945)
217.16 mm Hg *	0.286	71	Boublik et al. (1973) cite: Willingham et al. (1945)
261.75 mm Hg *	0.344	77	Boublik et al. (1973) cite: Willingham et al. (1945)
324.93 mm Hg *	0.428	83	Boublik et al. (1973) cite: Willingham et al. (1945)
402.43 mm Hg *	0.53	90	Boublik et al. (1973) cite: Willingham et al. (1945)
500.68 mm Hg *	0.659	96	Boublik et al. (1973) cite: Willingham et al. (1945)
627.93 mm Hg *	0.826	104	Boublik et al. (1973) cite: Willingham et al. (1945)
732.08 mm Hg *	0.963	109	Boublik et al. (1973) cite: Willingham et al. (1945)
744.05 mm Hg *	0.979	110	Boublik et al. (1973) cite: Willingham et al. (1945)
755.24 mm Hg *	0.004	110	Boublik et al. (1973) cite: Willingham et al. (1945)
767.95 mm Hg *	1.01	111	Boublik et al. (1973) cite: Willingham et al. (1945)
779.34 mm Hg *	1.03	111	Boublik et al. (1973) cite: Willingham et al. (1945)
6.75 mm Hg *	8.88E-03	0	Boublik et al. (1973) cite: Pitzer (1943)
14.4 mm Hg *	0.019	12	Boublik et al. (1973) cite: Pitzer (1943)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Vapor Pressure	Converted Vapor Pressure (atm)	Reference Temperature (°C)	Reference
28.4 mm Hg *	0.0373	25	Boublik et al. (1973) cite: Pitzer (1943)
52.7 mm Hg *	0.0694	38	Boublik et al. (1973) cite: Pitzer (1943)
92 mm Hg *	0.121	50	Boublik et al. (1973) cite: Pitzer (1943)
Mercury			
0.002 Torr	2.632E-06	25	EPA (1981)
1.3E-03 Torr	1.71E-06	25	MacKay and Leinonen (1975)
Arsenic			
Neglible			EPA (1981)
Cadmium			
Neglible			EPA (1981)
Chromium			
Neglible			EPA (1981)
Lead			
Neglible			EPA (1981)

* Denotes empirical data (i.e., not calculated)
NA Denotes data not available.

Table B.3-47 Summary of K_{oc} Distribution Assignments for Contaminants of Concern

Contaminant	n	Skewness Coefficient[1]	Distribution Assigned	$Y = \log_e (K_{oc})$ $\bar{y}$	S_y	P Value[2]
Aldrin	6	.230	Lognormal	11.93	1.162	1.0
Isodrin	0	NA	Lognormal	11.93	1.162	NA
Dieldrin	10	2.47	Lognormal	10.65	0.9158	0.47
Endrin	6	0.20	Lognormal	11.85	0.8531	1.0
Toluene	30	1.13	Lognormal	6.034	0.5824	1.0
Benzene	32	3.22	Lognormal	5.063	0.6102	0.37
Chloroform	10	1.41	Lognormal	4.398	0.3361	1.0
1,2-Dichloroethane	6	0.79	Lognormal	3.588	0.3499	1.0
1,1-Dichloroethylene	2	NA	Lognormal	4.087	0.3410	1.0
Methylene Chloride	4	-0.65	Lognormal	2.648	0.3410	1.0
Carbon Tetrachloride	9	0.29	Lognormal	6.125	0.4802	1.0
1,1,2,2-Tetrachloroethane	8	2.17	Lognormal	6.125	0.6844	1.0
Tetrachloroethylene	12	1.08	Lognormal	6.133	0.4978	1.0
Chlorobenzene	21	1.23	Lognormal	6.232	0.6054	0.37
Trichloroethylene	12	2.67	Lognormal	5.760	0.8509	0.24
DDT	33	4.94	Lognormal	13.39	1.249	1.0
DDE	9	1.79	Lognormal	13.27	0.5325	1.0
Chlordane	7	1.89	Lognormal	11.96	1.079	1.0
Hexachloropentadiene	2	NA	Lognormal	11.94	1.079	1.0
Dicyclopentadiene	0	NA	Lognormal	11.94	1.079	1.0
Chloroacetic acid	1	NA	Lognormal	0.5066	0.3846	NA
Arsenic[3]	12	4.476	Lognormal	4.021	1.530	DDT1.0
Cadmium[3]	11	3.43	Lognormal	4.081	1.452	1.0
Chromium[3]	11	1.68	Lognormal	2.412	1.121	1.0
Lead[3]	9	3.67	Lognormal	8.123	3.885	1.0
Mercury[3]	11	0.140	Lognormal	4.748	0.7165	1.0

1 Standard Skewness Coefficient
2 Probability of error if the distribution is rejected
3 Values are for $Y = \log_e (Kd)$
DDT Dichlorodiphenyltrichloroethane
DDE Dichlorodiphenyldichloroethene
n Number of K_{oc}
NA Not applicable
S_y Log standard deviation
$\bar{y}$ Log mean

Table B.3-48 Soil to Water Partition Coefficient Data for Organic Chemicals

Log (K_{ow})	Calculated Log (K_{oc})	Reference
Aldrin		
5.52	5.43	Garten and Trabalka 1983
5.30	5.21	Staples et al. 1983 cite: Maybey et al. 1981
5.66*	5.56	Geyer et al. 1984
5.17	5.08	EPA 1981
4.30	4.23	Isnard and Lambert 1989
5.66	5.57	Kenaga 1980b
Benzene		
2.13*	2.09	Chiou 1985 cite: Kemula et al. 1964
1.56*	1.53	Sabljic 1987 cite: Rogers 1969
2.15*	2.11	Leo et al. 1971 cite: Tickey et al.
2.1 ± 0.2	2.06	Platford 1983 cite: Platford 1979
2.11	2.07	Schwarzenbach and Westall 1981 cite: Karickhoff 1979
2.12*	2.08	Veith et al. 1980
2.48*	2.44	Eadsforth 1986
2.13	2.09	Eadsforth 1986
2.73	2.68	Gosset et al. 1983 cite: Hansche and Leo 1980
	1.92	Kenaga 1980b cite: Kenaga and Goring 1978
2.30	2.26	Yoshida et al. 1983
2.02	1.99	Reupert et al. 1985 cite: Rekker and deKort 1979
2.37	2.33	Platford 1976 cite: Leahy 1986
2.22	2.18	Taft et al. 1985
2.01*	1.98	Valvani et al. 1981 cite: Hansche and Leo 1979
	2.96	Wijayaratne and Means 1984
2.13*	2.09	Veith et al. 1980
2.15	2.11	Veith and Morris 1978
2.48*	2.44	Swann et al. 1983

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
2.39*	2.35	Veith and Morris 1978
	1.98*	Schwarzenbach and Westall 1981 cite: Rogers 1980
2.12 ± 0.08	2.08	Arbuckle 1983 cite: Banerjee 1980
1.91	1.88	Banerjee and Howard 1988
2.19 ± 0.01*	2.15	De Bruijn et al. 1989
2.14	2.10	Doucette and Andren 1988 cite: Computer program of Leo 1985
2.09	2.05	Doucette and Andren 1988 cite: Method of Nys and Recker 1983
2.50	2.46	Doucette and Andren 1988 cite: Sarna et al. 1984
2.56	2.52	Doucette and Andren 1988
2.28	2.24	Doucette and Andren 1988 cite: Kier and Hall 1980
2.52	2.48	Doucette and Andren 1988 cite: Indiana University Chemistry Dept
2.41	2.37	Yoshida et al. 1983
2.33	2.29	Chin et al. 1986
Tetrachloride		
2.73*	2.68	Veith et al. 1980
2.96 ± 0.2	2.91	Veith et al. 1980 cite: Leo-Pomona college
2.6 ± 0.2	2.56	Platford 1983
2.83*	2.78	Valvani et al. 1981 cite: Hansche and Leo 1979
2.64	2.60	Leo et al. 1971
2.96	2.91	Eadsforth 1986
2.83	2.78	Yoshida et al. 1983
2.41	2.37	Yoshida et al. 1983
2.39	2.35	NLM Hazardous Substance Databank cite: Hansche and Leo 1984

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
Chlordane		
5.48	5.38	Staples et al. 1983
6.00	5.90	Kenaga 1980a
	5.57*	Chin et al. 1988
	5.15*	Chin et al. 1988
5.16	5.07	Kenaga 1980b
	4.78*	Johnson-Logan et al. 1991
	4.52*	Johnson-Logan et al. 1991
Chloroacetic Acid		
0.22	0.22	Dunn et al. 1986 cite: Data Bank Pomona College
Chlorobenzene		
2.90 ± 0.01*	2.85	De Bruijn et al. 1989
2.98*	2.93	Tewari et al. 1982
2.81 ± 0.01*	2.76	Garst and Wilson 1984
2.84 ± 0.01*	2.79	Garst and Wilson 1984
2.18	2.14	Garst and Wilson 1984
2.83	2.78	Yalkowsky et al. 1983
2.51	2.47	De Bruijn et al. 1989 cite: Banjeree 1988
2.84*	2.79	De Bruijn et al. 1989 cite: Hansche and Leo 1979
2.64*	2.60	De Bruijn et al. 1989 cite: Hansche and Leo 1979
2.63	2.59	Mackay et al. 1980
3.07	3.02	Doucette and Andren 1988 cite: Calc Nys and Rekker
3.18	3.13	Doucette and Andren 1988 cite: Calc by M.W.
2.82	2.77	Doucette and Andren 1988 cite: Calc by MCI
2.11	2.07	Schwarzenbach et al. 1981 cite: Isnard and Lambert 1988

* Denotes empirical data (i.e., not calculated)

Table B.3-48 Soil to Water Partition Coefficient Data for Organic Chemicals Page 4 of 10

Log (K_{ow})	Calculated Log (K_{oc})	Reference
2.71	2.66	Leo et al. 1971
2.69	2.64	Taft et al. 1985
2.98 ± 0.04*	2.93	Wasik et al. 1983
2.46*	2.41	De Bruijn et al. 1989 cite: Hansche and Leo 1979
2.89	2.84	De Bruijn et al. 1989 cite: Rekker and deKort 1979
2.83*	2.78	Hammers et al. 1982
2.94	2.89	Doucette et al. 1988 cite: Indiana University Chemistry Dept.
Chloroform		
1.89 ± 0.04	1.87	Arbuckle 1983 cite: Banerjee 1980
1.66	1.63	Banerjee and Howard 1988
1.97*	1.94	Banerjee and Howard 1988 cite: Hansche and Leo 1985
1.90*	1.87	Veith et al. 1980
1.96*	1.93	Valvani et al. 1981 cite: Hansche and Leo 1979
1.94*	1.91	Leahy 1986
1.80	1.77	Leahy 1986
2.22	2.18	Yoshida et al. 1983
2.04	2.01	Yoshida et al. 1983
2.02	1.99	Abernathy and Mackay 1988 cite: Konemann 1981
Dibromochloropropane		
2.43	2.39	NLM Hazardous Substance Databank cite: EPA-Drinking Water
	2.1	Cohen et al. 1984
	0.13	Cohen et al. 1984
	0.28	Cohen et al. 1984

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
Dichlorodiphenyldichloroethene (DDE)		
5.69	5.59	Swann et al. 1983 cite: Veith et al. 1978
5.63	5.54	Swann et al. 1983 cite: Veith et al. 1978
5.69*	5.59	Gosset et al. 1983 cite: Hanche and Leo 1980
5.99*	5.89	Webster et al. 1985 cite: Woodburn data
5.60*	5.51	Webster et al. 1985 cite: Woodburn data
6.11*	6.01	Webster et al. 1985 cite: Woodburn data
5.91*	5.81	Webster et al. 1985 cite: Woodburn data
5.83	5.73	Garten and Trabalka 1983 cite: Garten et al. 1978
6.29	6.18	Chin et al. 1986
6.96	6.84	Mabey et al. 1982
Dichlorodiphenyltrichloroethane (DDT)		
5.98	5.88	Geyer et al. 1984
6.19	6.09	Geyer et al. 1984
6.28	6.17	Geyer et al. 1984
6.36*	6.25	Hodson and Williams 1988 cite: Chiou et al. 1982
5.53*	5.44	Webster et al. 1985 cite: Woodburn data
5.18*	5.09	Webster et al. 1985 cite: Woodburn data
5.65*	5.55	Webster et al. 1985 cite: Woodburn data
5.47*	5.38	Webster et al. 1985 cite: Woodburn data
	5.38*	Hodson and Williams 1988 cite: Kenaga et al. 1980
	5.63*	Hodson and Williams 1988 cite: Brooke et al. 1980
5.98*	5.98	Briggs 1981 cite: Kenaga et al. 1979 Symposium
6.89	6.78	Briggs 1981
5.44	5.35	Gerstl and Mingelgrin 1984

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
	5.18*	Swann et al. 1983
	4.64*	Swann et al. 1983
6.90	6.79	Staples et al. 1983 cite: Maybey et al. 1981
	5.14*	Schwarzenbach and Westall 1981 cite: Chiou et al. 1979
5.1 ± 0.1*	5.01	Platford 1983
6.01	5.91	Mackay et al. 1986
6.21*	6.10	Eadsforth 1986
6.91	6.79	Eadsforth 1986 MACCs Calc
	5.38*	Kenaga et al. 1980b, cite: Kenaga et al. 1978 Symposium
6.17*	6.07	Brooke et al. 1986
6.16*	6.06	Brooke et al. 1986
6.22*	6.11	Brooke et al. 1986
6.24*	6.13	Brooke et al. 1986
6.06	5.96	Chin et al. 1986
6.91	6.79	Mabey et al. 1982
	6.25*	Schwarzenbach and Westall 1985 cite: Pierce et al. 1974
	5.95*	Caron et al. 1985 cite: Carter 1982
		Garst et al. 1984
5.76	5.66	Garten and Trabalka 1983 cite: Garten et al. 1978
5.75	5.65	Isnard and Lambert 1989
5.57	5.48	McDuffie 1981 cite: Kenaga 1975
Methylene Chloride		
1.15*	1.13	Leahy 1986
1.02	1.00	Leahy 1986
1.25*	1.23	Valvani et al. 1981 cite: Hansche and Leo 1979
1.26	1.24	Dobbs et al. 1989 cite: Hansche and Leo 1979

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
1,2-Dichloroethane		
1.76	1.73	Callahan et al. 1979 Veith et al. 1983
1.44	1.42	Banerjee and Howard 1988
1.48*	1.46	Banerjee and Howard 1988 cite: Hansche and Leo 1985
1.45*	1.43	Veith et al. 1980
1.58	1.55	Leahy 1986
1.79*	1.76	Sabljic 1987 cite: Hansche and Leo 1979
1,1-Dichloroethylene		
2.13	2.09	Dobbs et al. 1989 cite: Hansche and Leo 1979
1.48	1.46	EPA 1981
Dieldrin		
4.32	4.25	Geyer et al. 1987
5.48	5.39	Thomann 1989
5.16	5.07	Isnard and Lambert 1989
4.5	4.42	Mackay et al. 1986
4.51*	4.43	Brooke et al. 1986
4.49*	4.41	Brooke et al. 1986
4.60*	4.52	Brooke et al. 1986
4.55*	4.47	Brooke et al. 1986
5.16	5.07	Isnard and Lambert 1988 cite: Geyer et al. 1988
4.32	4.25	Geyer et al. 1987 cite: Kenaga et al. 1980b

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
Endrin		
5.34*	5.25	De Bruijn et al. 1989 cite: Kenega and Goring 1980
5.16*	5.07	De Bruijn et al. 1989 cite: Garten et al. 1983
5.54	5.45	Staples et al. 1983 cite: Mabey et al. 1981
5.6	5.51	EPA 1981
4.56	4.48	Isnard and Lambert 1989
5.19 ± 0.01	5.11	De Bruijn et al. 1989
Hexachlorocyclopentadiene		
5.51*	5.42	Isnard and Lambert 1988
5.04	4.95	Geyer et al. 1984
1,1,2,2,-Tetrachloroethane		
3.01	2.96	Call et al. 1985 cite: Callahan et al. 1979
2.39	2.35	Abernathy et al. 1988 cite: Banerjee 1980
2.39*	2.35	Veith et al. 1980
2.66 ± 0.15	2.62	Veith et al. 1980 cite: Leo-Pomona College
2.60	2.56	Thomann 1989
2.56	2.52	Callahan et al. 1979 cite: Tate 1971
3.27	3.21	Yoshida et al. 1983
2.76	2.71	Yoshida et al. 1983
Tetrachloroethylene		
2.5289	2.49	Banerjee et al. 1980
2.53*	2.49	Veith et al. 1980
2.67*	2.62	Veith et al. 1980
3.03 ± 0.25	2.98	Veith et al. 1980 cite: Leo-Pomona College
2.60	2.56	Gosset et al. 1983 cite: Hansche and Leo 1980

* Denotes empirical data (i.e., not calculated)

Log (K_{ow})	Calculated Log (K_{oc})	Reference
2.88*	2.83	Leahy 1986
2.85	2.80	Dobbs et al. 1989 cite: Callahan 1979
2.26	2.22	Haque and Freed 1975 cite: Hansche and Leo 1972
2.76	2.71	Yoshida et al. 1983
2.72	2.67	Yoshida et al. 1983
2.67 ± 0.08*	2.62	Veith et al. 1980
3.02	2.97	Abdul et al. 1987
Trichloroethylene		
2.42	2.38	Abernathy and Mackay 1988 cite: Banerjee 1980
2.32	2.28	Yoshida et al. 1983
2.53*	2.49	Tewari et al. 1982
2.29*	2.25	Gosset et al. 1983 cite: Hansche and Leo 1980
3.24	3.19	Geyer et al. 1984
3.30	3.24	Geyer et al. 1984
2.20	2.16	Eadsforth 1986
2.42*	2.38	Hodson and Williams 1988 cite: Veith et al. 1980
2.33	2.29	Cohen and Ryan 1985 cite: Mackay 1980
2.24	2.25	O'Conner et al. 1984 cite: Leehr 1983; Lymann 1981
2.84	2.79	Eadsforth 1986
2.36	2.32	Yoshida et al. 1983
Toluene		
2.69*	2.64	Yoshida et al. 1983 cite: Yoshida et al. 1979
2.51	2.47	Mackay et al. 1980
2.65*	2.61	Tewari et al. 1982
3.06*	3.01	Eadsforth 1986

* Denotes empirical data (i.e., not calculated)

Table B.3-48 Soil to Water Partition Coefficient Data for Organic Chemicals Page 10 of 10

Log (K_{ow})	Calculated Log (K_{oc})	Reference
2.80	2.75	Eadsforth 1986 MACCS
2.73	2.68	Leo et al. 1971
2.76	2.71	Yoshida et al. 1983
2.52	2.48	Yoshida et al. 1983
2.21*	2.17	Veith et al. 1980
2.99 ± 0.03*	2.94	Veith et al. 1980
2.79 ± 0.15	2.74	Veith et al. 1980 cite: Leo-Pomona College
2.59	2.55	Abernathy and Mackay 1988 cite: Mackay et al. 1988
2.21 ± 0.97	2.17	Banerjee et al. 1980
2.93*	2.88	Veith and Morris 1978 cite: Doucette 1985
2.60	2.56	Veith and Morris 1978 cite: Doucette 1985
2.98	2.93	Veith and Morris 1978 cite: Doucette 1985
2.87	2.82	Veith and Morris 1978 cite: Doucette 1985
2.12*	2.08	Abernathy and Mackay 1988 cite: Banjeree et al. 1980
2.39	2.35	Banjeree and Howard 1988
2.58*	2.54	Eadsforth 1986
2.79 ± 0.01*	2.74	De Bruijn et al. 1989
2.65*	2.61	Doucette and Andren 1988 cite: Sarene et al. 1984
2.93*	2.88	Doucette and Andren 1988
2.81	2.76	Doucette and Andren 1988
2.75	2.70	Doucette and Andren 1988
3.01	2.96	Doucette and Andren 1988
2.63	2.59	Sarna et al. 1984 cite: Yalkowsky 1983
2.66	2.62	Taft et al. 1985
2.65 ± 0.02*	2.61	Wasik et al. 1983
		Leo et al. 1971
2.11*	2.07	Leo et al. 1971 cite Rogers 1969

* Denotes empirical data (i.e., not calculated)

Table B.3-49 Distribution Coefficients (K_d) for Inorganic Chemicals

Log (K_d)	Isotherm n Values	Soil Type/ pH	Reference
Arsenic			
2.56			JRB Associates 1984
1.679*	0.636	Alligator/4.8	Butcher et al. 1989
0.948*	0.554	Calciorthid/8.5	Butcher et al. 1989
1.297*	0.618	Cecil/5.4, 5.7	Butcher et al. 1989
3.176*	1.462	Kula/5.9, 6.2	Butcher et al. 1989
1.851*	0.747	Lafitte/3.9	Butcher et al. 1989
2.194*	0.561	Molokai/6.0	Butcher et al. 1989
0.931*	0.510	Norwood/6.9	Butcher et al. 1989
1.663*	0.548	Oliver/6.6	Butcher et al. 1989
1.273*	0.797	Spodosol/4.3	Butcher et al. 1989
1.373*	0.648	Webster/7.6	Butcher et al. 1989
2.021*	0.601	Windsor/5.3, 5.8	Butcher et al. 1989
Cadmium			
1.720*	0.902	Alligator/4.8	Butcher et al. 1989
2.460*	0.568	Calciorthid/8.5	Butcher et al. 1989
1.142*	0.768	Cecil/5.7, 5.4	Butcher et al. 1989
2.271*	0.721	Kula/5.9, 6.2	Butcher et al. 1989
1.722*	0.850	Lafitte/3.9	Butcher et al. 1989
1.460*	0.773	Molokai/6.0	Butcher et al. 1989
1.459*	0.668	Norwood/6.9	Butcher et al. 1989
1.991*	0.658	Oliver/6.6	Butcher et al. 1989
0.738*	0.840	Spodosol/4.3	Butcher et al. 1989
2.878*	0.569	Webster/7.6	Butcher et al. 1989
1.157*	0.782	Windsor/5.3, 5.8	Butcher et al. 1989
Chromium			
0.533*	0.504	Alligator/4.8	Butcher et al. 1989

Table B.3-49 Distribution Coefficients (K_d) for Inorganic Chemicals

Log (K_d)	Isotherm n Values	Soil Type/ pH	Reference
No Sorption*[1]	No Sorption	Calciorthid/8.5	Butcher et al. 1989
No Sorption*	No Sorption	Cecil/5.7, 5.4	Butcher et al. 1989
1.798*	0.609	Kula/5.9, 6.2	Butcher et al. 1989
1.482*	0.374	Lafitte/3.9	Butcher et al. 1989
0.807	0.607	Molokai/6.0	Butcher et al. 1989
No Sorption*	No Sorption	Norwood/6.9	Butcher et al. 1989
No Sorption*	No Sorption	Oliver/6.6	Butcher et al. 1989
0.738*	0.394	Spodosol/4.3	Butcher et al. 1989
No Sorption*	No Sorption	Webster/7.6	Butcher et al. 1989
0.928	0.521	Windsor/5.3, 5.8	Butcher et al. 1989
Lead			
3.257*	0.853	Alligator/4.8	Butcher et al. 1989
2.372*	0.662	Cecil/5.7, 5.4	Butcher et al. 1989
7.635*	5.385	Kula/5.9, 6.2	Butcher et al. 1989
2.963*	0.558	Lafitte/3.9	Butcher et al. 1989
3.912*	1.678	Molokai/6.0	Butcher et al. 1989
2.585*	0.741	Norwood/6.9	Butcher et al. 1989
4.215*	0.998	Oliver/6.6	Butcher et al. 1989
2.135*	0.743	Spodosol/4.3	Butcher et al. 1989
2.674*	0.743	Windsor/5.3, 5.8	Butcher et al. 1989
Complete Sorption*	Complete Sorption	Calcierthid/8.5	Butcher et al. 1989
Complete Sorption*	Complete Sorption	Webster/7.6	Butcher et al. 1989
Mercury			
2.035*	0.741	Alligator/4.8	Butcher et al. 1989
1.292*	0.313	Calciorthid/8.5	Butcher et al. 1989
1.910*	0.564	Cecil/5.7, 5.4	Butcher et al. 1989
2.397*	1.700	Kula/5.9, 6.2	Butcher et al. 1989

Log (K_d)	Isotherm n Values	Soil Type/ pH	Reference
2.278*	0.751	Lafitte/3.9	Butcher et al. 1989
2.053*	0.582	Norwood/6.9	Butcher et al. 1989
2.109*	1.122	Oliver/6.6	Butcher et al. 1989
1.936*	0.513	Spodosol/4.3	Butcher et al. 1989
2.476*	2.158	Webster/7.6	Butcher et al. 1989
2.115*	0.681	Windsor/5.3, 5.8	Butcher et al. 1989
2.079*	0.960	Molokai/6.0	Butcher et al. 1989
3.60			Akagi et al. 1979

[1] Concentrations in soil below detection
[2] Concentrations in aqueous phase below detection
* Denotes empirical data (i.e., not calculated)

Summary for Temperature

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ALL
1948	-2.8	-3.1	0.1	11.0	14.7	19.1	22.8	22.7	19.6	10.5	2.5	-1.1	9.7
1949	-9.2	-1.1	3.6	10.0	13.9	18.3	22.2	22.0	16.9	9.3	9.1	-0.3	9.6
1950	-1.4	3.3	3.7	8.7	11.7	19.5	20.5	20.6	15.4	15.1	3.5	2.0	10.3
1951	-3.0	1.0	2.2	6.4	14.1	15.8	22.7	21.2	16.2	8.7	3.0	-1.7	8.9
1952	1.2	1.5	0.9	9.1	13.8	22.5	22.8	21.9	18.5	11.5	-0.4	0.0	10.3
1953	4.3	0.3	6.3	5.8	12.0	21.1	23.0	21.6	18.9	12.1	5.8	-0.3	11.0
1954	1.6	6.7	1.6	12.1	14.0	20.9	24.4	22.5	18.5	11.0	6.4	0.9	11.7
1955	-3.0	-3.0	2.6	10.3	15.1	17.6	24.0	22.1	17.6	11.8	1.8	1.6	10.0
1956	0.4	-2.7	4.6	7.8	15.9	23.1	22.3	20.7	18.9	13.1	2.3	1.5	10.7
1957	-3.8	4.3	3.5	5.3	11.9	18.9	22.8	21.9	16.1	10.4	2.2	3.8	9.8
1958	-0.2	2.6	0.2	6.9	16.5	20.0	20.9	22.9	17.8	11.8	4.2	1.5	10.4
1959	-1.7	-1.2	2.7	8.0	13.4	21.3	22.6	22.6	16.0	8.5	3.0	1.5	9.8
1960	-3.0	-4.1	3.3	10.5	14.2	20.4	22.7	22.9	18.0	10.9	3.5	-2.9	9.8
1961	-1.1	1.5	3.6	7.8	13.1	19.0	21.5	21.7	13.0	9.6	1.0	-2.8	9.0
1962	-7.3	-1.3	1.4	10.1	15.5	18.3	22.4	22.4	16.7	11.5	4.7	0.1	9.6
1963	-7.8	2.9	3.3	10.2	16.1	19.7	23.7	19.8	18.5	13.8	4.7	-2.3	10.2
1964	-1.0	-2.5	0.6	8.3	15.4	18.4	24.4	21.3	16.9	11.0	4.1	0.5	9.8
1965	1.6	-2.3	-1.9	10.6	13.9	17.6	22.2	20.8	12.7	12.2	5.7	1.2	10.8
1966	-2.3	-2.4	5.7	6.9	15.1	18.0	24.4	21.2	17.8	10.7	4.3	-1.2	9.9
1967	0.8	1.7	6.3	9.6	11.2	15.4	20.0	19.8	16.5	11.0	3.9	-3.1	7.2
1968	-1.9	0.9	4.7	6.1	11.9	20.2	21.5	19.7	15.7	10.8	1.9	-1.6	9.2
1969	1.0	1.5	0.0	11.3	15.1	16.2	23.4	23.0	17.6	3.7	3.0	-0.2	8.6
1970	-1.0	3.2	0.9	6.7	15.0	18.5	22.1	22.7	14.9	7.3	3.5	0.1	9.5
1971	0.1	-1.0	3.5	8.8	12.1	20.6	21.2	22.0	14.1	9.5	3.5	-0.8	9.5
1972	-1.0	2.3	7.5	9.3	14.1	20.1	21.0	21.0	16.5	10.6	0.3	-4.2	9.8
1973	-2.8	1.3	3.9	6.2	13.4	20.3	21.4	22.7	15.5	12.0	3.7	-0.2	9.8
1974	-4.5	1.5	6.3	9.3	16.8	20.5	23.3	20.7	15.1	11.2	2.8	-0.9	10.2
1975	-0.4	-0.6	2.9	6.9	12.4	18.2	22.4	21.4	15.1	11.8	2.2	2.0	9.6
1976	-0.4	4.2	3.2	9.4	13.6	19.4	23.4	20.7	16.2	8.5	3.0	1.1	10.2
1977	-2.2	3.1	4.1	10.3	16.2	22.0	23.0	20.9	19.2	11.5	4.3	1.8	11.2
1978	-3.6	-0.9	6.2	10.0	12.7	19.4	23.4	20.6	18.6	11.2	2.7	-4.5	9.7
1979	-7.8	0.4	4.7	9.6	12.3	18.9	22.9	20.4	19.0	11.8	-0.1	1.0	9.5
1980	-3.5	1.3	3.5	8.8	13.9	22.7	24.4	22.6	19.1	11.0	5.4	4.9	11.2
1981	1.9	2.4	5.1	13.5	13.6	21.4	24.0	21.7	19.8	11.2	7.4	1.9	12.2
1982	-0.6	0.0	5.3	8.8	12.7	17.1	22.6	22.3	16.1	9.0	1.4	-1.1	9.5
1983	0.0	2.4	2.3	5.0	10.9	17.2	22.7	23.0	18.4	11.2	2.3	-7.9	9.0
1984	-2.9	0.9	2.8	5.5	15.8	19.0	23.4	21.7	15.8	6.8	4.0	0.4	9.4
1985	-3.9	-2.7	5.1	10.5	15.6	20.0	22.3	22.5	14.5	9.9	-1.6	-1.6	9.3

Table B.3-50 Monthly Average Air Temperatures[1] Stapleton Airport 1948–1987—Temperatures in °C

Summary for Temperature

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ALL
1986	4.1	2.2	8.4	9.9	13.7	21.0	22.8	22.0	15.4	9.4	3.3	-1.4	10.9
1987	-0.2	1.9	3.5	11.3	14.8	20.4	23.5	21.0	16.5	10.7	3.6	-2.0	10.5
Average	-1.7	0.7	3.4	8.8	14.0	19.4	22.7	21.6	16.8	10.6	3.3	-0.4	9.9
St. Deviation	3.0	2.4	2.2	2.0	1.5	1.8	1.1	0.9	1.8	1.9	2.0	2.3	0.9
Maximum	4.3	6.7	8.4	13.5	16.8	23.1	24.4	23.0	19.8	15.1	9.1	4.9	12.2
Minimum	-9.2	-4.1	-1.9	5.0	10.9	15.4	20.0	19.7	12.7	3.7	-1.6	-7.9	7.2

1 Mean annual air temperature for the years 1948 through 1987 (9.9 °C) is used as a surrogate value for annual average soil temperature.

Table B.3-51 Soil Bulk Density Data (g/cm^3)

Soil Series	Data Source	
	Walsh (1988)	Soil Conservation Service (1987)
Ascalon	1.39	1.61
	1.58	1.62
	1.62	1.66
	0.91	1.46
	1.62	1.50
	1.61	1.53
	1.60	1.62
	1.82	1.66
		1.45
		1.55
		1.30
		1.40
		1.30
		1.45
		1.50
		1.60
		1.25
		1.35
		1.45
		1.15
Bresser	1.78	1.62
	2.04	1.58
	1.38	1.69
	1.59	1.78
	1.55	1.72
	1.80	1.63
	1.74	1.62
	1.65	1.71
	1.71	1.75
		1.25
Bresser	N/A	1.35
		1.25
		1.35
		1.30
		1.40
		1.35
		1.45
Bresser		1.50

Soil Series	Data Source: Walsh (1988)	Data Source: Soil Conservation Service (1987)
		1.60
		1.55
		1.65
		1.55
		1.65
		1.65
		1.70
		1.50
		1.65
		1.60
		1.70
		1.60
		1.70
		1.55
		1.40
		1.60
Nunn	N/A	1.35
		1.40
		1.35
		1.45
		1.50
		1.60
		1.35
		1.40
		1.40
		1.45
		1.35
		1.45
		1.15
		1.25
		1.10
		1.20
		1.25
		1.35
		1.20
		1.30
Nunn		1.25
		1.35
		1.35

Table B.3-51 Soil Bulk Density Data (g/cm^3)

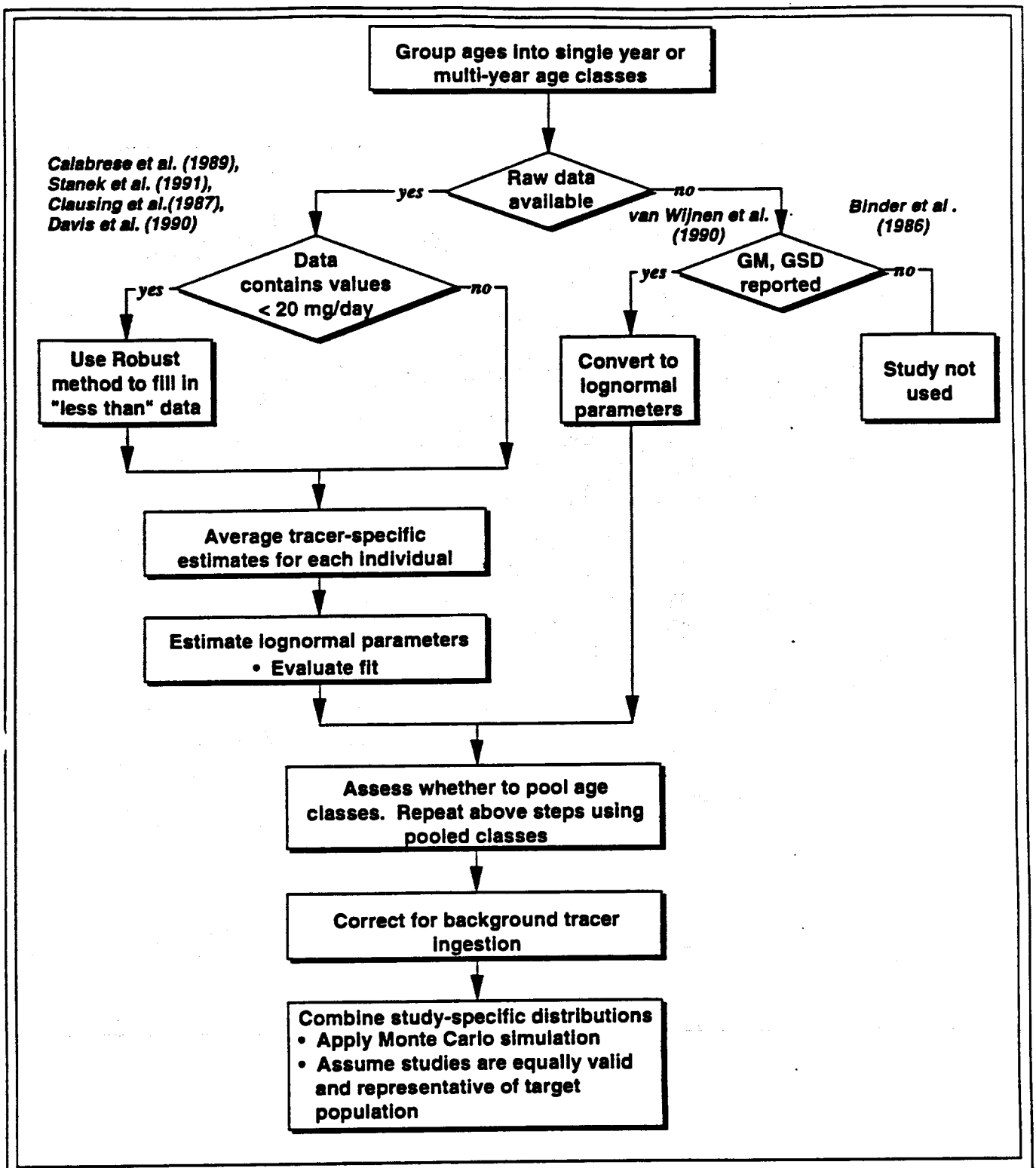
Soil Series	Data Source: Walsh (1988)	Data Source: Soil Conservation Service (1987)
		1.45
		1.30
		1.40
		1.10
		1.50
		1.30
		1.40
		1.25
		1.35
		1.25
		1.40
		1.20
		1.30
		1.15
		1.25
		1.20
		1.30
		1.20
		1.30
		1.55
		1.70
		1.20
		1.30
		1.20
		1.30
		1.20
		1.30
		1.40
		1.50
		1.35
Satanta		1.45
	1.70	
	2.12	1.30
Satanta	1.56	1.37
	1.61	1.28
	1.53	1.35
	1.57	1.33
	1.63	1.43
	1.53	1.48
		1.60

Soil Series	Data Source: Walsh (1988)	Data Source: Soil Conservation Service (1987)
	1.55	1.30
	1.49	1.40
		1.30
		1.40
		1.30
		1.40
		1.30
		1.40
		1.30
		1.40
		1.35
		1.50
		1.30
		1.45
Truckton	1.60	1.64
	1.94	1.70
	1.84	1.62
	1.63	1.74
	1.77	1.73
		1.45
		1.55
		1.35
Truckton	N/A	1.45
		1.45
		1.55
		1.40
		1.60
Weld	N/A	1.36
		1.42
		1.51
		1.46
Weld		1.38
		1.32
		1.41
		1.44
		1.39
		1.41

Table B.3-52 Proportion of RMA Soil Attributed to Each Soil Type[1]

Soil Series	Fraction of RMA Soil (f_s)
1. Bresser	.512
2. Weld	.226
3. Ascalon	.136
4. Santana	.049
5. Truckton	.05
6. Nunn	.027
Total	1.0

[1] Fractions differ slightly from those given in F_{oc} distribution development because fewer soil types were sampled for Henry's Law. The original fractions for each soil were adjusted to sum up to a value of 1.0.



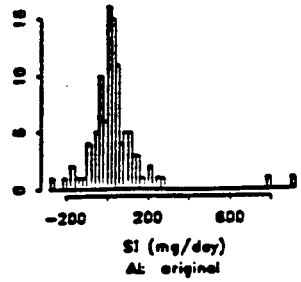
RMA IEA/RC B.3 1.94 eb

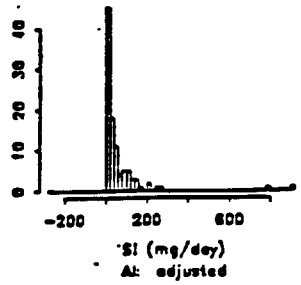
Figure B.3-1

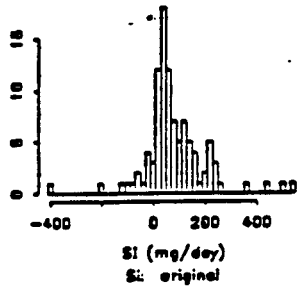
Diagram of Steps in Integration of Child Soil Ingestion Distributions from Different Studies

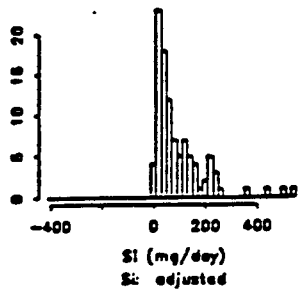
Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

Davis et al. (1990)(Ages 2-7)

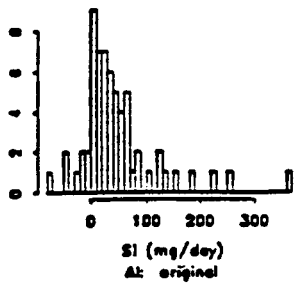


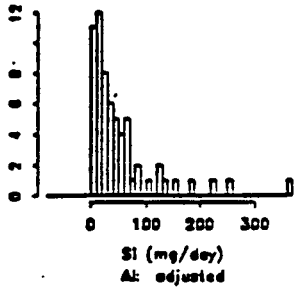


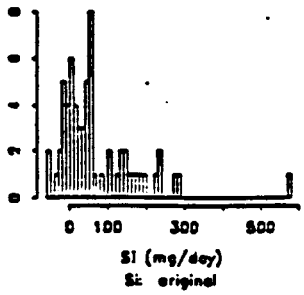


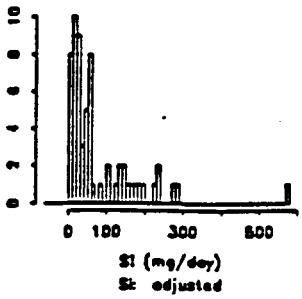


Stanek et al. (1991) (Ages 1-3)









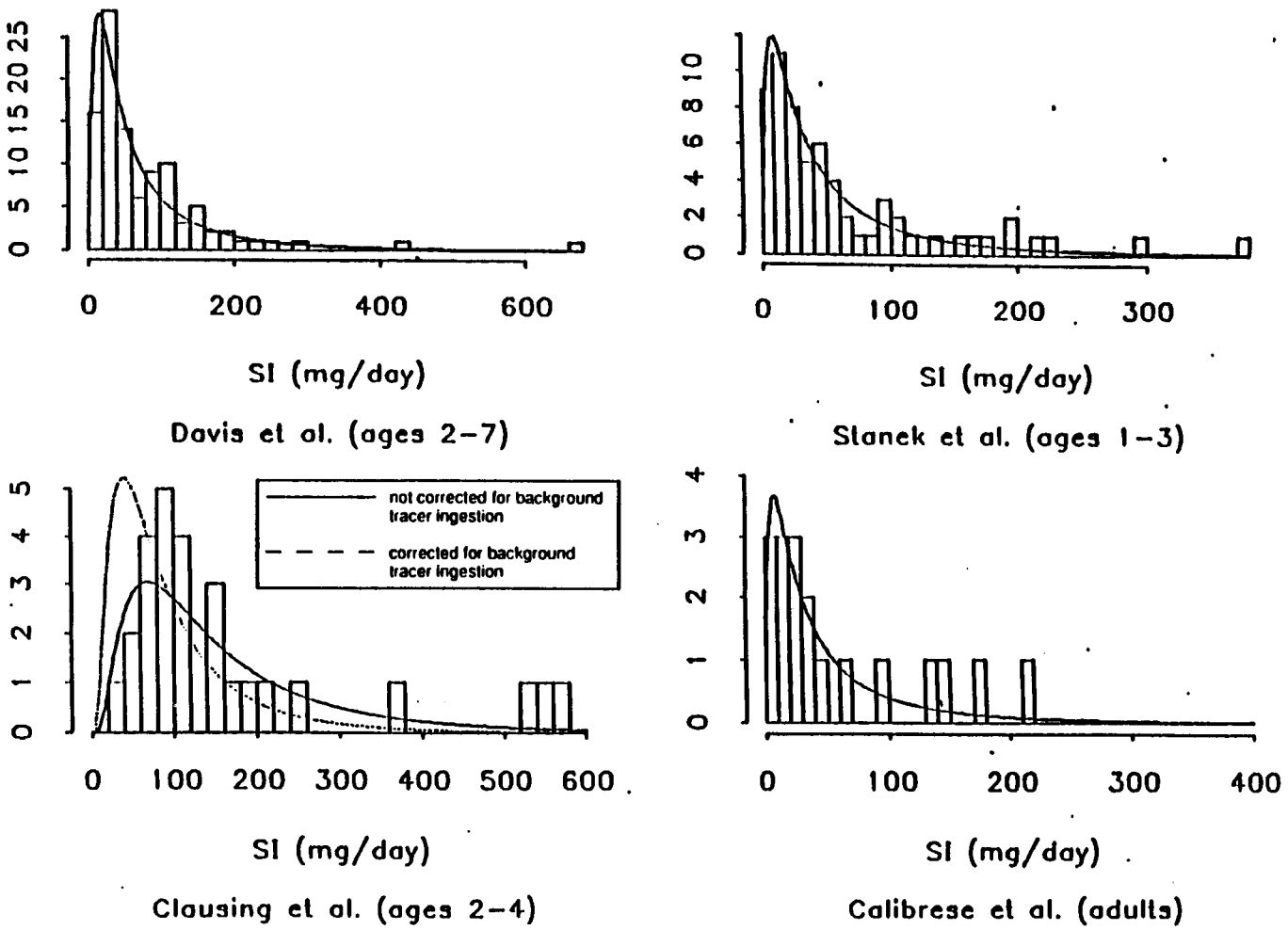
RMA IEA/RC B.3 8.93.jb

Figure B.3-2

Original Data Compared to Robust Method Data for Mass Balance Studies

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

(data < 20 mg/day was replaced with estimates from the Robust Method)



RMA IEA/RC B.3 8.93.jb

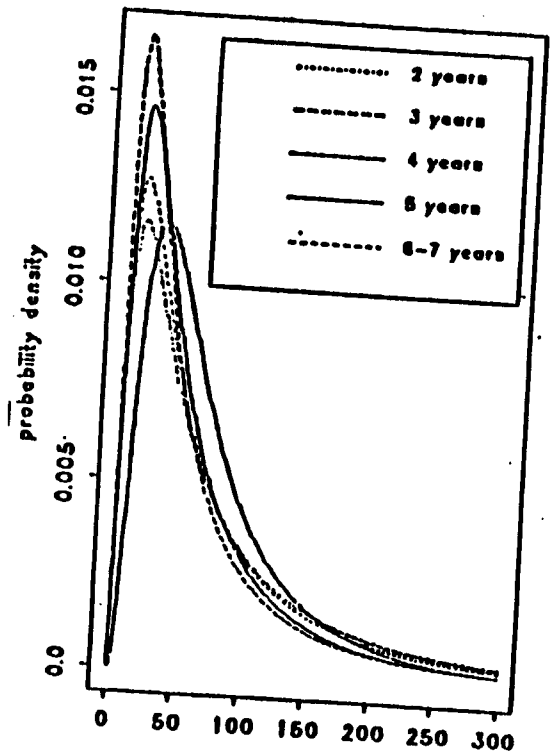
Figure B.3-3

Fit of Study-Specific Distributions to Data

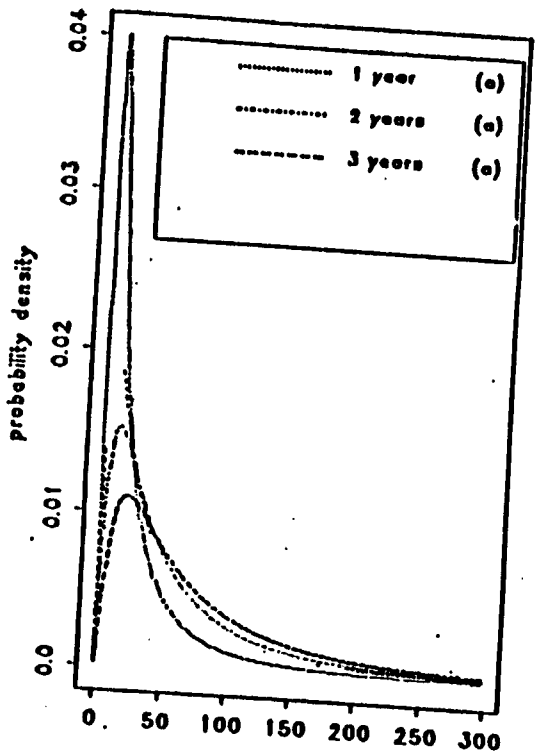
Sources:

Davis et al. (1990)
Stanek et al. (1991)
Clausing et al. (1987)
Calibrese et al. (1990)

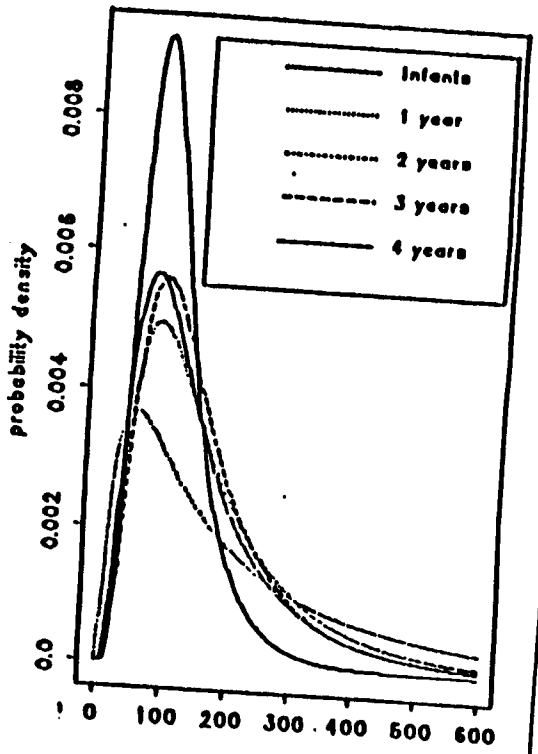
Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



Davis et al. (1990)



Stanek et al. (1991) (a) and
Calabrese et al. (1989) (b)



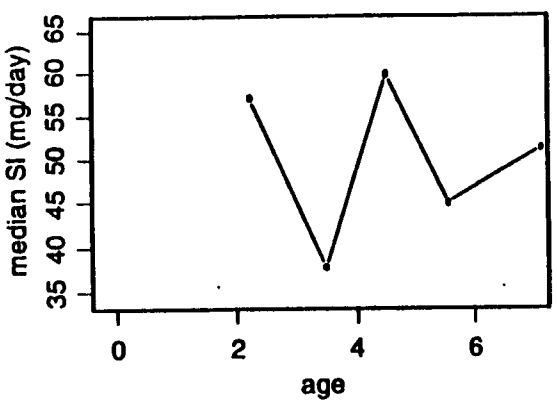
van Wijnen et al. (1990)
(not corrected for background tracer ingestion)

RMA IEA/RC B.3 8.93.jb

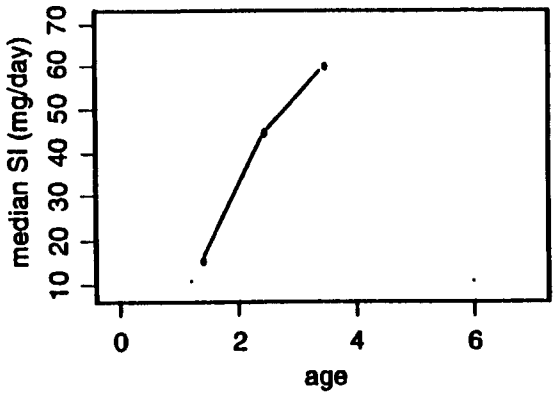
Figure B.3-4

Study-Specific Distributions for Single Year Classes

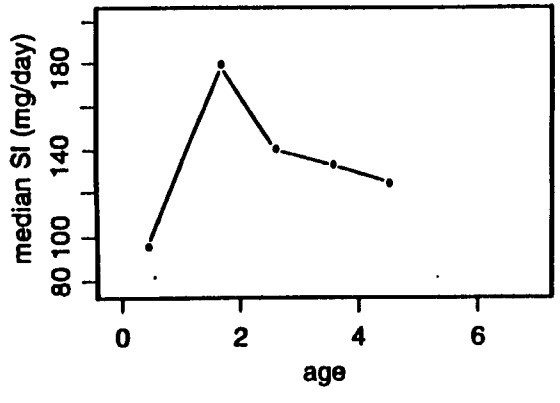
Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



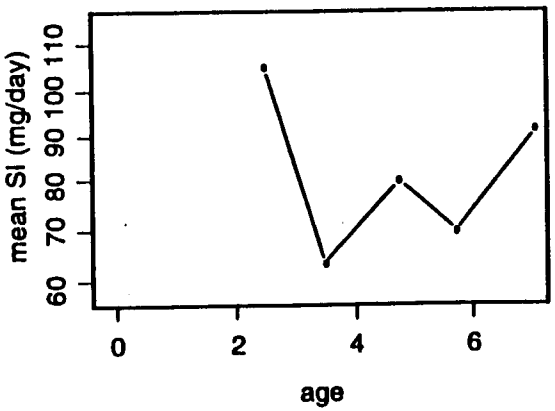
Median SI
(Davis et al. 1990)



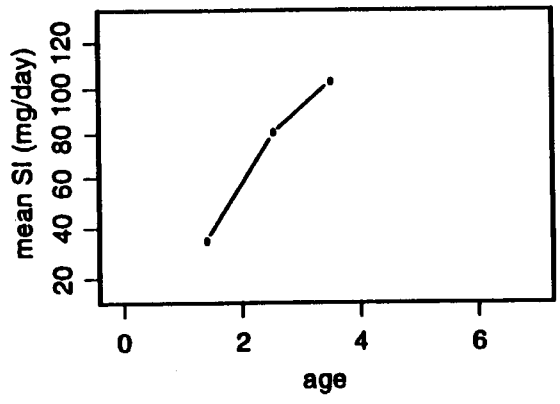
Median SI
(Stanek et al. 1991)



Median SI
(van Wijnen et al. (1990), not corrected for background tracer ingestion)



Mean SI
(Davis et al. 1990)



Mean SI
(Stanek et al. 1991)

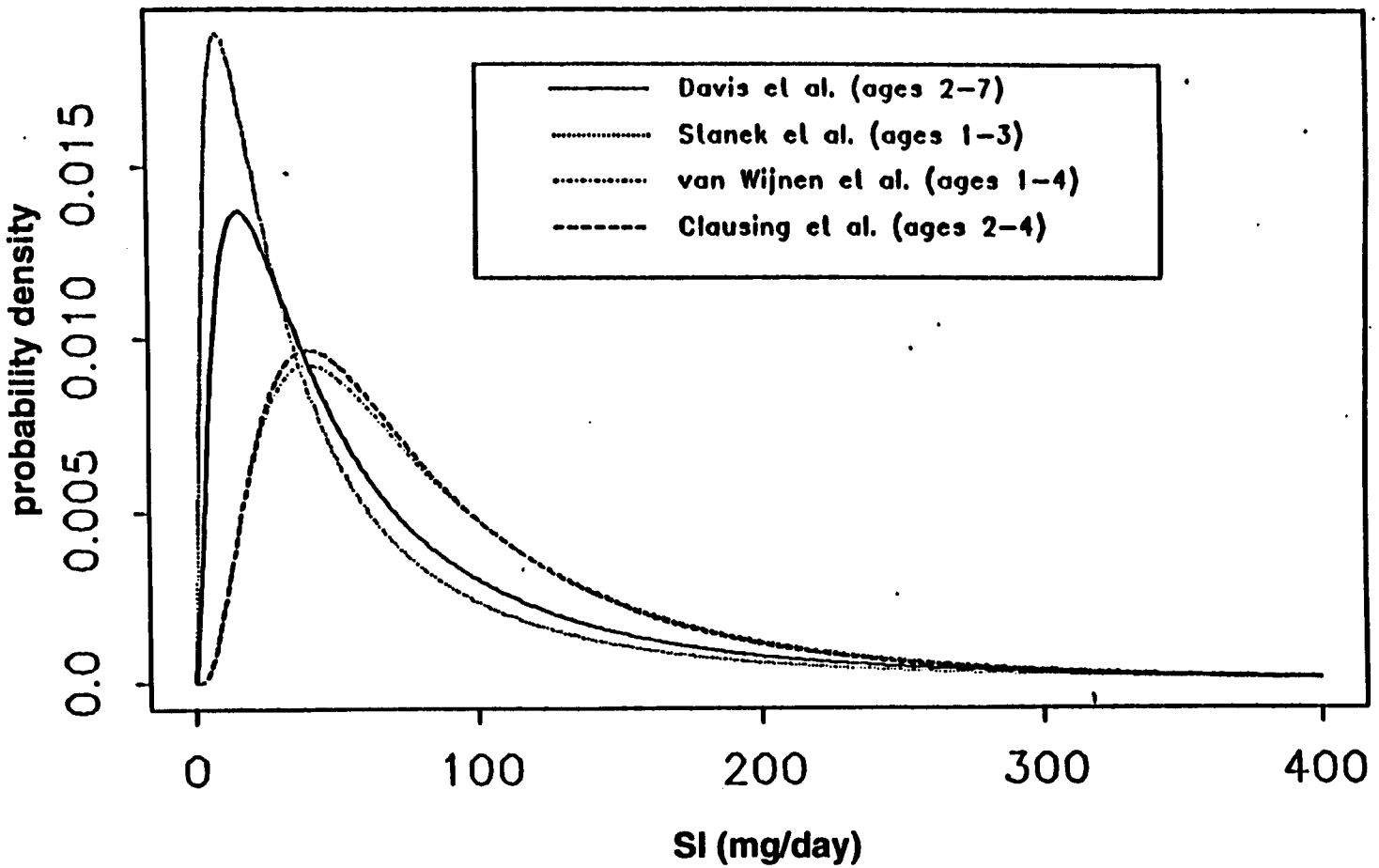
Mean SI
(van Wijnen et al. (1990), uncorrected)

RMA IEA/RC B.3 8.93.jb

Figure B.3-5

Relationship Between Age and Median or Mean Soil Ingestion for Ages 1 to 7

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



RMA IEA/RC B.3 8.93.jb

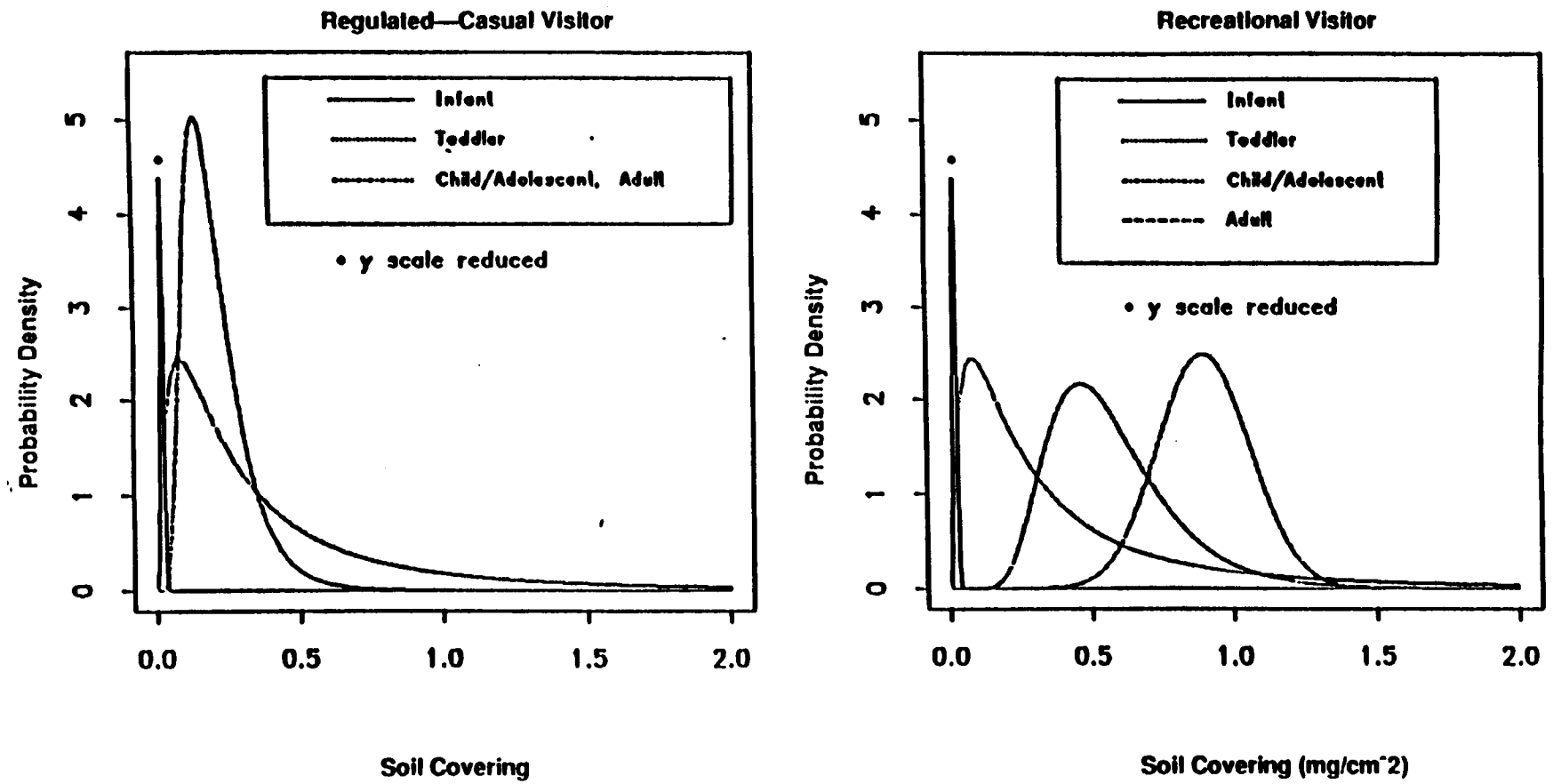
Sources:

Davis et al. (1990)
Stanek et al. (1991)
Clausing et al. (1987)
Calibrese et al. (1990)

Figure B.3-6

Comparison of Study-Specific Distributions for Ages 1 to 7

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

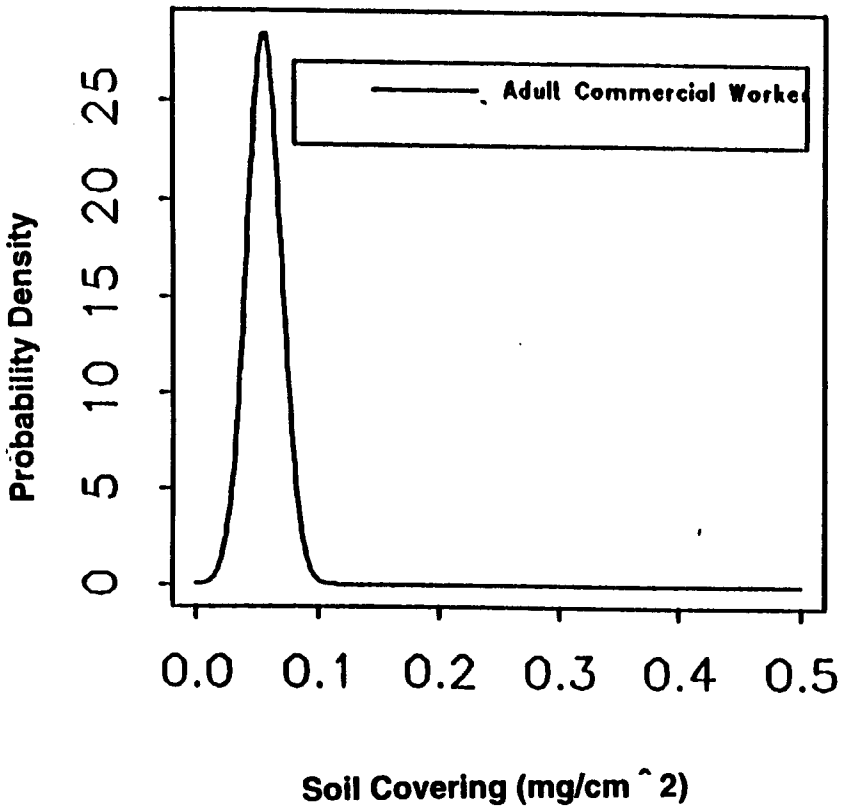


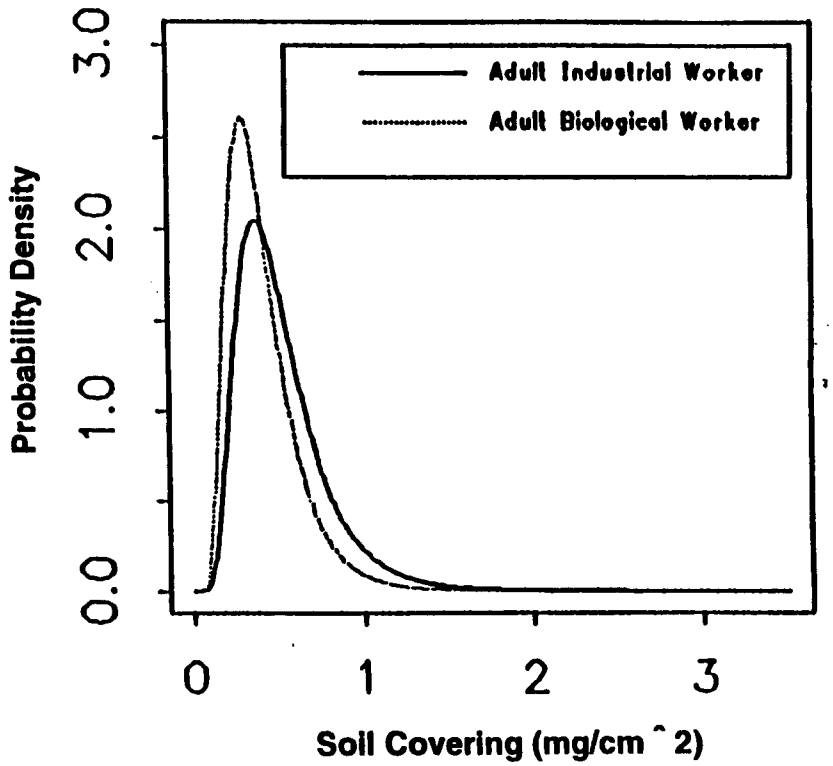
RMA IEA/RC B.3 8.93.jb

Figure B.3-7

Probability Distributions for Soil Covering for Visitor Populations

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



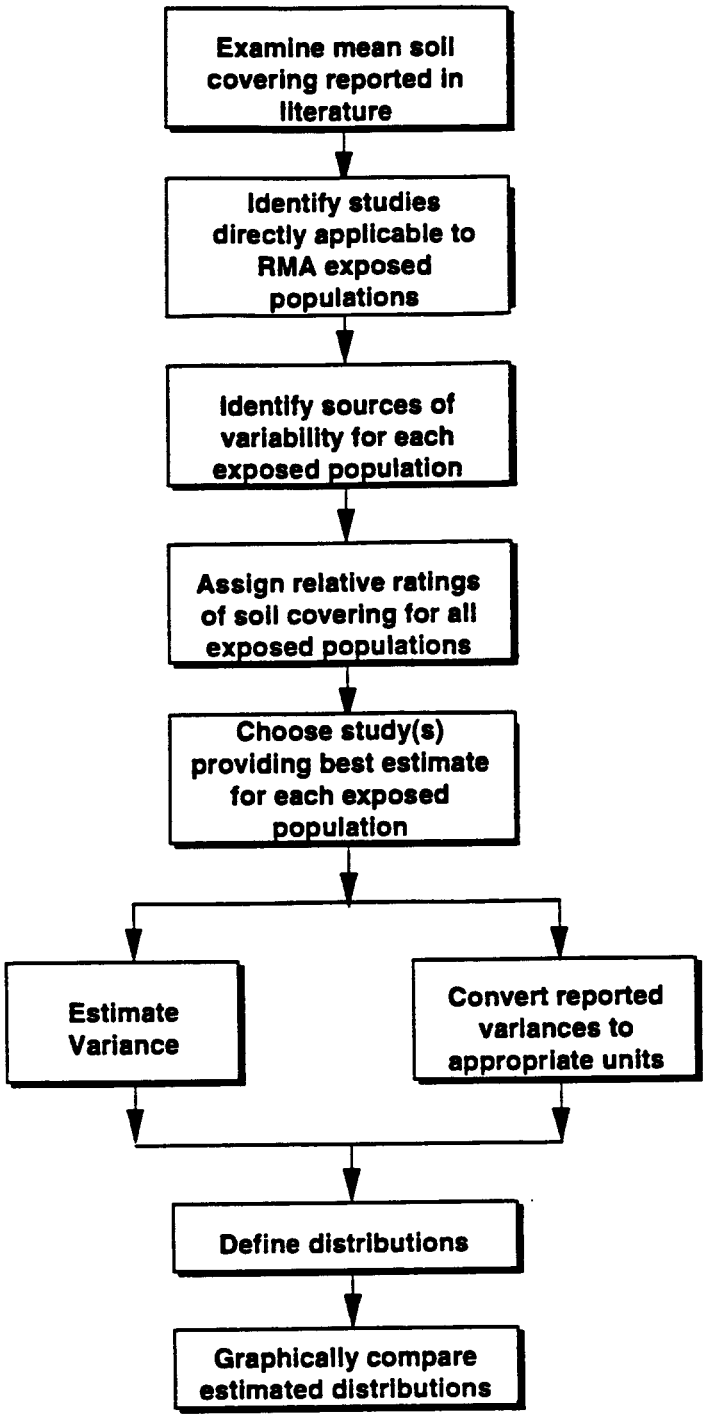


RMA IEA/RC B.3 8.93.jb

Figure B.3-8

Probability Distributions for Soil Covering for Worker Populations

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

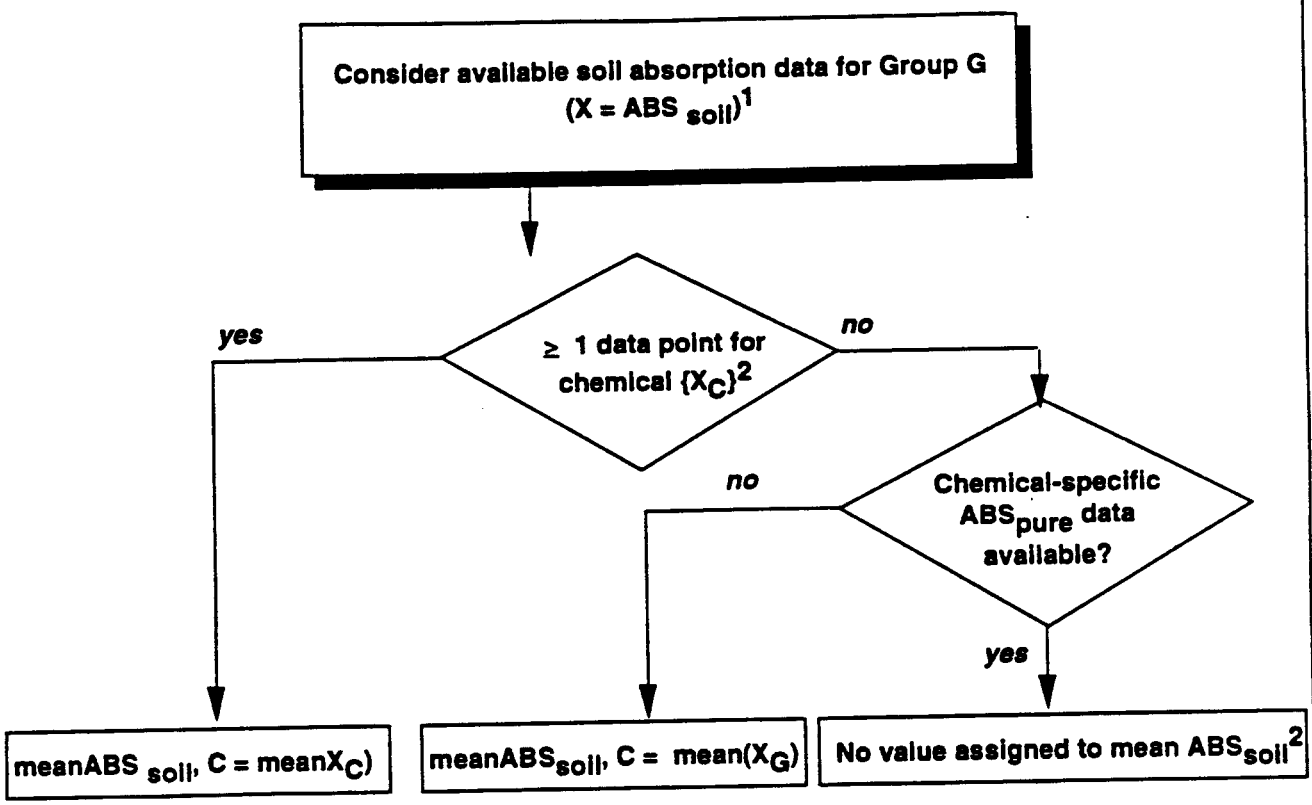


RMA IEA/RC B.3 1.94 eb

Figure B.3-9

Diagram of Steps in Estimating Distributions for Soil Covering

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



1 Mean of chemical-specific means. No extrapolation for metals.

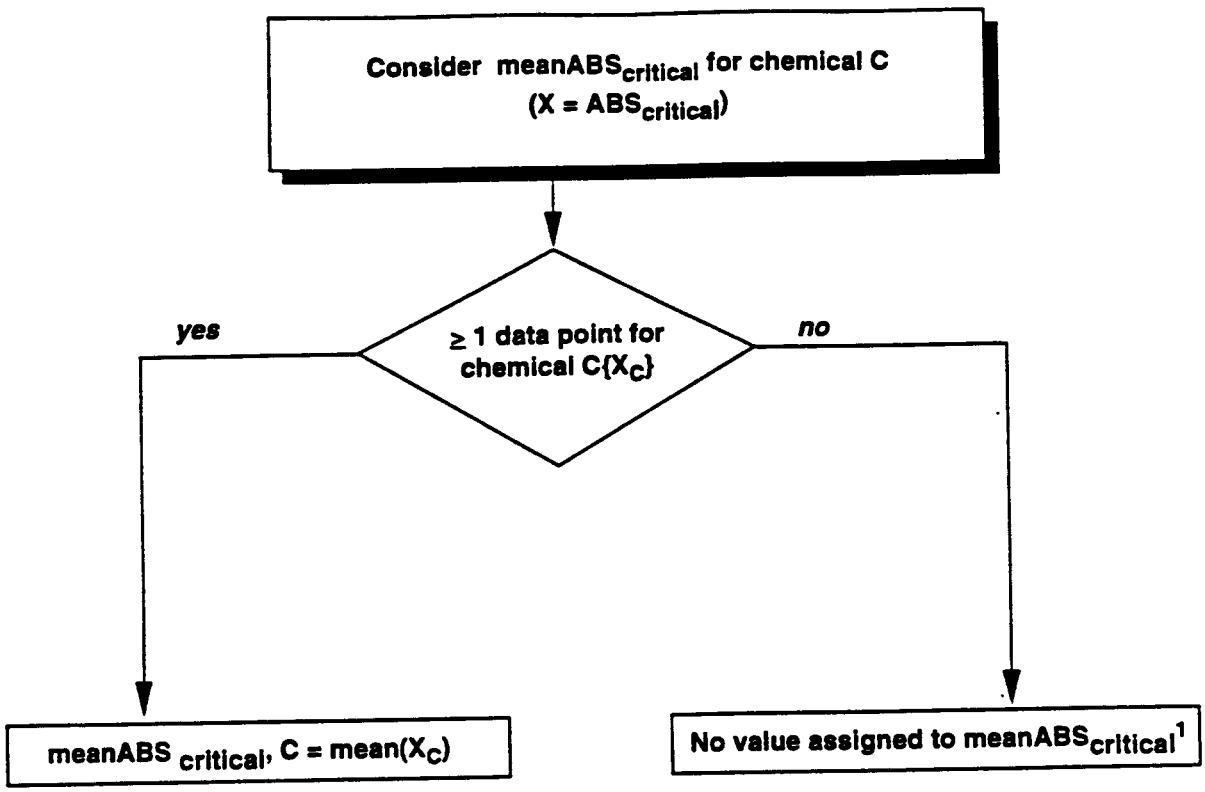
2 For aldrin and dieldrin, dermal RAF is estimated using pure compound data as shown in Figure B.3-13

RMA IEA/RC B.3 1.94 eb

Figure B.3-10

Estimation of Mean ABS soil for Dermal and Oral Pathway

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



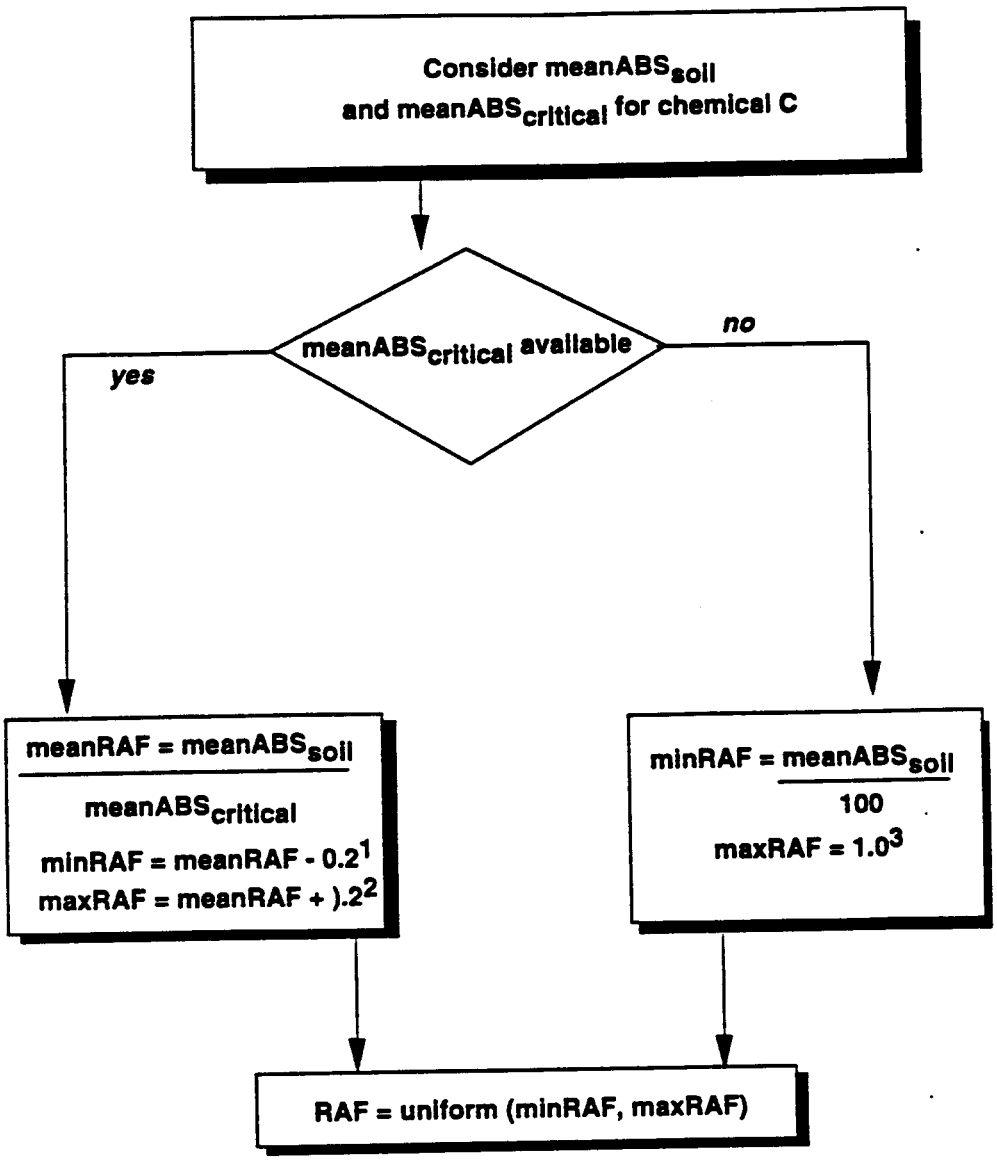
[1] For these chemicals, the range of RAF is estimated as shown in Figures B.3-12 and B.3-13 for oral and dermal pathways, respectively.

RMA IEA/RC B.3 1.94 eb

Figure B.3-11

Estimation of Mean ABS $_{critical}$ for Dermal and Oral Pathway

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



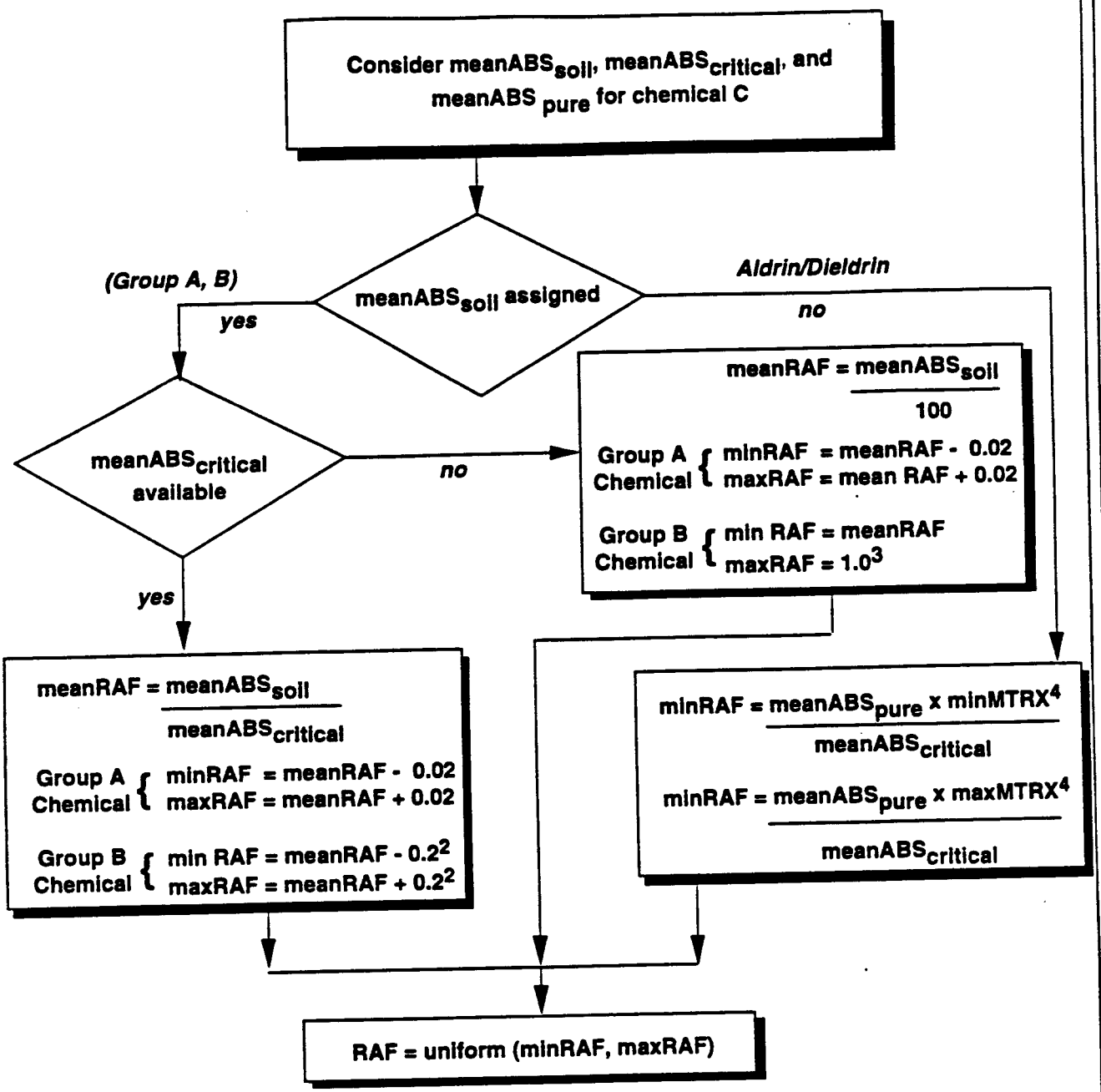
[1] 0.2 not subtracted if meanRAF ≤ 0.2
[2] maxRAF is not allowed to exceed 1.0
[3] maxRAF set to 1.0 because of uncertainty regarding the true value of the critical toxicity absorption

RMA IEA/RC B.3 1.94 eb

Figure B.3-12

Estimation of RAF Distribution for Oral Pathway

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



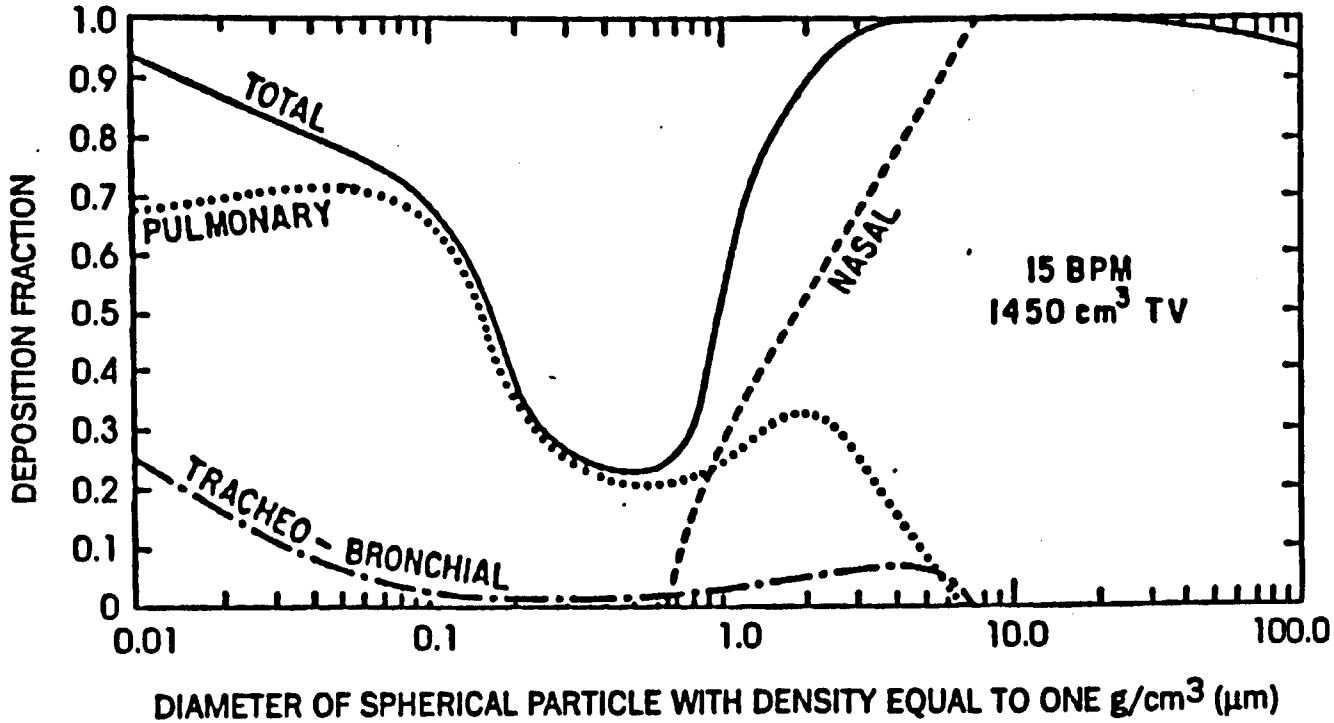
1 No RAF developed for metals (evaluated qualitatively)
2 0.2 not subtracted if mean ≤ 0.2; maxRAF is not allowed to exceed 1.0
3 maxRAF set to 1.0 because of uncertainty regarding the true value of the critical toxicity absorption
4 Values assigned to minMTRX and maxMTRX are 0.06 and 0.50, respectively. meanABS pure based on 12-hour experimental value.

RMA IEA/RC B.3 1.94 eb

Figure B.3-13

Estimation of RAF Distribution for Dermal Pathway

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

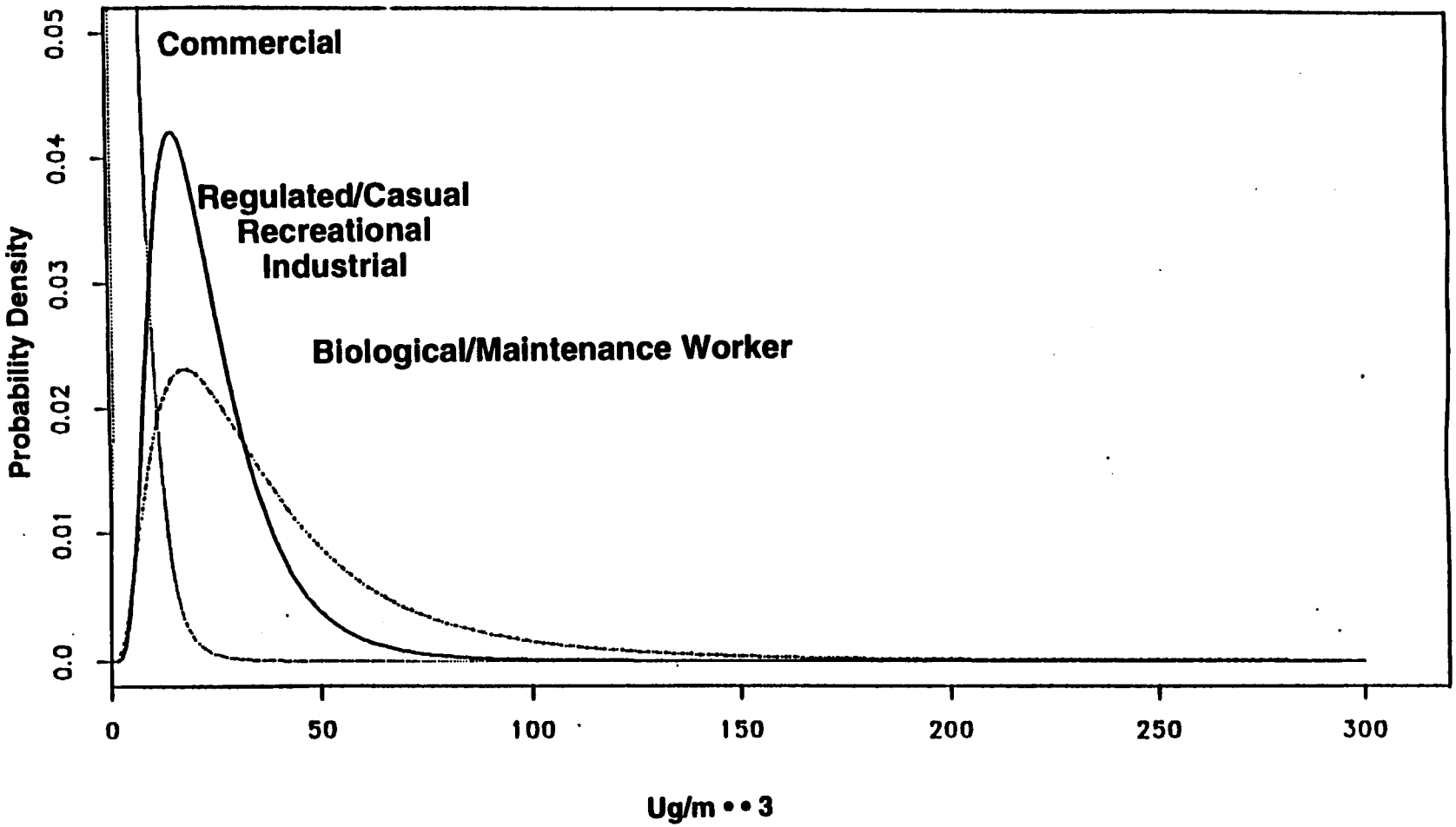


RMA IEA/RC B.3 1.94 eb

Figure B.3-14

Total and regional deposition fractions in the human respiratory tract for various sizes of inhaled airborne spherical particles with physical density of 1 gram per cubic centimeter as calculated by the ICRP Task Group on Lung Dynamics (Morrow et al., 1966) for nose breathing at a rate of 15 breaths per minute (BPM) and a tidal volume (TV) of 1,450 ml. (Reproduced from Raabe [1984]).

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

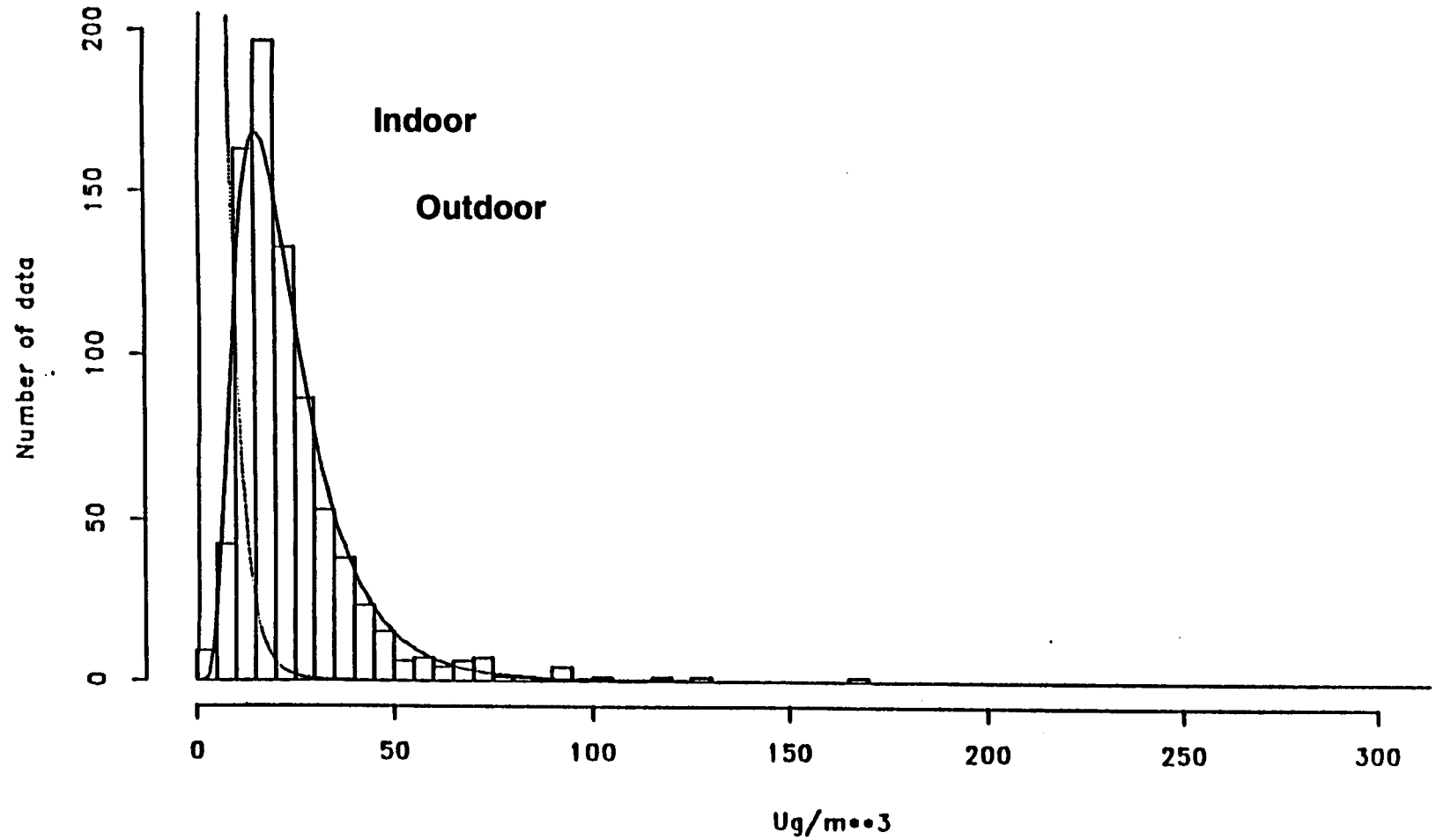


RMA IEA/RC B.3 1.94 eb

Figure B.3-15

Assigned Dust Loading Factor (CSS) Distributions

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

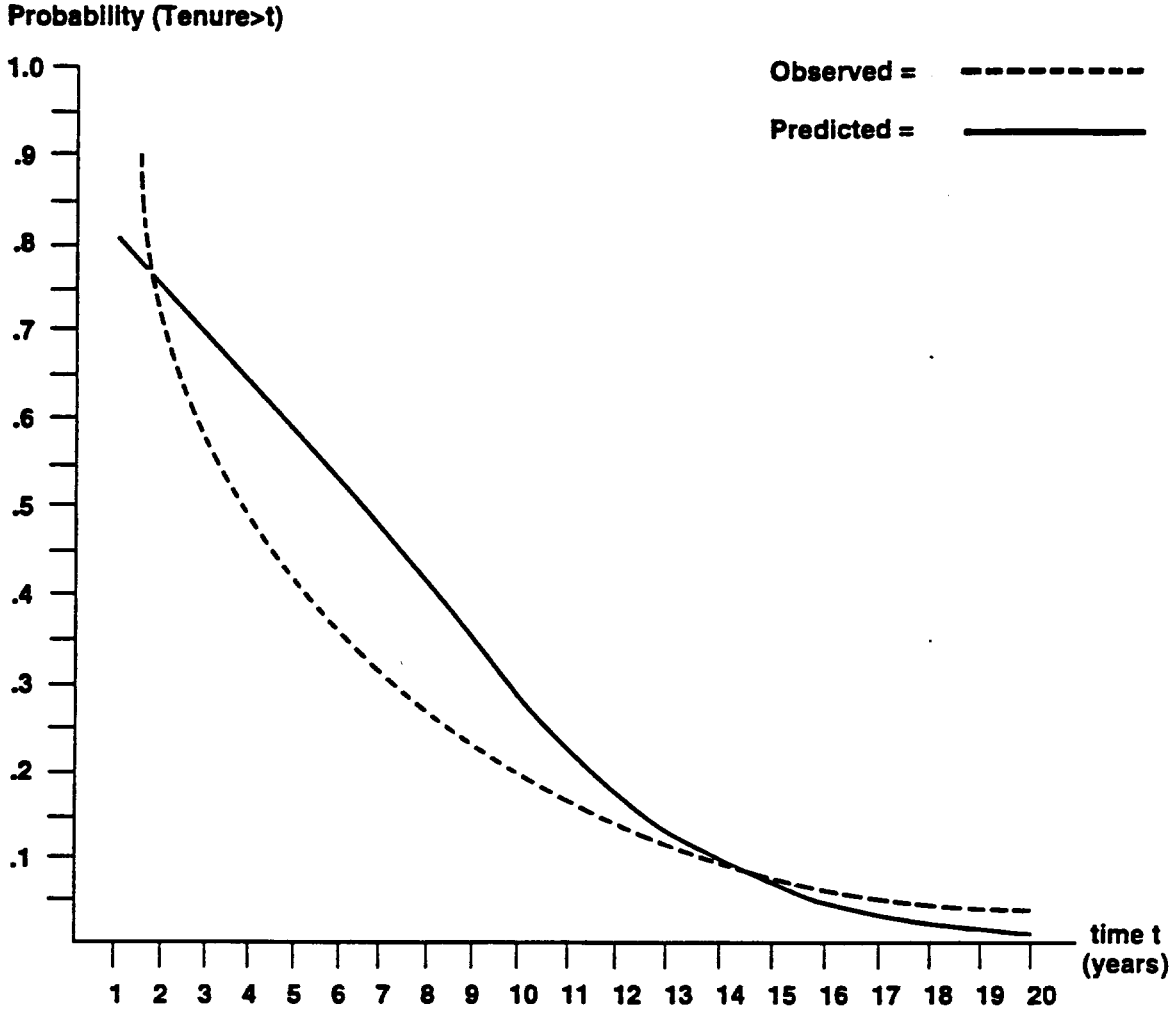


RMA IEA/RC B.3 8.93.jb

Figure B.3-16

Indoor and Outdoor Ambient Dust Loading Factor (CSS) Distributions

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

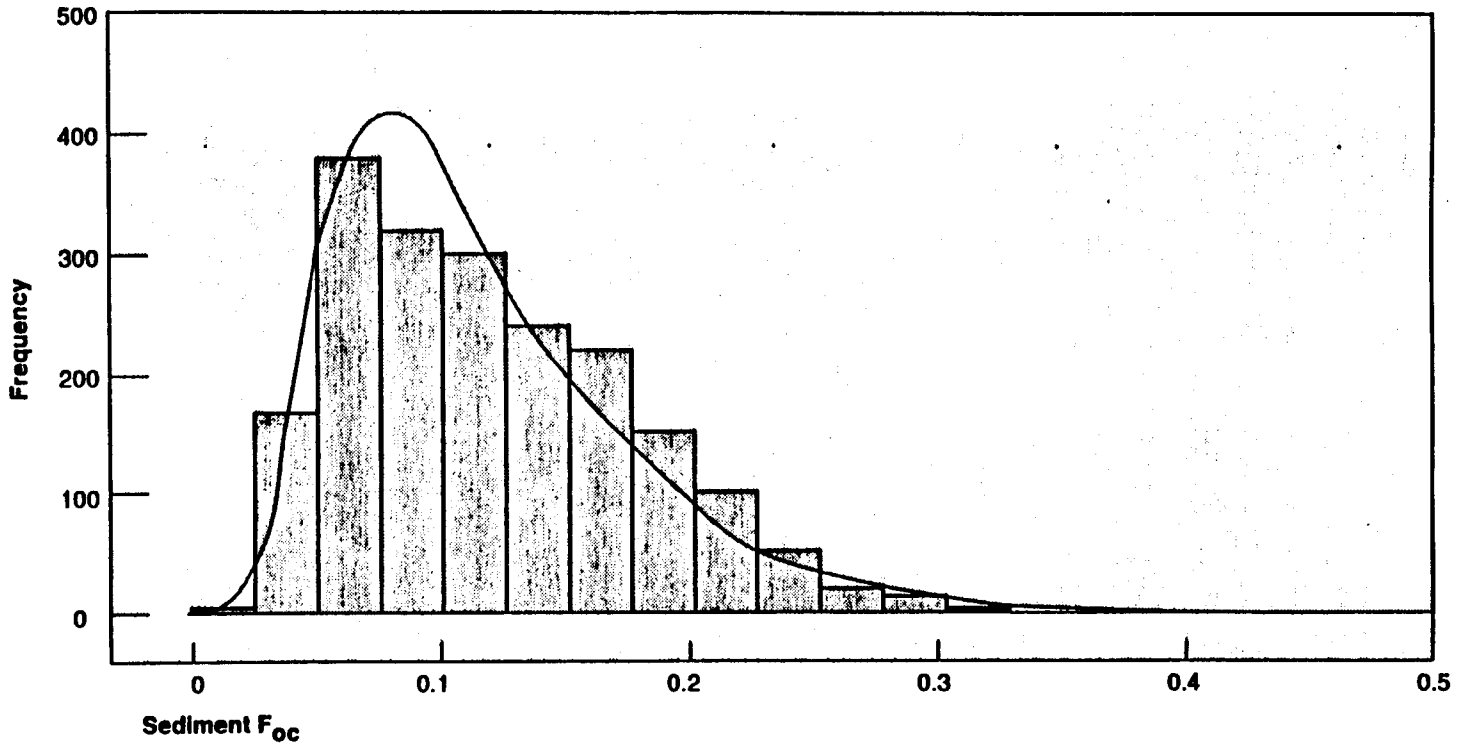


RMA IEA/RC B.3 8.93.jb

Figure B.3-17

A Graphical Comparison of the Observed and Predicted Biological Worker Tenures at a Single Refuge

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

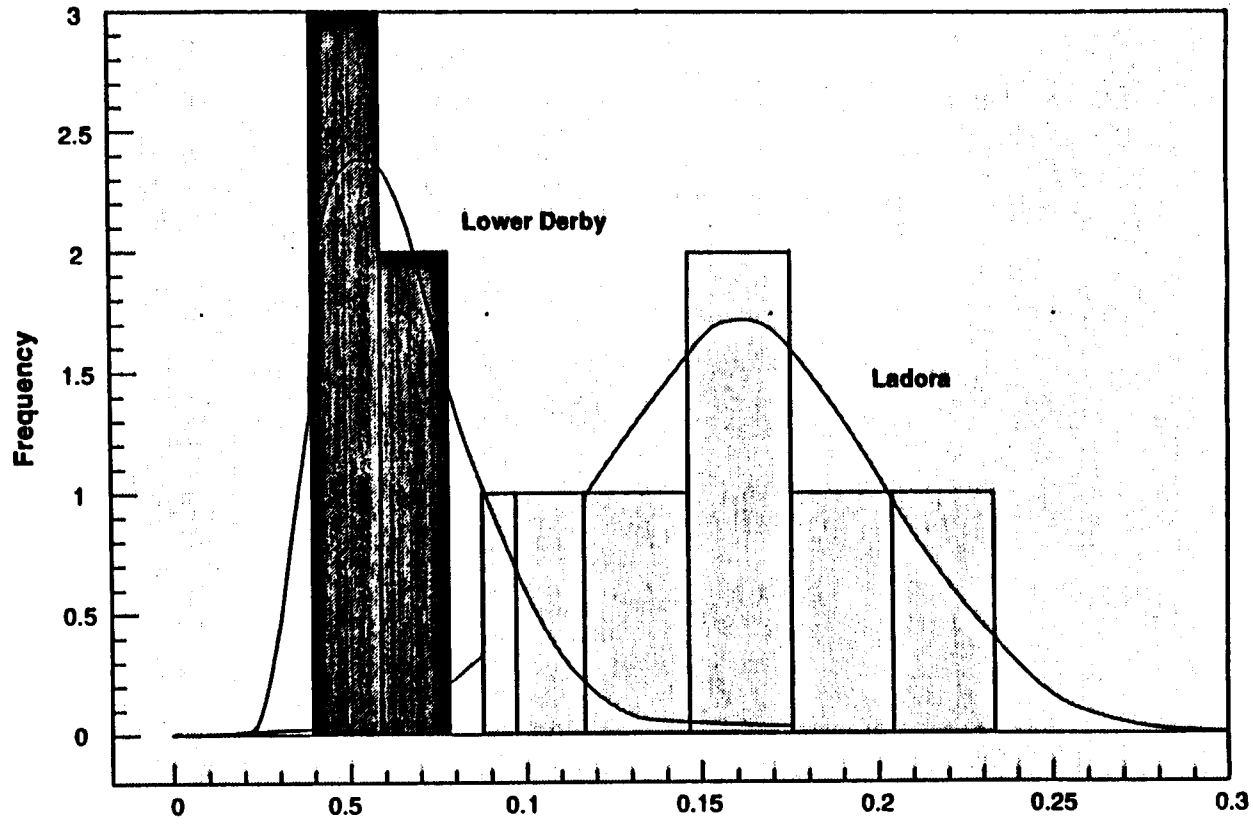


RMA IEA/RC B.3 1.93 eb

Figure B.3-18

Simulated Sediment F_{oc} and Fitted Distribution

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

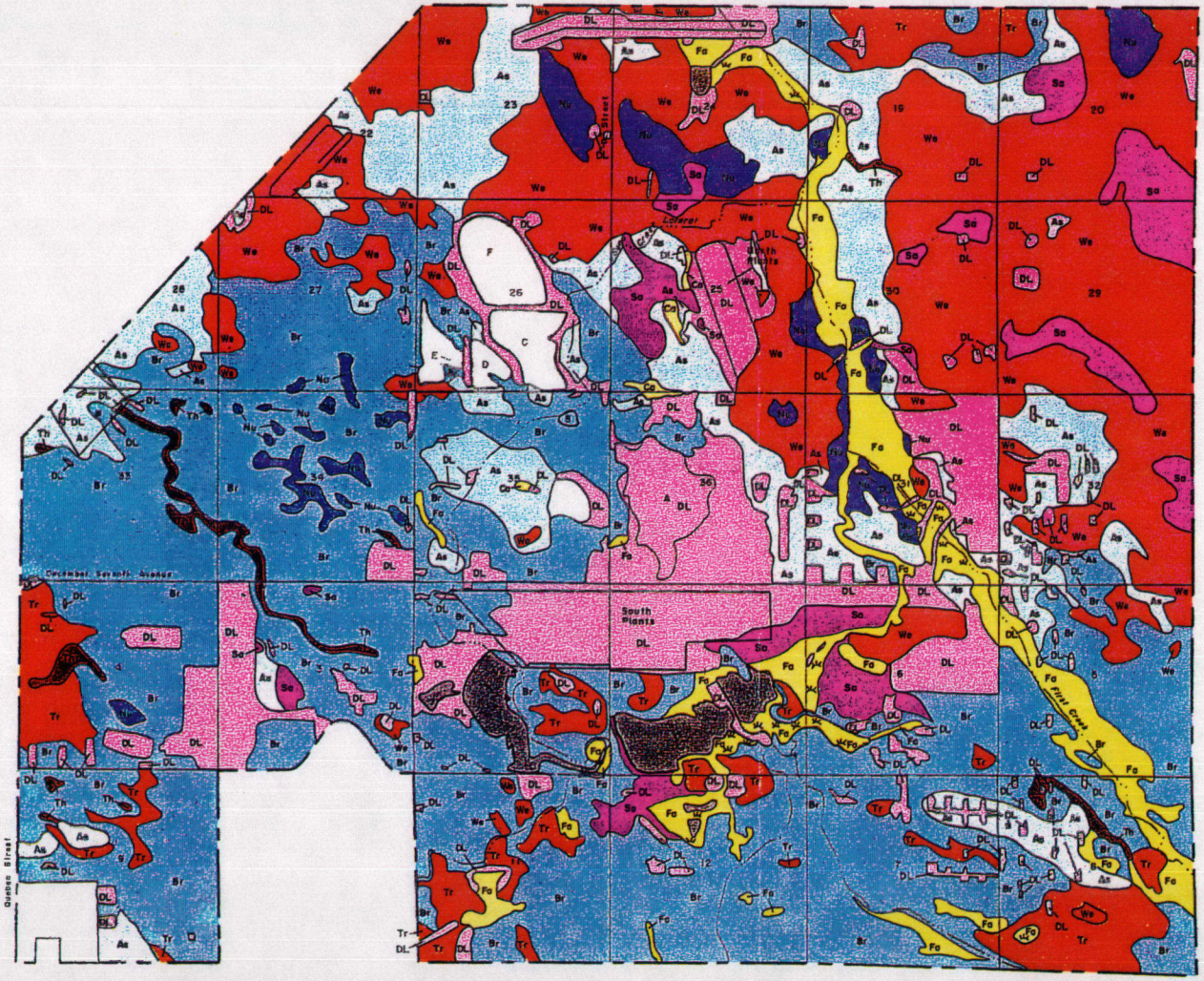


RMA IEA/RC B.3 1.94 eb

Figure B.3-19

Comparison of Sediment for Distributions for Lower Derby and Ladora Lakes

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



Legend

- Rocky Mountain Arsenal Boundary
- Road or Section Lines
- Stream or Drainage Ditch
- Lakes
- A — Waste Basins
- Intermittent Water Body
- Br — Bresser - sandy loam, 0-10% slopes
- We — Weld - loam, 0-3% slopes
- As — Ascalon - sandy loam, 0-10% slopes
- Nu — Nunn - clay loam, 0-10% slopes
- Sa — Satanta - loam, 0-10% slopes
- Tr — Truckton - loamy sand, 0-10% slopes
- Th — Typic Haplustolls - sandy loam, 0-3% slopes
- Fa — Aquic Haplustolls - sandy loam-loam, 0-3% slopes
- Ca — Petrocalcic Paleustolls - 1-3% slopes
- DL — Disturbed Land - sandy to clayey, 0-3% slopes
- Uncharacterized Soil Types

Note: Soil types underlying lakes, ponds, and basins are shown where characterized.

N

0 3000 Feet

Scale: 1" = 3000'

Source: J.P. Walsh, 1988 (preliminary draft)

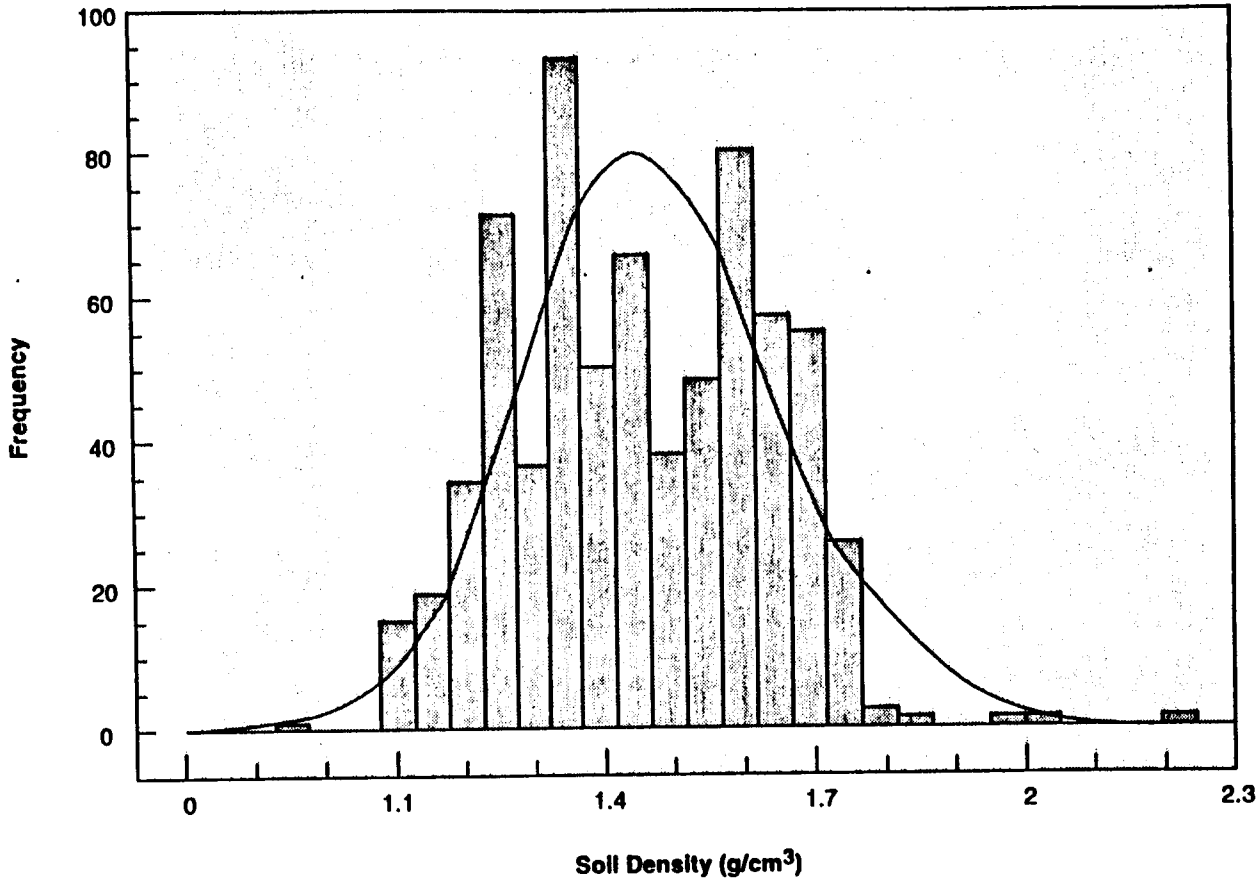
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE B.3-20

Soil Types at Rocky Mountain Arsenal

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

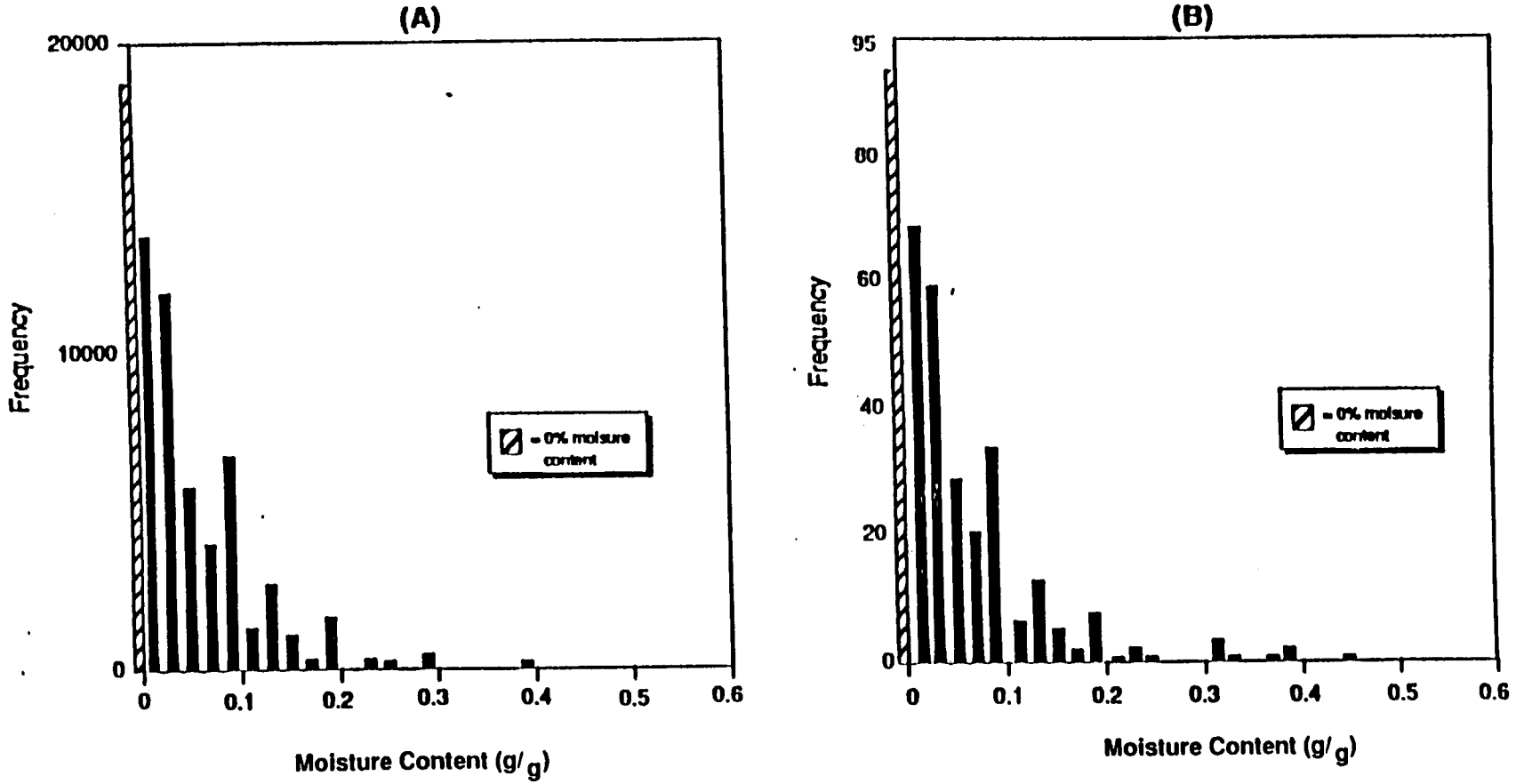


RMA IEA/RC B.3 1.94 eb

Figure B.3-21

Normal Distribution Fit to Combined Soil Density Data for All Soil Series

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

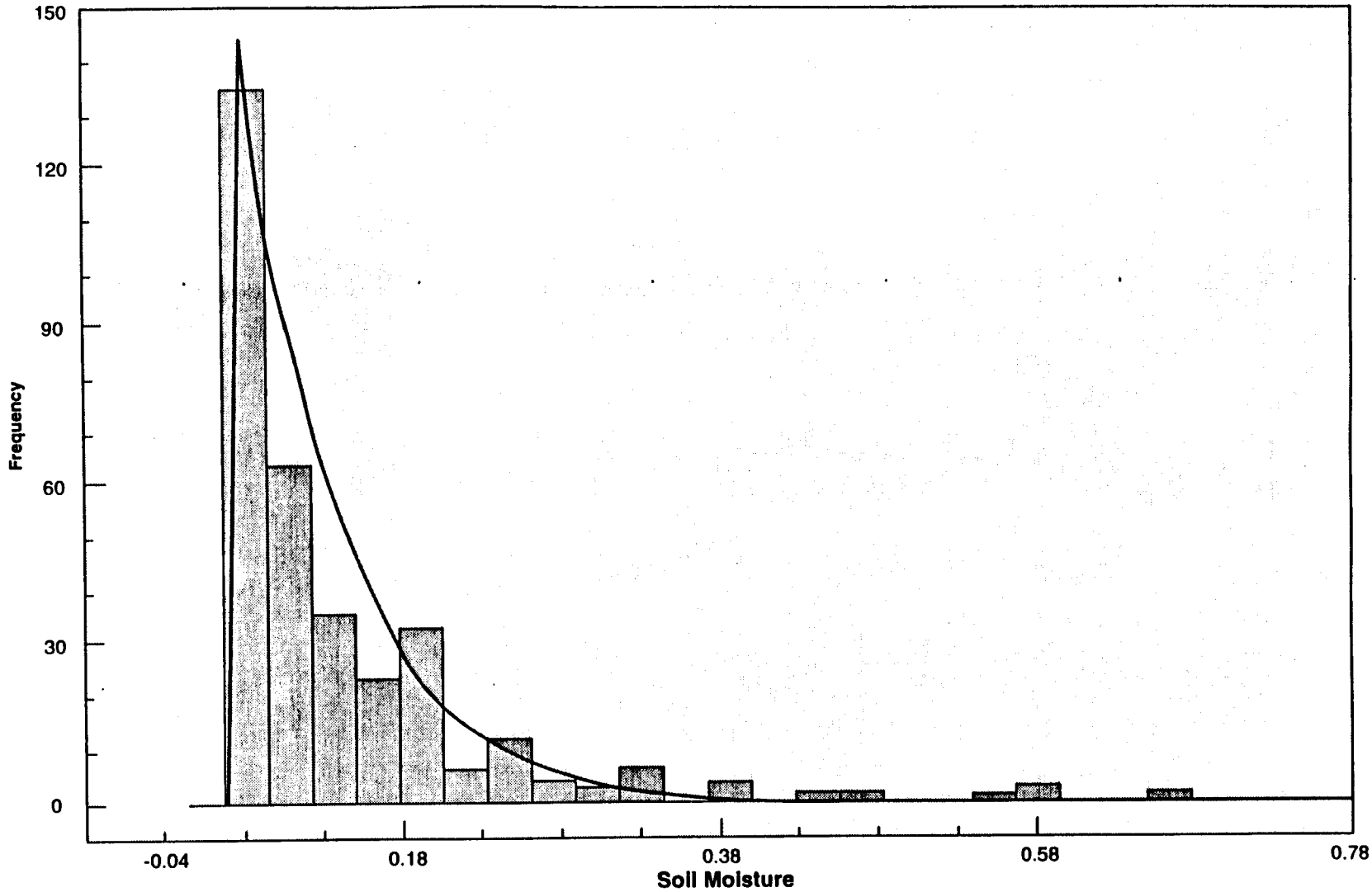


RMA IEA/RC B.3 1.94 eb

Figure B.3-22

(A) Actual Soil Moisture Data (N = 69612); (B) Contrived Soil Moisture Data (N = 605)

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

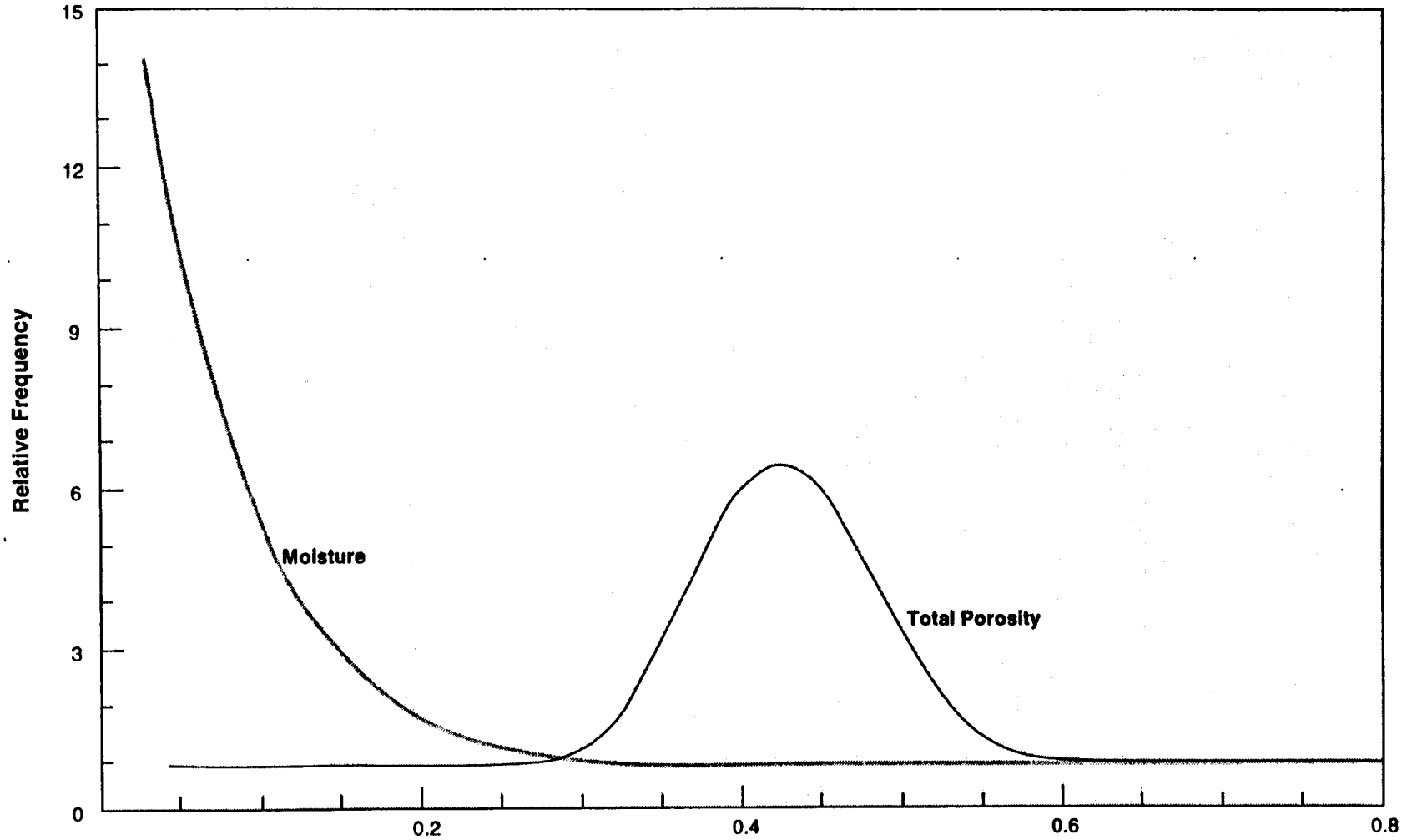


RMA IEA/RC B.3 1.94 eb

Figure B.3-23

Fit of Exponential Distribution to Contrived Soil Moisture Data (g/cm^3)

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated



RMA IEA/RC B.3 1.94 eb

Figure B.3-24

Comparison of Moisture Content and Total Porosity Distribution

Rocky Mountain Arsenal
Prepared by: EBASCO Services Incorporated

ATTACHMENT B.3-1

RE-EXAMINATION OF RAF CHEMICAL GROUP CLASSIFICATIONS BASED ON REVISED SOIL-WATER PARTITIONING DATA

The original group classifications based on K_{OC} used in the draft relative absorption factor (RAF) documentation packet are as follows: log K_{OC} > 5.0, Group A; 3.0 < log K_{OC} < 5.0, Group B; log K_{OC} < 3.0, Group C. These classifications were developed prior to completion of the packet containing the organic carbon partition coefficient (K_{OC}) and the n-octanol/water partition coefficient (K_{OW}) data and were estimated on the information available at that time. In addition, the K_{OC}/K_{OW} data packet used the regression equation developed by DiToro (1985) that corrects "particle effects" for all K_{OC} estimates from K_{OW} values. Based on comments to the RAF packet (letter from W.J. McKinney to K. Blose, September 30, 1991), these group classifications have been reevaluated in light of the more complete K_{OC}/K_{OW} data now available. The process and results of this evaluation are presented below.

The initial step in the re-evaluation process was a screening of the K_{OC}/K_{OW} data packets for possible outliers. Recent statistical analyses using these data indicated some extreme data points have significant leverage (i.e., alter the mean log K_{OC} value by up to 0.5 log unit), which may be inappropriate for group classification purposes. Data greater than approximately one log unit (factor of 10) from the adjacent K_{OC} value were reviewed and rejected if the experimental techniques or data source were questionable. This screening resulted in the rejection of the following data from the draft K_{OC} data packet:

Compound	Log K_{OC}	Reference[1]
Aldrin	7.27	Briggs 1981
	2.96	Gosset et al 1983
Chlordane	2.73	EPA 1981
DDE	6.84	Mabey et al. 1982
DDT	3.99	Anliker et al. 1987
	3.91	Sabljic 1987
Dieldrin	6.09	Briggs 1981
	2.55	Gosset et al. 1983
	3.48	Mabey et al. 1982
Hexachlorocyclopentadiene	3.92	EPA 1981

The K_{OC} values presented were developed from K_{OW} values and the DiToro (1985) regression. In each case, these values were noticeably divergent from the calculated means for each compound (Table 1).

[1] Reference citations are contained in Appendix B, Section B.3.11

The next step in the process was to calculate the geometric means (i.e., arithmetic means of the log values) for the K_{OC} values for each compound, the associated standard deviation(s) and the corresponding 95th percentile confidence interval (assuming a normal distribution about log K_{OC}). This was accomplished for all contaminants of concern (COCs), excluding metals and those compounds with only one published K_{OC} value. The results of these calculations are presented in Table 1 of this attachment.

The data from Table 1 were then plotted on a contiguous scale to illustrate the mean K_{OC} value and the uncertainty associated with +/- one standard deviation and the 95 percentile confidence interval (Figure 1). Additional K_{OC} values are plotted for COCs with a single data point or for compounds of related interest, as suggested in the comment letter. It is immediately evident from Figure 1 that the data fall into two clear groupings, with log K_{OC} values slightly higher than 5.0 and log K_{OC} values less than 3.0. The original groupings for Groups A and B are therefore no longer valid, unless dieldrin is forced into Group B as the only compound in that group, and such a division cannot be defended given the associated uncertainty and the lack of COCs with K_{OC} values that range between 3.0 and 5.0. Therefore, based on K_{OC} alone, it appears that a reasonable approach is to collapse Groups A and B. The new Group A would represent compounds with log $K_{OC} > 3.0$. Remaining chemicals would represent compounds with log $K_{OC} < 3.0$ (or maintain current breakdown).

It is important to note the distinction between group identification and differences within a group. Just because the compounds are grouped in general together by their K_{OC} values does not indicate that there are no significant differences between the individual K_{OC} values (and hence the chemical/physical properties indicated by a K_{OC} value). To illustrate this point, analysis of variance (ANOVA) and Kruskal Wallis test statistics were run on the aldrin, dieldrin, and endrin values, with the null hypothesis that the K_{OC} values are the same. The results of these tests are presented in Table 1, and clearly show that the dieldrin K_{OC} value is statistically significantly different, (i.e. statistically different) from the aldrin and endrin K_{OC} values. Therefore, although these compounds may be correctly grouped together by K_{OC} values, there are, nevertheless clear differences between the individual values (i.e., within-group variation is allowed and is chemically and physically meaningful).

Table 1(Att.B.3-1) Log K_{OC} Means, Standard Deviations, and Confidence Intervals

COMPOUND	N	X	S	50% (+0.67S)	95% (+1.96S)
Aldrin	6	5.18	0.504	0.338	0.989
Benzene	32	2.20	0.265	0.178	0.519
Carbon Tetrachloride	9	2.66	0.209	0.140	0.408
Chlordane	5	5.41	0.335	0.225	0.657
Chloracetic Acid	1	0.22			
Chlorobenzene	21	2.71	0.263	0.176	0.515
Chloroform	10	1.91	0.146	0.098	0.286
Dibromochloropropane	1	2.39			
DDE	9	5.76	0.231	0.155	0.453
DDT	33	5.82	0.543	0.364	1.065
Methylene Chloride	4	1.15	0.112	0.075	0.219
1,2-Dichloroethane	6	1.56	0.152	0.102	0.298
1,1-Dichloroethylene	2	1.78	0.445	0.298	0.873
Dieldrin	10	4.63	0.398	0.266	0.784
Endrin	6	5.15	0.370	0.248	0.726
Hexachlorocyclopentadiene	2	5.19	0.332	0.222	0.651
1,1,2,2-Tetrachloroethane	8	2.66	0.297	0.199	0.582
Tetrachloroethylene	12	2.66	0.216	0.145	0.424
Trichloroethylene	12	2.50	0.370	0.248	0.724
Toluene	30	2.62	0.253	0.169	0.496

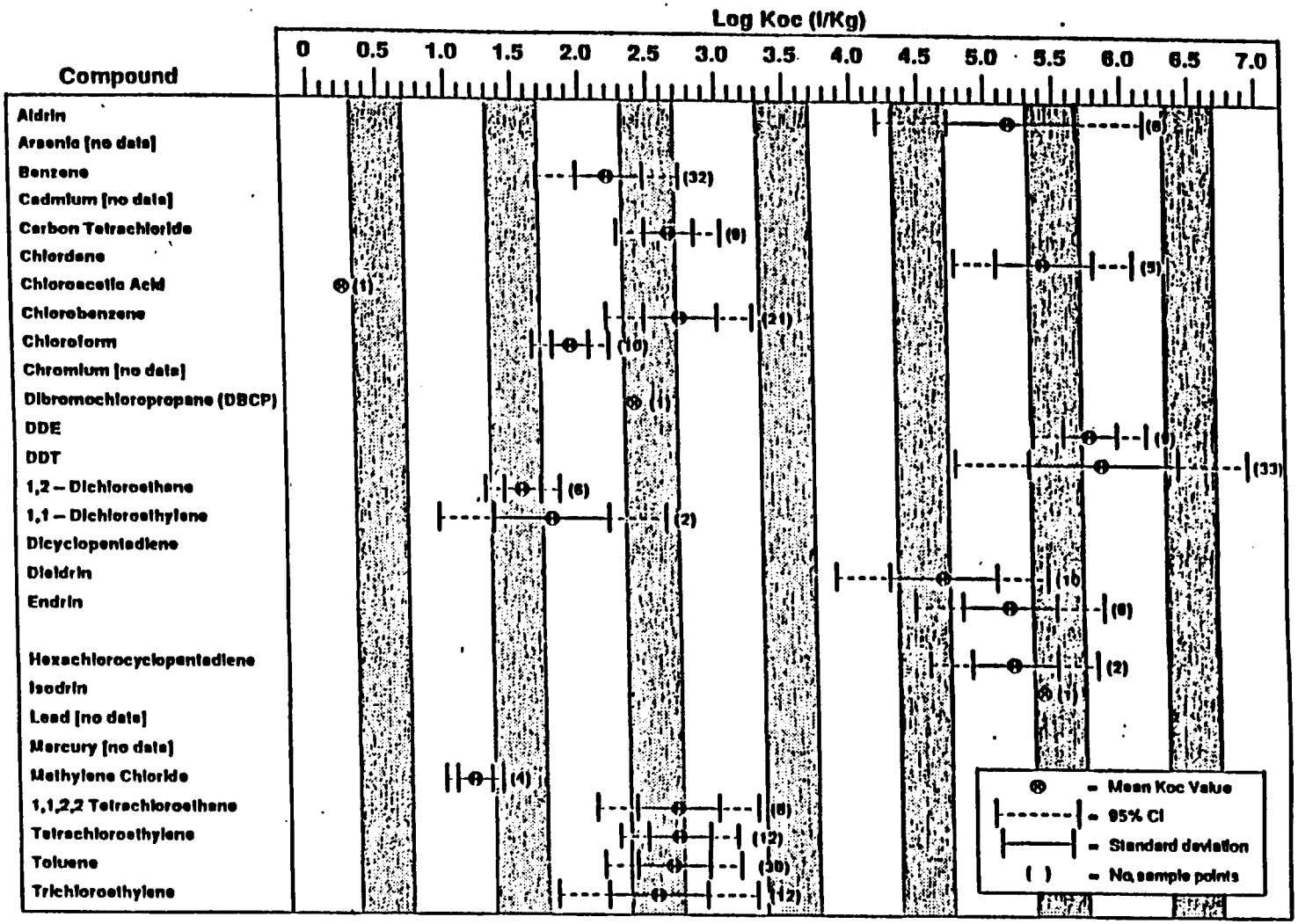
DDE dichlorodiphenyldichloroethene
DDT dichlorodiphenyltrichloroethane
N # of samples
X log mean
S log standard deviation
50% (+0.675) 50th percentile of log K_{OC} distribution
95% (+1.965) 95th percentile of log K_{OC} distribution

Table 2(Att.B.3-1) Analysis of Variance Results

Nonparametric Test	P-Value[1]
Kruskal Wallis Test on three chemicals: Aldrin, Dieldrin, Endrin	0.03
Parametric ANOVA on $\log_e$ transformed data: multiple pairwise tests	**Approximate P-value[2]**
Aldrin, Dieldrin	0.013
Aldrin, Endrin	0.308
Dieldrin, Endrin	0.029

1 P value = probability an error is made if chemicals are pronounced significantly different.

2 P value is approximate because multiple tests were performed.



RMA IEA/RC B.3.8.93.jb

Figure 1

Means, Standard Deviations, and 95th Percent Confidence Intervals for Log Koc Values

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

ATTACHMENT B.3-2

SUPPORTING INFORMATION FOR SURROGATE ABSORPTION STUDIES AND DERMAL ABSORPTION OF PURE COMPOUNDS

INTRODUCTION

As discussed in Section B.3.3.3, no absorption estimates were available for any of the COCs from critical toxicity studies summarized within the Integrated Risk Information System. Therefore, surrogate absorption studies were sought from a chemical-specific literature search matching the media, route of administration, and species with that used in the critical toxicity studies. Supporting information on absorption data identified is presented in the following table (Table 1). This attachment also summarizes supporting information for the dermal absorption of pure compounds (Table 2). This information was used to derive dermal RAFs for aldrin and dieldrin.

Table 1(Att.B.3-2) Supporting Information on Absorption from Surrogate Studies

	Critical Toxicity Study Data[1]			Surrogate Absorption Study[1]	
Chemical	Media	Species	Reference[2]	Media	Species
Aldrin	Diet	Rat	Fitzhugh et al. 1964	Diet	Rat
Arsenic	Drinking Water	Human	Tseng 1977	ND	ND
Benzene	ND	ND	ND	ND	ND
Cadmium	Diet	Human (model)	EPA 1985	ND	ND
Carbon Tetrachloride	Corn Oil	Rat	Bruckner et al. 1986	ND	ND
Chlordane	Diet	Rat	Vesicol Chem. Co. 1983	ND	ND
Chloroacetic Acid	Intubation	Rat	IRDC 1982; EPA 1988	ND	ND
Chlorobenzene	Capsule	Dog	Monsanto Co. 1967; Knapp et al. 1971	ND	ND
Chloroform	Capsule (toothpaste base)	Dog	Heywood et al. 1979	ND	ND
Chromium VI	Drinking Water	Rat	Mackenzie et al. 1958	ND	ND
Dibromochloropropane	ND	ND	ND	ND	ND
DDE	ND	ND	ND	ND	ND
DDT	Diet	Rat	Laug et al. 1950	ND	ND
1,1-Dichloroethylene	Drinking Water	Rat	Quast et al. 1983	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND
Dicyclopentadiene	Diet	Rat	Litton Bionetics 1980; EPA 1987	ND	ND
Dieldrin	Diet	Rat	Walker et al. 1969	Diet	Rat
Endrin	Diet	Dog	Velsicol 1969	ND	ND
Fluoroacetic Acid	ND	ND	ND	ND	ND
Hexachlorocyclopentadiene	Corn Oil	Rat	Abdo et al. 1984	Corn Oil	Rat

1 Oral studies only.
2 See reference Section B.3.11.
ND Denotes no data available.

Table 1(Att. B.3-2) Supporting Information on Absorption from Surrogate Studies

	Critical Toxicity Study Data[1]			Surrogate Absorption Study[1]	
Chemical	Media	Species	Reference	Media	Species
Isodrin	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND
Mercury	Oral/Parenteral	Rat	Druet et al. 1978; Bernaudin et al. 1981; Andres 1984; EPA 1993, 1990	ND	ND
Methylene chloride	Drinking Water/Inhalation	Rat/Mice	NCA 1983	ND	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	ND
Tetrachloroethylene	Corn Oil	Mice	Buben and O'Flaherty 1985	ND	ND
Toluene	Corn Oil	Rat	NTP 1989	ND	ND
Trichloroethylene	ND	ND	ND	ND	ND

1 Oral studies only.
2 See reference Section B.3.11.
ND Denotes no data available.

Table 2(Att.B.3-2) Supporting Information for Dermal Absorption of Pure Compounds

Chemical	Species	% ABS	Reference	Comments
Aldrin	Human	1.0	Feldman and Maibach 1974	Ventral forearm, non-occluded (12 hour value)
Chlordane	ND	ND	ND	
Dieldrin	Human	2.0	Feldman and Maibach 1974	Ventral forearm, non-occluded (12 hour value)
Endrin	ND	ND	ND	
Hexachlorocyclopentadiene	ND	ND	ND	
Isodrin	ND	ND	ND	

NOTE:

Factors to consider when evaluating the pure compound data (Feldman and Maibach 1974) used to derive dermal RAFs for aldrin and dieldrin are discussed below.

1] Only 3% of IV doses of aldrin and dieldrin was excreted in the urine in the Feldman and Maibach study (1974), which indicates that most of the dose was either sequestered in fat tissue of excreted via the GI tract. Both of these observations have been documented in studies with dieldrin. (Aldrin is rapidly metabolized to dieldrin, so the same mechanisms apply.) Therefore, urinary excretion alone may not be the best way to measure absorption.

2] The extent of absorption depends on the anatomical site to which the pesticide is applied. In Feldman and Maibach (1974), the compound was applied to the ventral forearm. However, the authors acknowledged that the face, forehead, scalp, and neck absorb 2 to 6 times more than the forearm. Note, however, that compounds were applied in an acetone vehicle, which would likely overestimate absorption of neat compound.

3] The absorption rates cited above for aldrin and dieldrin, 1.0% and 2.0% are 12-hour mean values representing the mean of measurements in the six male subjects. The authors acknowledged that the six experimental subjects differed by a factor of 5 in the amount of percutaneous absorption.

4] Although the Feldmann and Maibach study duration was 5 days, a 12-hour mean value was used in accordance with EPA's Dermal Exposure Assessment guidance, which states that a default value of 12 hours should be used when actual contact time cannot be estimated (1992). Several studies, however, indicate that pesticides persist on the skin even after washing for 2 minutes with soap and water, and that the percent of absorbed chemical can continue to increase even after washing (see Wester and Maibach 1985). Pesticides are often highly fat soluble and can enter the fatty layer of the dermis relatively quickly where they are not easily washed away. In this instance, dermal fat could then act as a reservoir of continued slow absorption of the pesticide. The fact that the urinary excretion rate of aldrin and dieldrin remained relatively constant over the 5-day study period after dermal administration (in contrast to the rapid peak and decline after IV administration) might indicate that aldrin and dieldrin were being continuously absorbed from the skin, even after it had been washed. (Subjects could wash after 24 hours from time of administration). Upon completion of the 5-day study, the pure compound

absorption rates cited for aldrin and dieldrin were 7.8% (SD of 2.9) and 7.7% (SD of 3.2) respectively.

5] Other factors that should be considered in evaluating pure compound data include the age, condition, and temperature of the skin, applied concentration and surface area impacts of multiple-dose applications, skin binding, and occlusion (covering the skin). These factors, which apply to the dermal RAFs assumed for all chemicals, are qualitatively addressed in Appendix Section B.3.3.

As discussed in Section B.3.3, no absorption estimates were available for any of the COCs from critical toxicity studies summarized within the Integrated Risk Information System. Therefore, surrogate absorption studies were sought from a chemical-specific literature search matching the media, route of administration, and species with that used in the critical toxicity studies. Supporting information on absorption data identified is presented in Table 1.

ATTACHMENT B.3-3

MEAN AND VARIANCE OF THE RELATIVE ABSORPTION PARAMETER

MEAN OF RELATIVE ABSORPTION FACTOR

E(x) represents the expected value, also known as the mean, of the argument x. In the discussion below $x = ABS_{soil}$ and $y = ABS_{critical}$.

The Taylor series approximation of the mean of a quotient is as follows:

$$E(RAF) = E\left\langle \frac{\hat{x}}{\bar{y}} \right\rangle \approx \frac{\mu x}{\mu y} - \frac{\Gamma \sigma x \sigma y}{\mu y} + \frac{\mu x \sigma x 2}{\mu y 3} \qquad (1)$$

term 1 term 2 term 3

μ_X and μ_Y can be estimated by $\bar{x}$ and $\bar{y}$, respectively, if the distributions of x and y are approximately normal. However, the estimation of the mean relative absorption factor (RAF) by the quotient of $\bar{x}$ and $\bar{y}$ ignores the terms 2 and 3 in equation (1), implying a bias. If σ_X and σ_Y are assumed to be roughly equal, and r is assumed to be positive, then term 2 will cancel or dominate term 3 if

$$r \geq \frac{\mu x}{\mu \bar{y}^2} \qquad (2)$$

If σ_X is not equal to σ_Y, then term 2 will cancel or dominate term 3 if

$$r \geq \frac{\mu x}{\mu \bar{y}^2} \frac{\sigma \bar{x}^2}{\sigma x \sigma y} \qquad (3)$$

In either case, it is likely that r will exceed the right side of these equations, which have values on the order of $20/30^2 = 0.022$, $70/90^2 = .009$, and $(20/30^2) \times (5^2/5x2) = 0.056$. A value of $r < .05$ is highly unlikely given the numerous common factors affecting the RAF components. This implies that $\bar{x}\sqrt{y}$ will tend to be larger than the mean of x/y and that the mean RAF will tend to be overestimated to an unknown extent.

VARIANCE OF RAF

The Taylor series approximation of the variance of a quotient is as follows:

$$V\left\langle \frac{x}{y} \right\rangle = \left\langle \frac{\mu x}{\mu y} \right\rangle 2 \left\langle \frac{\sigma_{\bar{x}}^2}{\mu_{\bar{x}}^2} + \frac{\sigma_{\bar{y}}^2}{\mu_{\bar{y}}^2} + \frac{-2r\sigma x \sigma y}{\mu x \mu y} \right\rangle \qquad (4)$$

The variance of RAF is not closely related to the variance of ABS_{soil} when the value of r and σy are not known. Therefore, the variance of RAF cannot be estimated from the available data set.

ATTACHMENT B.3-4

TIME-DEPENDENT VARIABLES FOR VISITOR AND REFUGE WORKER POPULATIONS

INTRODUCTION

This Attachment contains two sections. In the first section, a summary of Shell's frequency distributions for lifetime exposure duration (i.e., days per year x hours per day x years per lifetime) for the most exposed visitor subpopulations developed in the IEA/RC and the general neighborhood visitor populations developed by Shell are provided. In the second section, Shell's time-dependent variables for the general refuge worker population are developed. The TDVs described in this attachment are not used in the PPLV or risk calculations. Rather, they are provided to give perspective on how the subpopulations developed in Section B.3.7 might relate to their respective general populations. A further description of Shell's TDV evaluation is provided in Attachment B.3.5

COMPARISON OF VISITOR FREQUENCY DISTRIBUTIONS

Table 1 at the end of this attachment lists frequency distributions of lifetime exposure duration for the regulated/casual and recreational visitor subpopulations and the general populations. The values for the subpopulations are based on the results of the Army's TDV evaluation presented in Appendix B.3.7. The values for the general populations are based on Shell's TDV evaluation presented in Attachment B.3-5. The distributions are shown in graphical form in Figures 1 and 2, respectively, for the regulated/casual visitor and recreational visitor populations.

REFUGE WORKER TDV EVALUATION

All TDV information for the refuge workers was obtained from the National Wildlife Refuge survey, which is described in Appendix B, Section B.2. A summary of refuge worker TDV distributions is provided in Table 2 at the end of this Attachment.

HOURS PER DAY AND DAYS PER YEAR

Refuge workers were requested to provide a time/activity/soil interval breakdowns. Their answers were recorded and accepted in whatever manner they were given as long as their answers could be used in conjunction with other available data to calculate their total number of hours on the refuge per year. For example, a respondent might have indicated annual attendance at off-refuge training classes for 2 weeks. Because length of service in the U.S. Fish and Wildlife Service was known, the respondent's number of vacation days and holidays were known. In this example, the total hours per year on the refuge would be calculated as follows:

$$TM \times DW = [\{260 \text{ weekdays/year}) - (\text{number of vacation days and holidays}) - (10 \text{ weekdays at classes})] \times [8 \text{ hours/day}] \quad (1)$$

where the total number of hours on the refuge is denoted by TM x DW, with TM denoting the number of hours spent at the refuge per day and DW denoting the number of days spent at the refuge per year. The total number of hours per year on the refuge excludes only vacation days, holidays, and the "time spent off-refuge in the conduct of job."

Although the survey provides a scattering of information on TM and DW separately, the survey primarily provides data on the total number (TM x DW) of hours spent at the worker's refuge during a year. Therefore, the most complete and consistent data are on the product TM x DW and not TM and DW separately.

Because the lifetime exposure depends on TM and DW only through the product TM x DW, the survey data are appropriate for the purposes of determining lifetime exposure. For the purposes of time-dependent exposure parameter development, TM is at 8 hours per day, and DW is herein defined to be the number of 8-hour days spent at the refuge during a year. Hence, DW is calculated as follows:

$$DW = [TM \times DW \text{ (hours/year)}] / [8 \text{ (hours/day)}] \quad (2)$$

Table B.3-4 indicates the duration data on each of the 33 refuge workers interviewed. Included in Table B.3-4 are the survey data on hours per year (i.e., TM x DW) for each of the respondents. Table 3 at the end of this Attachment indicates the frequency distribution of DW values (i.e., "Hrs/Yr"/8) among the 33 respondents. The range of DW values is from 164.5 days per year to 240 days per year; the 95th percentile of the sample is 240 days per year.

The data given in Table 3 at the end of this attachment are negatively skewed (standardized skewness coefficient of -4.81). Normal, lognormal, and Weibull distributions were fit to the data, with the best fit provided by the Weibull distribution with shape parameter 22.21 and scale parameter 229.4. Because the Weibull distribution is not available in the Latin Hypercube sampling code, a triangular distribution with a lower limit of 195, an apex of 229, and a maximum of 250, provided a close approximation to both the fitted Weibull distribution and the main portion of the data. Therefore, this triangular distribution was assigned to represent days per year for the refuge worker. The percentile fits of the normal, Weibull, and triangular distributions are presented below:

Percentage	Data Percentile	Error in approximation (Data-Fitted) (Normal)	(Weibull)	(Triangular)
0.05	202.1125	-0.7901764	1.462503	-2.5574969
0.10	209.4000	2.4990082	2.139994	0.7199939
0.25	219.3750	5.7910767	2.525000	2.7550000
0.50	223.7500	2.7500000	-1.860000	-1.8300000
0.75	233.5000	5.0839233	0.730000	0.4900000
0.90	240.0000	4.9009857	1.850000	0.7500000
0.95	240.0000	0.9026794	-0.980000	-2.4000000

As indicated by the approximation errors above, the normal distribution provides a poorer fit to the middle portion of the data and implies underestimation of DW in this range. The Weibull distribution provides a closer fit throughout the range of the data. The triangular distribution provides a fit that is similar to the Weibull except that DW is overestimated in both the upper and lower tails.

YEARS PER LIFETIME

The survey provides data on the duration of a refuge worker's tenure at a particular refuge. Here, TE refers to the number of years a refuge worker spends at one refuge and does not necessarily equal the number of years spent in the U.S. Fish and Wildlife Service. The survey data are presented in Table 4 at the end of this attachment. These data include the total time spent at a refuge regardless of whether that time was in one or more jobs and regardless of whether the periods of time were consecutive; that is, observations include all of the time spent at the same refuge. There are 80 refuge tenure observations associated with the 33 refuge workers. These 80 observations are of two types—47 observations refer to completed tenures, and 33 observations refer to incomplete tenures. The incomplete tenures represent a worker who is still on the job and therefore will have a completed tenure greater than the current tenure given in Table 4. Because the incomplete tenure observations imply values greater than the current tenure, the data set is "censored" and requires a statistical estimation method to accommodate the censored data.

The rationale of the TE distribution development is presented below, followed by the estimation of the TE distribution using censored data.

Each of the 33 refuge workers interviewed were active employees, and their current lengths of time at their refuges are incomplete tenures. An incomplete tenure is only a lower bound on that worker's tenure at that refuge. For example, if a refuge worker has been at a refuge for 7 years and is still on the job, then the refuge worker's completed tenure will be some number greater than 7 years. The "greater than" symbol (>) associated with the last tenure observation for each

worker indicates that observation is an incomplete tenure and that the lifetime tenure at the current refuge will exceed the reported value for years at the current job.

Some of the 33 refuge workers interviewed at the Crab Orchard Malheur, and Minnesota Valley refuges had held other jobs with the U.S. Fish and Wildlife Service at other refuges. The 47 tenures at these other refuges are assumed to be completed tenures, i. e., it is assumed that these refuge workers will not return to work at their earlier refuges.

The 33 incomplete tenures are the only tenures known to have occurred on the three selected refuges (the complete tenures occurred on different refuges). However, it is impossible to statistically estimate the TE distribution without some completed tenure observations. The only completed tenures available at the time the TE distribution was being estimated were the 47 completed tenures for the refuge workers who had previously completed tenures at other refuges. The completed tenures are tenures completed at a single refuge and are therefore a sample data set drawn from the pool of all single-refuge completed tenures occurring at any refuge in the U.S. Fish and Wildlife Service system. The uncompleted tenures, with some unknown future increment, are also samples drawn from the pool of all completed tenures. The sample set of all 80 tenures combined is not a completely random sample because of two factors. The first factor is the special, nonrandom selection of the three refuges. This factor is intentional and beneficial as it increases the relevance of the data to RMA. The second factor is the possible correlation, whether positive or negative, between the tenures reported by a given individual. Any such correlation might introduce some unknown bias into the estimated TE distribution, but this bias and its impact are expected to be small relative to the tendency of the normal distribution estimated to overestimate the probability of tenures exceeding 2 to 13 years (see below).

ESTIMATION OF THE TE DISTRIBUTION USING CENSORED DATA

The 33 incomplete tenures and 47 completed tenures each provide some information about refuge worker tenure. When the lognormal, normal, and gamma distributions were fit to these 80 observations, the fitting procedure had to reflect the differences between completed and incomplete tenures. The maximum likelihood estimation procedure used to fit these distributions reflects the differences in the information contained in completed and incomplete tenures. The maximum likelihood estimation procedure identifies the parameters in the fitting distribution that maximize the likelihood of observing the 80 observations that were, in fact, observed. The likelihood function being maximized is a product of 80 likelihood terms. If the observation is a completed tenure, then the likelihood term is the probability density function evaluated at the observed duration.

For example, if TE is the tenure and an observation of a completed tenure is 10 years, then the likelihood term is the probability density function (PDF) evaluated at TE = 10.0. The probability density function then becomes PDF (TE = 10.0). If the observation is an incomplete tenure, then the likelihood term is the probability that the tenure is greater than the observed duration. For example, if an observation of an incomplete tenure is 8 years, then the likelihood term is the probability that TE>8.0. In this case, the probability takes the form P(TE>8.0). This probability is equal to 1.0 minus the cumulative distribution function evaluated at 8.0. The likelihood function being maximized is the product of the 33 likelihood terms of the form PDF(TE=t) and the 47 likelihood terms of the form P(TE>t).

Table 5 at the end of this attachment shows each of the 80 observations and the likelihood contribution corresponding to the best-fitting normal distribution. For the first 5 of the 80 observations, a graphical indication of the likelihood contribution is given. The normal distribution is shown truncated in these graphs. For example, the third observation is "3" and the accompanying figure indicates that the likelihood contribution is the relative likelihood of the observation being equal to 3 (the height of the TE distribution at 3), whereas the fourth observation is ">7" and the accompanying figure indicates that the likelihood contribution is the cumulative likelihood of all values greater than 7.

The best-fitting distribution to the 80 observations is a normal distribution with a mean of 6.8 years and a standard deviation of 6.14 years. The characteristics of this fitted curve are indicated in Table 6 at the end of this attachment. To avoid negative values of TE arising from a random sample, this normal distribution was truncated at its 15th percentile. The truncation results in approximately 15 percent of the samples being assigned a value of 0.44 and no values being assigned a lesser value.

Figure 3 at the end of this attachment provides a graphical comparison between observed and predicted TE values for refuge workers. The probabilities in this figure are the observed and predicted probabilities that the completed tenure TE will exceed t for t = 1, 2, ..., 20. The predicted values are simply the probability of TE exceeding t years, t = 1, 2, ..., 20, for the best-fitting, not truncated, normal distribution. In order to appropriately reflect the information in the incomplete tenure observations, the observed value of the proportion of the data with TE > t is calculated as follows:

1. Let SUM equal the number of completed tenures exceeding t plus the number of incomplete tenures exceeding t.

2. For each incomplete tenure observation not exceeding t, increase the SUM by the predicted conditional probability that the incomplete tenure will last long enough to exceed t. This conditional probability is the likelihood that the completed tenure will exceed t given that the completed tenure exceeds the current duration of the incomplete tenure. For each of the observations described in step (1), 1 was added to SUM because these observations are known to exceed t. In contrast for each incomplete tenure not exceeding t, the fraction corresponding to the conditional probability is added.

3. The "observed value" is SUM divided by the number of tenure observations (i.e., SUM/80).

Figure 3 at the end of this attachment indicates that the predicted values under predict for values equal to 1 or greater than 13 and overpredict for values between 2 and 13. For example, at t=2, the prediction is that the completed tenure of a refuge worker will exceed 2 years approximately 78.4 percent of the time, whereas the observed data suggests that completed tenures will only exceed 2 years 75.5 percent of the time. The maximum likelihood estimation procedure is a standard procedure for fitting a distribution to data with "greater than" values, constituting right-censored data.

Table 1(Att.B.3-4) Frequency Distribution of Lifetime Duration of Exposure (Hours/Lifetime)

Perc.	Regulated/Casual Visiotrs		Recreational Visitors	
	Subpopulation of Most Concern	General Neighborhood Population	Subpopulation of Most Concern	General Neighborhood Population
99.9	26,771	46,878	46,896	23,680
99.75	17,814	29,873	29,730	12,920
99.5	12,656	20,466	20,493	8,379
99	8,823	13,731	13,716	5,615
97.5	5,173	7,607	7,606	2,903
95	3,272	4,582	4,581	1,570
92.5	2,428	3,294	3,292	1,067
90	1,929	2,555	2,553	781
80	1,017	1,258	1,258	334
75	798	962	961	239
70	641	734	755	175
60	432	488	488	103
50	299	325	325	62
40	207	216	216	38
30	139	140	140	22
25	112	110	110	16
20	88	84	84	16
10	48	43	41	4
5	27	23	23	2

Table 2(AttB.3-4) Summary of Refuge Worker Time-Dependent Variables (TDVs) Page 1 of 1

Parameter	Distribution	Mean	Standard Deviation	Minimum Value	Most Likely Value	95th Percentile
exposure time (hours/day)	Fixed	–	–	–	–	8
exposure frequency (days/year)	Triangular	–	–	195	229	242
exposure duration (years/lifetime)	Normal	6.82	6.14	–	–	16.92

Table 3(Att.B.3-4) Observed Frequency Distribution of the Number of 8-Hour Days Worked per Year by Refuge workers at Crab Orchard, Illinois, Malheur, Oregon, and Minnesota valley, Minnesota

Rank Order	Number of Days/Year (DW)	Cumulative Proportion
1	164.5	0.030
2	201.25	0.061
3	207	0.091
4	210	0.121
5	211.5	0.152
6	211.5	0.182
7	216	0.212
8	217.5	0.242
9	220	0.273
10	220	0.303
11	220	0.333
12	221.25	0.364
13	222.5	0.394
14	223.25	0.424
15	223.25	0.455
16	223.25	0.485
17	223.75	0.515
18	227	0.545
19	227	0.576
20	228	0.606
21	228	0.636
22	230	0.667
23	230	0.697
24	231	0.727
25	233	0.758
26	235	0.789
27	235	0.818
28	238	0.848
29	240	0.879
30	240	0.909
31	240	0.934
32	240	0.970
33	240	1.000

Note:
The number of 8 hour work days is calculated by dividing the total hours worked per year by 8. Thirty three refuge workers were interviewed.

Table 4(Att.B.3-4) Observed Numbers of the Years Worked at a Refuge by Each Individual Refuge Worker Currently Working at Crab Orchard, Illinois, Malheur, Oregon, and Minnesota Valley, Minnesota

M-A	(Maintenance Mechanic)	: >15 years
M-B	(Engineering Equipment Operator	: 3.5, 3, >7 years
M-C	(Archaeologist)	: >1.42 years
M-D	(Refuge Manager)	: 0.25, 1, 3, 3, 2, 3.5, 6.5, >2 yrs
M-E	(Outdoor Recreation Planner)	: 2, >2.5 years
M-F	(Habitat Management Specialist	: 2, .33, 5, >0.21 years
M-G	Assistant Refuge Manager)	: 3.5, 2.5, 6.5, >0.5 years
M-H	(Wildlife Biologist Assistant)	: 2.5, 2.5, 5, >1.5 years
M-I	(Refuge Fire Mgmt. Oficer)	: 2.5, 6, 4.5, >1.25 years
M-J	(Work Supervisor)	: 0.5,).833, 7, >6 years
M-K	(Assistant Archaeologist)	: >0.417 years
MV-A	(Biologist Technician)	: >2 years
MV-B	(Wildlife Biologist)	: 0.75, 1.5, 2, >8.5 years
MV-C	(Engineering Equipment Operator)	: >11.75 years
MV-D	(Refuge Operations Spec.)	: 8.833, >6 years
MV-E	(Refuge Manager)	: 1, 3, 3, 1, >5 years
MV-F	(Maintenance Mechanic)	: >1.25 years
MV-G	(Refuge Guide)	: >1.0833 years
MV-H	(Refuge Guide)	: >1.0833 years
MV-I	(Refuge Guide)	: >1.33 years
MV-J	(Outdoor Recreation Planner)	: >4.167 years
CO-A	(Administrative Officer)	: >17 years
CO-B	(Supervisory Refuge Oper. Spec.)	: 2, 2.5, 1, 2.5, 3.5, >1 years
CO-C	(Biologist Technician)	: >7 years
CO-D	(Outdoor Recreation Planner)	: 15.5, >8 years
CO-E	(Forester)	: 8.25, >3.5 years
CO-F	(Wildlife Biologist)	: 1.5, 4, 1.5, 1.5, >7 years
CO-G	(Refuge Manager)	: 5, 2, 13, >6 years
CO-H	(Refuge Guide)	: >1.833 years
CO-I	(Maintenance Mechanic)	: >1.0833 years
CO-J	(Tractor Operator)	: >5.833 years
CO-K	(Maintenance Supervisor)	: >17.0833 years
CO-L	(Engineering Equipment Operator)	: >31 years

Thirty-three refuge workers were interviewed. The 80 durations in this table are the durations corresponding to the 80 tenures these 33 workers have had at different refuges. For example, a worker who has been at Crab Orchard for 8 years and was previously at one other refuge for 15.5 years contributes two refuge durations, namely 15.5 and >8.0.

CO denotes that the worker's current refuge is Crab Orchard, illinois.
M denotes that the worker's current refuge is Malheur, Oregon.
MV denotes that the worker's current refuge is Minnesota Valley, Minnesota.

Tenure Data: > # years, implies that the individual is still on the job and has been at this refuge for # years.

Table 5 (Att.B.3-4) The Contributions of the Completed and Incomplete Tenures to the Maximum Likelihood Estimation of the Distribution of the Duration (TE) of a Refuge Worker's Tenure at a Single Refuge

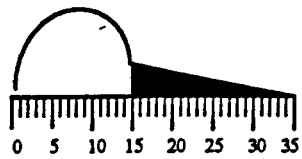
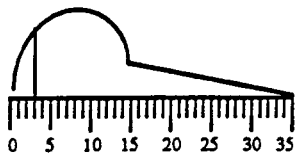
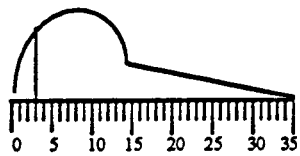
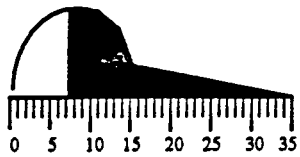
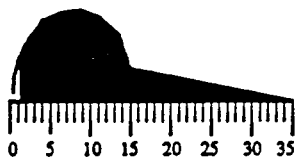
#	Id.	Observation (years)	Likelihood Contribution (Obs=t)	Likelihood Contribution P(Obs>t)	Graphical Representation of Likelihood Contribution
1	M-A	>15	-	0.09162	
2	M-B	3.5	0.29769		
3	M-B	3	0.27079		
4	M-B	>7		0.48858	
5	M-C	>1.42		0.81047	

Table 5 (Att.B.3-4) The Contributions of the Completed and Incomplete Tenures to the Maximum Likelihood Estimation of the Distribution of the Duration (TE) of a Refuge Worker's Tenure at a Single Refuge

#	Id.	Observation (years)	Likelihood Contribution (Obs=t)	Likelihood Contribution P(Obs>t)	Graphical Representation of Likelihood Contribution
6	M-D	0.25	0.12694		
7	M-D	1	0.16241		
8	M-D	3	0.27079		
9	M-D	3	0.27079		
10	M-D	2	0.21534		
11	M-D	3.5	0.29769		
12	M-D	6.5	0.39783		
13	M-D	>2		0.78384	
14	M-E	2	0.21534		
15	M-E	>2.5		0.75924	
16	M-F	2	0.21534		
17	M-F	0.33	0.13051		
18	M-F	5	0.36528		
19	M-F	>0.21		0.85917	
20	M-G	3.5	0.29769		
21	M-G	2.5	0.24309		
22	M-G	6.5	0.39783		
23	M-G	>0.5		0.84835	
24	M-H	2.5	0.24309		
25	M-H	2.5	0.24309		
26	M-H	5	0.36528		
27	M-H	>1.5		0.80693	
28	M-I	2.5	0.24309		
29	M-I	6	0.39183		
30	M-I	4.5	0.34575		
31	M-I	>1.25		0.81788	
32	M-J	0.5	0.13826		
33	M-J	0.833	0.15413		
34	M-J	7	0.39862		
35	M-J	>6		0.55335	
36	M-K	>0.417		0.85150	
37	MV-A	>2		0.78384	
38	MV-B	0.75	0.15010		
39	MV-B	1.5	0.18825		
40	MV-B	2	0.21534		
41	MV-B	>8.5		0.39250	
42	MV-C	>11.75		0.21133	
43	MV-D	8.833	0.35848		
44	MV-D	>6		0.55335	
45	MV-E	1	0.16241		
46	MV-E	3	0.27079		
47	MV-E	3	0.27079		
48	MV-E	1	0.16241		
49	MV-E	>5		0.61673	
50	MV-E	>1.,25		0.81788	
51	MV-G	>1.0833		0.82496	
52	MV-H	>1.0833		0.82496	
53	MV-I	>1.33		0.81442	
54	MV-J	>4.167		0.66731	
55	CO-A	>17		0.04882	
56	CO-B	2	0.21534		
57	CO-B	2.5	0.24309		
58	CO-B	1	0.16241		

Table 5 (Att.B.3-4) The Contributions of the Completed and Incomplete Tenures to the Maximum Likelihood Estimation of the Distribution of the Duration (TE) of a Refuge Worker's Tenure at a Single Refuge

#	Id.	Observation (years)	Likelihood Contribution (Obs=t)	Likelihood Contribution P(Obs>t)	Graphical Representation of Likelihood Contribution
59	CO-B	2.5	0.24309		
60	CO-B	3.5	0.29769		
61	CO-B	>1		0.82844	
62	CO-C	>7		0.48858	
63	CO-D	15.5	0.05429		
64	CO-D	>8		0.42410	
65	CO-E	8.25	0.37802		
66	CO-E	>3.5		0.70577	
67	CO-F	1.5	0.18825		
68	CO-F	4	0.32295		
69	CO-F	1.5	0.18825		
70	CO-F	1.5	0.18825		
71	CO-F	>7		0.48858	
72	CO-G	5	0.36528		
73	CO-G	2	0.21534		
74	CO-G	13	0.14521		
75	CO-G	>6		0.55335	
76	CO-H	>1.833		0.79172	
77	CO-I	>1.0833		0.82496	
78	CO-J	>5.833		0.56408	
79	CO-K	>17.0833		0.04746	
80	CO-L	>31		0.00004	

Thirty-three refuge workers were interviewed. The 80 durations in this table are the durations corresponding to the 80 tenures these 33 workers have had at different refuges. For example, a worker who has been at Crab Orchard for 8 years and was previously at one other refuge for 15.5 years contributes two refuge durations, namely a completed tenure of 15.5 and a incomplete tenure > 8.0.

Tenure Data > # years implies that the individual is still on the job and has been at this refuge for # years.

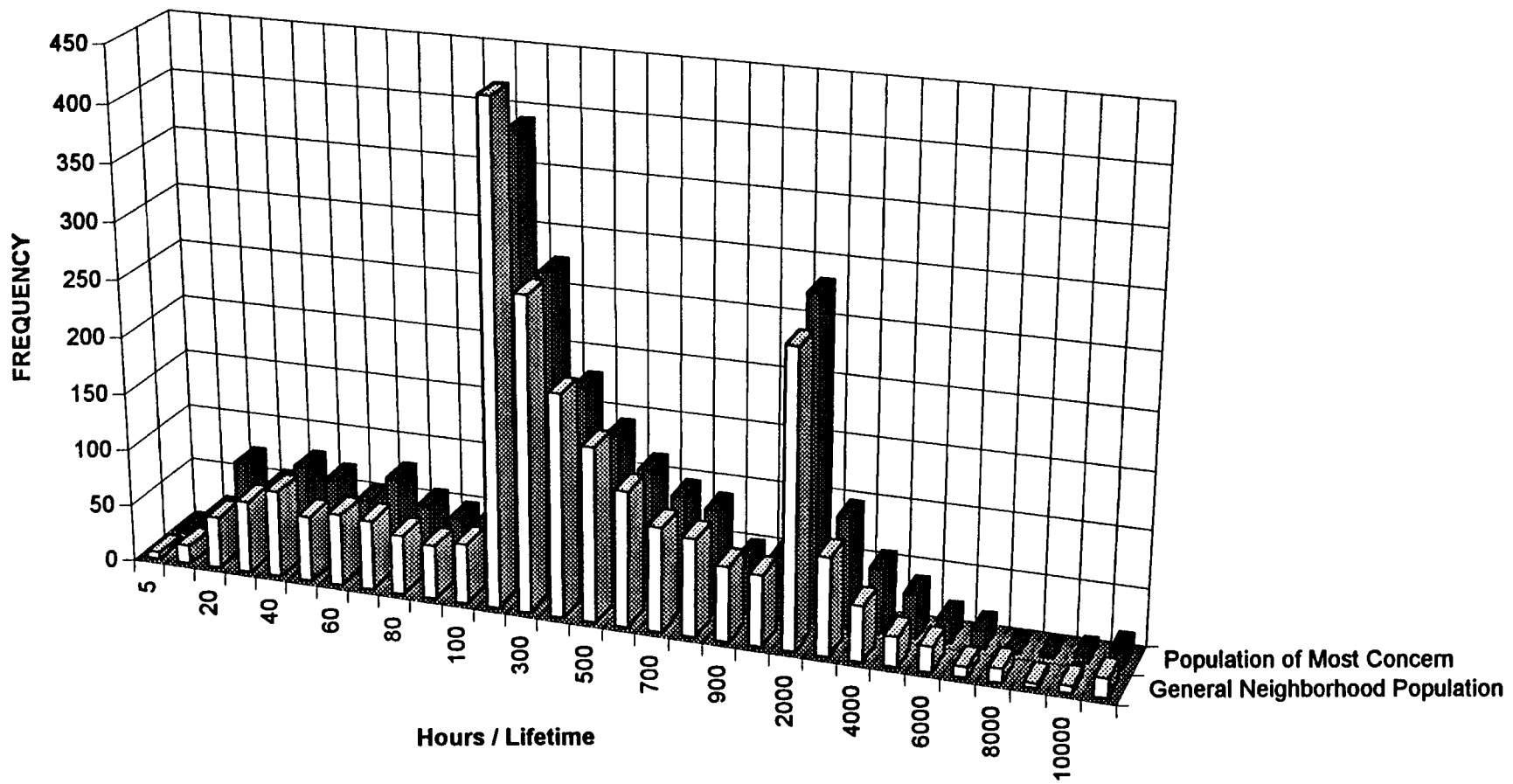
Table 6(Att.B.3-4) Normal Distribution Corresponding to the Maximum Likelihood Fit of the Observed Frequency Distribution of the Years Worked at a Refuge by Refuge Workers Currently Working at Crab Orchard, Illinois, Malheur, Oregon, and Minnesota Valley, Minnesota

Normal Distribution

Mean	=	6.82404D+00
Standard Deviation	=	6.14344D+00

Individual Tenure Probabilities				Cumulative Distribution Function			
P(	0 < Tenure <=	1) =	.17156	P(	Tenure <=	1) =	.17156
P(	1 < Tenure <=	2) =	.04460	P(	Tenure <=	2) =	.21616
P(	2 < Tenure <=	3) =	.05066	P(	Tenure <=	3) =	.26682
P(	3 < Tenure <=	4) =	.05605	P(	Tenure <=	4) =	.32287
P(	4 < Tenure <=	5) =	.06040	P(	Tenure <=	5) =	.38327
P(	5 < Tenure <=	6) =	.06338	P(	Tenure <=	6) =	.44665
P(	6 < Tenure <=	7) =	.06478	P(	Tenure <=	7) =	.51142
P(	7 < Tenure <=	8) =	.06448	P(	Tenure <=	8) =	.57590
P(	8 < Tenure <=	9) =	.06250	P(	Tenure <=	9) =	.63840
P(	9 < Tenure <=	10) =	.05901	P(	Tenure <=	10) =	.69741
P(	10 < Tenure <=	11) =	.05426	P(	Tenure <=	11) =	.75167
P(	11 < Tenure <=	12) =	.04858	P(	Tenure <=	12) =	.80025
P(	12 < Tenure <=	31) =	.04237	P(	Tenure <=	13) =	.84262
P(	13 < Tenure <=	14) =	.03599	P(	Tenure <=	14) =	.87861
P(	14 < Tenure <=	15) =	.02977	P(	Tenure <=	15) =	.90838
P(	15 < Tenure <=	16) =	.02398	P(	Tenure <=	16) =	.93236
P(	16 < Tenure <=	17) =	.01882	P(	Tenure <=	17) =	.95118
P(	17 < Tenure <=	18) =	.01438	P(	Tenure <=	18) =	.96556
P(	18 < Tenure <=	19) =	.01070	P(	Tenure <=	19) =	.97626
P(	19 < Tenure <=	20) =	.0776	P(	Tenure <=	20) =	.98401
P(	20 < Tenure <=	21) =	.00547	P(	Tenure <=	21) =	.98949
P(	21 < Tenure <=	22) =	.00376	P(	Tenure <=	22) =	.99325
P(	22 < Tenure <=	23) =	.00252	P(	Tenure <=	23) =	.99577
P(	23 < Tenure <=	24) =	.00164	P(	Tenure <=	24) =	.99741
P(	24 < Tenure <=	25) =	.00104	P(	Tenure <=	25) =	.99845
P(	25 < Tenure <=	26) =	.00065	P(	Tenure <=	26) =	.99910
P(	26 < Tenure <=	27) =	.00039	P(	Tenure <=	27) =	.99949
P(	27 < Tenure <=	28) =	.00023	P(	Tenure <=	28) =	.99972
P(	28 < Tenure <=	29) =	.00013	P(	Tenure <=	29) =	.99985
P(	29 < Tenure <=	30) =	.00007	P(	Tenure <=	30) =	.99992
P(	30 < Tenure <=	31) =	.00004	P(	Tenure <=	31) =	.99996
P(	31 < Tenure <=	32) =	.00002	P(	Tenure <=	32) =	.99998
P(	32 < Tenure <=	33) =	.00001	P(	Tenure <=	33) =	.99999
P(	33 < Tenure <=	34) =	.00001	P(	Tenure <=	34) =	.1.00000

FREQUENCY DISTRIBUTION OF LIFETIME DURATION OF EXPOSURE (Hours/Lifetime)



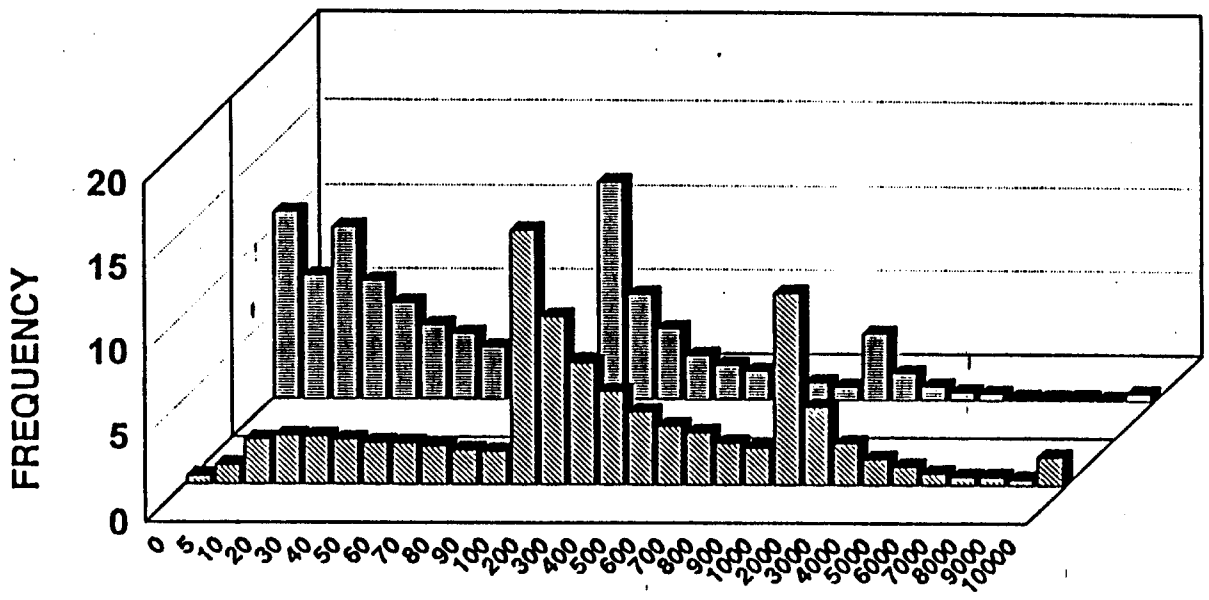
RMA IEA/RC 8.93.jb

Figure 1 (Att.B.3-4)

Regulated and Casual Visitors

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

FREQUENCY DISTRIBUTION OF LIFETIME DURATION OF EXPOSURE (Hours/Lifetime)



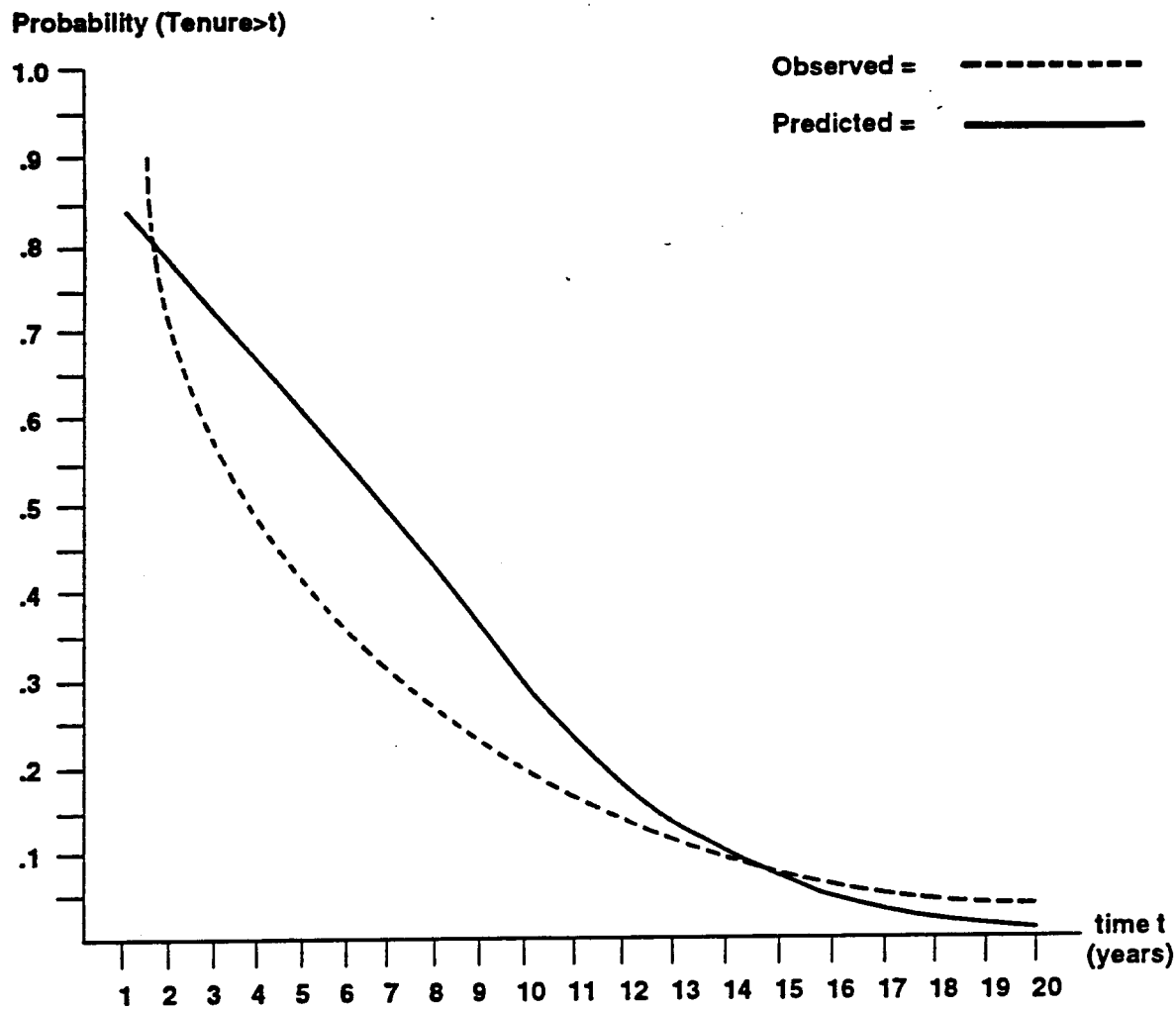
RMA IEA/RC 8.93.jb

Figure 2 (Att.B.3-4)

Recreational Visitors

Note: The subpopulation of most concern was evaluated in the IEA/RC; risks for the general neighborhood population were not quantified in the IEA/RC.

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



RMA IEA/RC B.3 8.93.jb

Figure 3 (Att.B.3-4)

A Graphical Comparison of the Observed and Predicted Refuge Worker Tenures at a Single Refuge

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

ATTACHMENT B.3-5

PROBABILITY DISTRIBUTIONS FOR TIME DEPENDENT EXPOSURE PARAMENTERS IN HUMAN HEALTH EXPOSURE ASSESSMENT (SHELL)

In this attachment, Shell's time dependent variable (TDV) evaluation for the potentially exposed populations is provided. The TDVs described in this attachment are not used in the PPLV or risk calculations. Rather, they are provided to give perspective on how Shell's TDV evaluation compares with the Army's, which is provided in Appendix Section B.3.7

PROBABILITY DISTRIBUTIONS FOR TIME DEPENDENT EXPOSURE PARAMETERS IN HUMAN HEALTH EXPOSURE ASSESSMENT

Prepared by
Shell Oil Company
MK Environmental Services
AWD Technologies
Sielken, Inc.

July 12, 1992

PROBABILITY DISTRIBUTIONS FOR TIME DEPENDENT EXPOSURE PARAMETERS IN HUMAN HEALTH EXPOSURE ASSESSMENT

EXECUTIVE SUMMARY

The conduct of a scientifically defensible human health exposure assessment requires research and quantitation of a number of parameters. The preferred characteristics of data and other qualitative information for development of these parameters are site-specificity, geographical and chronological relevance and applicability to future development at the site. To accurately characterize the realistic values for a given parameter, all available and relevant information must be considered. This approach results in a range of values in which all possibiliities are considered as well as the probable frequency of their occurrence. The distributional approach conveys the frequency of different exposure durations within the population in question and allows the PPLVs and associated risks to be interpreted in terms of protection for this same population.

The outcome of the human health exposure assessment is particularly sensitive to the time dependent exposure parameters, i.e., TM(hours/day), DW(days/year) and TE(years/lifetime), which combine to form the lifetime average daily dose. The variability within these parameters is a reflection of the inherent variability of human behaviors, and cannot be adequately or accurately represented by a single fixed value. The use of probability distributions incorporates all available and relevant information to express the likelihood that a given exposure may occur.

Probability distributions also aid risk management decisions in that they explicitly present all information concerning estimated exposure durations. The Risk Manager can readily discern exposure and hence, risk, to a given percentile of any evaluated population or subpopulation, as well as the uncertainty and variability about that exposure. The use of probability distributions is consistent with regulatory guidance and EPA Memoranda of Understanding.

Both the original subject document and this revision explicitly present probability distributions for each time dependent exposure parameter under each proposed land use scenario at the Arsenal, namely the combined Regulated and Casual, Recreational and the combined Commercial and Industrial scenario. Each subpopulation, as well as the combined or whole population, is evaluated within each scenario. In addition, this revision responds to past comments and suggestions of the Parties, evaluates and incorporates new data, and incorporates a 70 year life span to allow evaluation over the entire life of an individual rather than a snapshot in time. Further, it explicity identifies neighborhood and regional subpopulations, as follows:

EXECUTIVE SUMMARY
(cont'd)

Neighborhood		**Regulated/Casual**	**Recreational**
	Subpopulation Size	14,875	14,875
	Arsenal Visitors	8,315	9,649
Regional			
	Visitors/Year	45,575	126,199
	Visits/ Year	129,662	359,036
	Visits Sometime in 70 Years	118,624	296,101
	Organized Sports Visitors		3,376
	Anglers		602
Total Population		1,848,319	1,848,319

The sources of information used in the development and documentation of each parameter (for each population and subpopulation) is provided, and is followed by the probability distribution itself. The mathematical development subsections outline in detail the derivation of each parameter probability distribution.

Probability distributions were developed based on site-specific or regional data, metropolitan area data, and, in some cases, on national data. This information has been cited from numerous public and private source documents. All data sources were reviewed for their quality and the validity of their quantitative or qualitative incorporation. Relevant information that could not be quantitatively incorporated into the distributions is discussed qualitatively in the appropriate parameter/population subsection.

In parameter development, the form of the data required different approaches. In some cases where the data referred to a particular activity within the defined population, component distributions were developed to represent each activity. These component distributions were then combined based on information regarding the relative contribution of the activity to the whole population using a Monte Carlo simulation. In other cases, the data did not directly imply component distributions but provided the information necessary to derive a probabilistic model

EXECUTIVE SUMMARY
(cont'd)

which could then be used in a Monte Carlo simulation to estimate the parameter distribution. Although the derivation of parameter distributions based on such data is necessarily complex, the process allows for an enhanced understanding of resulting distribution itself. For example, a subpopulation or activity group having the largest influence on the parameter distribution can be readily assessed.

The probability distributions presented in this paper make the best use of available information relative to the Arsenal. Their use in the human health exposure assessment is scientifically defensible, reduces uncertainty and increases the validity of the outcome. The distributions for the time dependent exposure parameters are summarized in the following table, entitled *Parameters in Probability Distributions TM(hours/day), DW(days,year), TE(years/lifetime) Derived from Data in Sections 3.0, 4.0, and 5.0.*

TABLE 1. PARAMETERS IN PROBABILITY DISTRIBUTIONS TM(HOURS/DAY), DW(DAYS/YEAR), TE(YEARS/LIFETIME) DERIVED FROM DATA IN SECTIONS 3, 4, AND 5

	REGULATED / CASUAL VISITOR			RECREATIONAL VISITOR						COMM. IND. WORKER
	SUBPOPULATION		POP.	SUBPOPULATION				POPULATIONS		POP.
PARAMETER	NBR. GENERAL VISITOR	REG. GENERAL VISITOR		ANGLER	NBR. GENERAL VISITOR	REG. GENERAL VISITOR	ORGANIZED SPORTS VISITOR	REC.	EXPANDED REC.	
TM: MEAN	2.19	2.19	2.19	3.33	2.10	2.10	2.46	1.93	1.92	7.42
TM: S.D.	1.85	1.85	1.85	1.58	1.95	1.95	3.03	0.90	0.95	3.26
TM: LN(1)	0.5156	0.5156	0.5156	1.1015	0.433	0.433	0.44	0.5585	0.5425	
TM: LN(2)	0.7333	0.7333	0.7333	0.4504	0.7876	0.7876	0.96	0.4432	0.4671	
TM: 50TH	1.67	1.67	1.67	3.01	1.54	1.54	1.55	1.75	1.72	7.42
TM: 95TH	5.59	5.59	5.59	6.31	5.63	5.63	7.53	3.62	3.71	12.79
DW: MEAN	14.39	2.84	3.86	11.95	29.67	6.43	10.50	3.40	3.47	236.31
DW: S.D.	9.67	1.90	4.37	13.75	30.83	2.44	10.49	4.50	4.57	2.78
DW: LN(1)			0.9399	2.0592	3.0242	1.7943	2.0047	0.7183	0.7411	
DW: LN(2)			0.9077	0.9184	0.8556	0.3668	0.8323	1.0060	1.0030	
DW: 50TH	14.39	2.84	2.56	7.84	20.58	6.02	7.42	2.05	2.10	236.31
DW: 95TH	30.29	5.96	11.39	35.51	84.06	11.00	29.19	10.73	10.92	240.87
TE: MEAN	6.92	7.13	7.12	7.82	6.92	7.82	7.82	7.67	7.67	4.37
TE: S.D.	22.24	21.99	21.98	23.41	21.93	23.41	23.41	22.47	22.47	6.97
TE: LN(1)	0.7204	0.7885	0.7865	0.9064	0.7324	0.9064	0.9064	0.9078	0.9078	0.8453
TE: LN(2)	1.5581	1.5336	1.5342	1.5165	1.5502	1.5165	1.5165	1.5031	1.5032	1.1246
TE: 50TH	2.06	2.20	2.20	2.48	2.08	2.48	2.48	2.48	2.48	2.32
TE: 95TH	26.66	27.41	27.38	29.99	26.64	29.99	29.99	29.38	29.38	14.78

Legend: NBR. = Neighborhood; REG. = Regional; POP. = Population; S.D. = Standard Deviation; LN(1) = mean of ln(parameter); LN(2) = standard deviation of ln(parameter); 50th = 50th percentile; 95th = 95th percentile.

All distributions are either normal or lognormal distributions. Parameters with LN(1) and LN(2) values have lognormal distributions.

PROBABILITY DISTRIBUTIONS FOR TIME DEPENDENT EXPOSURE PARAMETERS IN HUMAN HEALTH EXPOSURE ASSESSMENT

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List of Acronyms Appearing in Document

BLS	Bureau of Labor Statistics
BNA	Bureau of National Affairs
BOR	U.S. Bureau of Outdoor Recreation
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
DRCOG	Denver Regional Council of Governments
DPOR	Division of Parks and Outdoor Recreation (Colorado)
DW	Days/Week
EA	Endangerment Assessment
EFH	Exposure Factors Handbook
EPA	Environmental Protection Agency
LADD	Lifetime Average Daily Dose
MLE	Most Likely Exposed individual
MSEC	Mountain States Employers' Council
NPS	National Park Service
NRPA	National Recreation and Parks Association
NSGA	National Sporting Goods Association
PPLV	Preliminary Pollutant Limit Value
PsCo	Public Service Company of Colorado
RMA	Rocky Mountain Arsenal
RME	Reasonable Maximum Exposure
TDV	Time Dependent Variable
TE	Years/Lifetime
TM	Hours/Day
USDOL	U.S. Department of Labor
USFWS	U.S. Fish and Wildlife Service
USGPO	U.S. Government Printing Office

PROBABILITY DISTRIBUTIONS FOR TIME DEPENDENT EXPOSURE PARAMETERS IN HUMAN HEALTH EXPOSURE ASSESSMENT

1.0 INTRODUCTION

1.1 PURPOSE

This report provides an update to Using Probability Distributions for Time Dependent Exposure Parameters to Improve Human Health Exposure Assessment, prepared by Shell and submitted to the Army in August, 1991. It also updates the January, 1992 revision of that document. The purpose of this report is to explain the rationale and justification for the use of probability distributions for the time dependent exposure parameters in human health exposure assessment and to provide the technical basis for the development of the distributions. This revision explicitly identifies neighborhood subpopulations, incorporates 70 year life span, new data and responses to EPA and State of Colorado comments regarding predecessor documents.

1.2 DOCUMENT FORMAT

Section 1.0 of this paper presents the purpose of the report, the rationale for the incorporation of probability distributions for the time dependent exposure parameters into the RMA Endangerment Assessment process, and the format of the sections within the report. Section 2.0 presents a description of the exposed populations for which time dependent exposure parameters are evaluated and the rationale for combining some populations together which have similar activities.

In Sections 3.0, 4.0 and 5.0, specific probability distributions are developed for each parameter, exposed populations and subpopulations. For each parameter/land use population combination, the discussion is organized in three subsections for ease of comprehension. The first subsection, Rationale for Probability Distribution, discusses the sources and quality of information available for use in the development and support of the distribution to represent that parameter/population combination. Information used to qualitatively support the distributions is also included in this section. In the second subsection, Probability Distribution, the actual distribution is presented for that parameter/land use combination. The third subsection, Mathematical Development, provides the supplemental mathematical derivation of each distribution using the data presented in the rationale section. References are included in Section 6.0. Figures illustrating the probability density functions and cumulative density functions are found in Section 7.0. Appendices A-H provide additional discussion and details on the derivation, use, and quantitative impact of these probability distributions.

1.3 TIME DEPENDENT EXPOSURE PARAMETERS

Time dependent exposure parameters should reflect the variability in the practices, conduct, and interests of the potentially exposed populations under each considered land use. These parameters, TM (hours/day), DW (days/year) and TE (years/lifetime), combine to express the lifetime average daily dose (LADD). The correct scientific expression of parameters with known and significant variability is through the use of probability distributions to express the likelihood that a given exposure may occur. The use of fixed values to characterize inherently variable human behaviors creates unnecessary uncertainty that can be greatly reduced by incorporating all the available information. Sufficient relevant data are available to support probability distributions for all three parameters. To reject the use of probability distributions would be to reject the use of relevant and applicable information in favor of arbitrary fixed default values bearing no particular relevance to the Arsenal.

Further, in *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual*, EPA encourages the development and use of area and site-specific information to define a number of parameters, including human activities, activity patterns, population characteristics, etc. This position was reiterated in *Supplemental Guidance to the Human Health Evaluation Manual*, OSWER Directive 9285.6-03.

Also on the national level, on February 26, 1992, EPA published a guidance document entitled Guidance on Risk Characterization for Risk Managers and Risk Assessors. This document clarifies that "...it is Agency policy to present information on the range of exposures derived from exposure scenarios and on the uses of multiple risk-descriptors, (i.e, central tendency, high end of individual risk, population risk, important subgroups, if known)...".

The duration of potential exposure is described by three parameters, TM (hours/day), DW (days/year) and TE (years/lifetime). The data review conducted by Shell indicates that fixed values do not reflect the significant variability found in data describing human behavior. The distributed range of values for these parameters will vary according to the proposed land use scenario and variations amongst the members of the potentially exposed populations. An explanation of how these time dependent exposure parameters interact in the calculation of the lifetime average daily dose is found in Appendix A.

1.4 USE OF PROBABILITY DISTRIBUTIONS

To accurately characterize the realistic values for a given parameter, all available and relevant information must be considered. This approach results in a range of values in which all possibilities are considered as well as the probable frequency of their occurrence. For each time dependent parameter within each exposure population, the variability in the data was such that realistic parameter values could only be characterized in the form of a probability distribution. The distributional approach conveys the frequency of different exposure durations within the population in question and allows the PPLVs and associated risks to be interpreted in terms of the protection for this same population.

Distributions for several subpopulations within the Regulated/Casual and Recreational Visitor scenarios are examined in addition to the total populations for these scenarios. The February 26, 1992 EPA guidance calls for "Fully visible information (to assure that) important features of the assessment are immediately available at each level of (risk) decision-making for evaluating whether risks are acceptable or unacceptable". Estimates of central tendency and variability are also presented for each distribution, as recommended in this guidance.

It is especially important to characterize parameters in terms of their probability distributions when information on multiple parameters is combined and calculations involving several parameters are made. The PPLV methodology combines information on several dozen parameters. Bounds on parameter values do not convey as much information as probability distributions. A bound does not convey how large the values are likely to be when they either exceed the bound or are less than the bound. When bounds are combined in equations, e.g., the PPLV equations, the result has no clear meaning. For example, when two 95% upper bounds are multiplied together, the result may be either greater than or less than a 95% bound on the product. In order to meaningfully interpret the results of combining several parameters in an equation, the probability distributions of the component distributions must be identified. It is particularly important to characterize the parameters in the PPLV methodology in terms of their probability distributions whenever possible.

1.4.1 Deductive Reasons to Use Probability Distributions

The paper, *Decision Analysis and Quantitative Risk Characterization* (Sielken, 1990), points out that:

> A risk characterization in the form of a probability distribution, as opposed to a single numerical value, has several advantages including greater use of available information, a truer reflection of the weight of evidence, a more reasonable format for incorporating new information and less chance for misleading the public. The probability distribution characterizations can also give the risk manager more information and a greater opportunity to utilize the tools of risk management.

On the other hand, the use of fixed values in the quantitative assessment considers only one alternative, generally the RME value. This alternative is assigned a probability of 1.0 and the remaining alternatives are assigned zero probabilities and may not even be identified. Potentially exposed populations are comprised of people who do not conduct their lives in an identical fashion, and who vary widely in their habits, work schedules, work assignments, hobbies, desires, preferences, interests, obligations and motivations. Such variation is documented by the state of knowledge at hand regarding the time dependent exposure factors for the proposed land uses at the Arsenal.

In reality almost all of the parameters in the PPLV equations have probability distributions and are not fixed numbers. If probability distributions are not used, the results can easily be biased

and misinterpreted. Furthermore, the direction of the bias is unknown (it can be overly conservative or not conservative at all). The magnitude of the bias is also unknown.

Variable parameters have a probability distribution. If the variation in the parameter values is ignored, the parameter's probability distribution is characterized by a fixed constant. This constant represents a degenerate distribution with all probability assigned to just one value. On the other hand, the variation in parameter values can be described by a probability distribution which has similar variability and constitutes the best available estimate of relative frequency of possible parameter values.

Using probability distributions does not make the implementation of the PPLV methodology more difficult in the sense that the use of probability distributions is already a part of the required sensitivity analyses. The use of probability distributions can reflect more of the available information and is less arbitrary than the use of fixed numbers. A probability distribution describes a parameter or situation with several possible values much more accurately than a fixed number.

When several parameters are included in a calculation, the use of probability distributions considers the outcomes for all possible combinations of values. If each probability distribution is replaced by a fixed number, there is no opportunity to consider the outcomes associated with different combinations of high and low values and how often these combinations would occur. The problems associated with using a fixed number to represent a parameter's distribution are compounded, and the possibilities for misinterpretations increased.

The utilization of ranges is sometimes better than using fixed numbers. However, ranges fail to indicate the relative likelihood or probability of the different numbers within the range. Therefore, probability distributions can reflect much more information than ranges. The errors introduced by replacing probability distributions by fixed numbers or ranges are usually much greater than errors resulting from using approximate or estimated probability distributions. The advantages of characterizing a variable by an estimated probability distribution rather than a fixed constant are discussed further in Appendix F.

1.4.2 Mathematical Reasons to Use Probability Distributions

Even when only 2 or 3 parameters are involved in a calculation, it is important to know the probability distributions of the parameters in order to understand the probabilities of the different possible outcomes of the calculation. It is not sufficient to use only a single value to represent the probability distribution for a parameter. Some simplified examples illustrating this point are found in Appendix B.

In order to determine the probabilities of different calculated values or the percentiles of the calculated values, the probability distributions of the components of the calculation must be known. In order to avoid biased representations, the entire probability distribution of each parameter needs to be utilized. Furthermore, avoiding the bias could mean either avoiding being

overly conservative or avoiding being insufficiently conservative. It is impossible to determine the direction or magnitude of the bias unless the probability distributions of the components are incorporated.

In simple terms, if a calculation is performed with only a single percentile representing what is in reality a probability distribution, the resulting calculation cannot be interpreted. It is unknown what the probabilities are of observing that value in the population, observing a smaller value, or observing a larger value. It is also possible that the result will be misinterpreted.

2.0 POTENTIALLY EXPOSED POPULATION AND TIME DEPENDENT EXPOSURE PARAMETER COMBINATIONS

The Final Human Health Exposure Assessment defined six separate potentially exposed populations. Within these populations, essentially identical values are proposed for the Industrial and Commercial populations and for the Regulated Visitor, Casual Visitor, and Recreational Visitor populations. Shell's studies of the time dependent exposure parameters also show that the distributions are very similar within these populations, as defined below. For ease of discussion and description of these parameters/populations, Shell has combined categories for which time dependent exposure factors have comparable distributions, as explained in the following discussion.

The Regulated Visitor and Casual Visitor represent potentially exposed populations under the Open Space concept for both the Nature Preserve and Wildlife Refuge land uses, respectively. These visitors would likely be members of the general public or school groups and would be expected to engage in picnicking, wildlife observation, photography, organized bus tours, and hiking. Because both types of visitors are assumed to participate in essentially similar activities in terms of exposure potential, the same probability distribution is used to express participation times.

Within the category of Regulated/Casual Visitor, two subpopulations comprise the population at potential risk, i.e., a "neighborhood subpopulation", or walking distance subpopulation, and a "regional subpopulation". These subpopulations are assumed to participate in similar activities while at the Arsenal under this scenario. However, the neighborhood population is assumed to have a higher visitation frequency as a function of its proximity to the Arsenal. The regional subpopulation would presumably visit the Arsenal at a lower frequency due to its distance from the Arsenal and the number of attractive alternative destinations. In this paper, separate distributions have been developed and are presented for the neighborhood subpopulation, the regional subpopulation and the whole or total Regulated/Casual visitor population. Each is discussed in detail in Section 3.2.

The Recreational Visitor represents a potentially exposed population under the Open Space concept for a Recreational Park. This scenario implies the most intense use under the Open Space concept which may include hiking, jogging, fishing, cross country skiing, field sports (baseball, soccer, etc.), etc. In terms of exposure potential, the uses are less similar than those outlined for the Regulated and Casual Visitor. Therefore, the Recreational Visitor category will have different probability distributions than the Regulated/Casual Visitor for time dependent exposure parameters.

Within the category of Recreational Visitor are four subpopulations which are at potential risk, i.e., anglers, organized sports participants and general visitors (Section 4.2). The latter subpopulation is further subdivided into a "neighborhood subpopulation" (or walking distance), and a "regional subpopulation", similar to subpopulations within the Regulated/Casual Visitor category, discussed in Section 3.2.

The Commercial Worker and Industrial Worker represent potentially exposed populations under the Economic Development scenario. Light industry, which is expected to be more realistic than heavy industrial development, includes warehousing, packaging plants, assembly and finishing plants. Commercial development could include retail, wholesale and service establishments, office and public use buildings, police stations, administrative facilities, air cargo businesses, trucking, rental car bases, etc. Because these groups are not known to differ in terms of exposure duration, the same probability distributions are used to express potential exposure durations for both populations.

3.0 REGULATED/CASUAL VISITORS

Regulated/Casual visitors to the Arsenal might include people who live very near to the Arsenal or people from the larger surrounding area. People who live within a quarter mile of the Arsenal at some time during their lifetime are referred to herein as the neighborhood subpopulation. People who visit the Arsenal and live within a quarter mile of the Arsenal at some time during their lifetime are referred to herein as the neighborhood visitor subpopulation. People who visit the Arsenal who are not part of the neighborhood population are referred to as the regional visitor subpopulation. If a person is not born into a residence within a quarter mile of the Arsenal but moves into a residence within a quarter mile of the Arsenal at some time during his or her lifetime, then that person is a member of the neighborhood subpopulation. The population of all regulated/casual visitors who belong to either the neighborhood or regional subpopulations is referred to as "the visitor population" or the "combined" or "whole" visitor population. These populations are described and quantified in Section 3.2.1.

Probability distributions for TM (duration of a visit in hours/day), DW (frequency of visits in days/year), and TE (years/lifetime) are developed for the regulated/casual visitors in the neighborhood visitor subpopulation, regional visitor subpopulation, and the combined visitor population.

As explained in more detail below, the format and presentation in Sections 3.1 through 3.5 is specially ordered because the regulated/casual visitor population is a combination of two subpopulations (neighborhood and regional visitors). Section 3.1 develops the TM distribution which applies to the whole visitor population and also to both the neighborhood and regional visitor subpopulations. It is assumed that the duration of a regulated/casual visitor activity on a visitation day is the same regardless of the location of a visitor's residence. The frequency of such visits (DW) and the number of years of visitation (TE) is assumed to depend on where a visitor resides. Sections 3.2 and 3.3 develop the visitor subpopulation distributions for DW and TE, respectively, for each of the two subpopulations. Section 3.3 also combines the component (neighborhood and regional) visitor subpopulation distributions for TE to obtain the whole visitor population distribution for TE. Then, as a necessary step in the development of a visitor population distribution for DW, Section 3.4 combines the component visitor subpopulation distributions for DW and TE to produce the whole visitor population distribution for DW*TE (days/lifetime). Section 3.5 develops the visitor population distribution for DW.

The development of the DW distribution depends on the development of the DW*TE distribution. This and the development of the TE distribution are explained as follows. The distributions of DW and TE for a neighborhood visitor are different than the distributions of DW and TE for a regional visitor. In order to reflect these differences and maximize the information obtained from each of these subpopulations, the data on neighborhood visitor activity frequencies (DW(neighborhood)) are combined only with the data on total years of residence in the neighborhood (TE(neighborhood)) while the data on regional visitor activity frequencies (DW(regional)) are combined only with the data on total years of residence in the region (TE(regional)). (See Section 3.2.1).

The total number of days per lifetime spent on the Arsenal by a regulated/casual visitor is denoted by DW*TE where DW denotes days/year and TE denotes years/lifetime. If a regulated/casual visitor is a member of the neighborhood subpopulation, then the number of days per lifetime spent on the Arsenal is equal to

DW(neighborhood)*TE(neighborhood)

If a regulated/casual visitor is a member of the regional subpopulation, then the number of days per lifetime spent on the Arsenal is equal to

DW(regional)*TE(regional)

The distribution for DW(neighborhood) and DW(regional) are developed in Section 3.2. The probability distributions for TE(neighborhood) and TE(regional) are developed in Section 3.3.

In Section 3.3, the subpopulation-specific distributions for TE are used in a Monte Carlo simulation procedure to develop a distribution for TE for the population obtained by combining the neighborhood and regional subpopulations.

In Section 3.4, a Monte Carlo simulation procedure is used to develop a distribution for DW*TE for the combined population. The DW*TE distribution represents the most accurate estimate of the distribution of days per lifetime for the combined population that can be obtained from the data.

Because DW and TE are always multiplied together in the PPLV equations, it is not necessary to determine separate distributions for DW and TE. However, for the sake of consistency, the distribution for DW for the combined population is determined in Section 3.5. This DW distribution is separated out of the population's DW*TE distribution using the population's TE distribution derived in Section 3.3.

The final DW and TE distributions for the neighborhood and regional subpopulations for use in the PPLV model for these subpopulations are those specified in Sections 3.2 and 3.3, respectively. The final DW and TE distributions for the combined population for use in the PPLV model for the whole populations are those specified in Sections 3.5 and 3.3, respectively.

The reason for deriving the distributions of DW and TE in this fashion is to fully utilize the distinct information on neighborhood and regional visitor subpopulations and to avoid inappropriate calculations such as:

DW(neighborhood) * TE(regional),

and

DW(regional) * TE(neighborhood).

3.1 TM - HOURS PER DAY: Regulated/Casual Visitors

3.1.1 TM - Rationale for Probability Distribution

The probability distribution of the number of hours that a regulated or casual visitor to the Arsenal would spend participating in activities at the Arsenal is derived from several data sources: "Estimates of Visitations to Alternative Recreational Surface Uses Proposed for the Rocky Mountain Arsenal," THK Associates (1990); the National Sporting Goods Association (1989); the National Park Service (1986); Walsh (1986); and the U.S. Bureau of Outdoor Recreation (1972). The probabilistic development of the TM distribution for regulated/casual visitors, described below, is complex. This complexity was required in order to incorporate the potential for an individual to participate in more than one activity on a given day.

Representative activities for regulated or casual visitors are considered to be picnicking, walking for pleasure, nature walks, bird watching, and wildlife and bird photography. While these activities do not comprise an exhaustive list of possible activities, the probability distributions of hours of participation per activity day for these five activities should provide a representative sample of the corresponding probability distributions for the possible activities.

Data on the average number of days of activity participation per participant and/or the proportion of the population that participate in the activity are given in all of the above reference sources. These data were used to determine the relative frequency of the five different activity duration (hours/day) probability distributions. When Colorado participation rates were available, they were used. When Colorado data were not available, data for the Western Region were used when available. The only activity for which national participation rates were used was Wildlife and Bird Photography. The specific sources for each participation rate are footnoted in the corresponding table.

Although there are data on the preferences among activities that are specific to Colorado or the Western regions, no data were known to be available on the average duration of those activities in an environment comparable or nearly comparable to that at the Arsenal. National data on the average number of hours of participation per activity day are given on page 78 in Walsh (1986). For each of the five representative activities, an activity duration probability distribution with the given average number of hours of participation for that activity was determined.

Two regulated/casual visitor subpopulations were introduced in Section 3.0, the neighborhood visitor subpopulation and the regional visitor subpopulation. For purposes of the TM parameter, however, duration of various activities is assumed to be the same for both subpopulations.

These five activity duration probability distributions were combined on the basis of the visitors' relative preferences among these activities. Greater emphasis was given to more preferred activities. State and regional preferences among activities were also considered. The distribution development incorporates the possibility of participation in more than one activity in the day. The result is a probability distribution on the duration in hours of a visit to the

Arsenal by a regulated or casual visitor. Duration refers only to days when there is a visit (not days when the regulated/casual visitor does not visit the Arsenal).

3.1.2 TM - Probability Distribution

The probability distribution for the duration (TM) in hours of an activity (on a day of activity participation) for the regulated/casual visitor is a lognormal distribution with the following percentiles:

Probability (TM ≤ 9.22 hours/activity day) = 0.99
Probability (TM ≤ 7.05 hours/activity day) = 0.975
Probability (TM ≤ 5.59 hours/activity day) = 0.95
Probability (TM ≤ 4.81 hours/activity day) = 0.925
Probability (TM ≤ 4.29 hours/activity day) = 0.90
Probability (TM ≤ 3.10 hours/activity day) = 0.80
Probability (TM ≤ 2.75 hours/activity day) = 0.75
Probability (TM ≤ 2.46 hours/activity day) = 0.70
Probability (TM ≤ 2.02 hours/activity day) = 0.60
Probability (TM ≤ 1.67 hours/activity day) = 0.50
Probability (TM ≤ 1.39 hours/activity day) = 0.40
Probability (TM ≤ 1.14 hours/activity day) = 0.30
Probability (TM ≤ 1.02 hours/activity day) = 0.25
Probability (TM ≤ 0.90 hours/activity day) = 0.20
Probability (TM ≤ 0.65 hours/activity day) = 0.10
Probability (TM ≤ 0.58 hours/activity day) = 0.075
Probability (TM ≤ 0.50 hours/activity day) = 0.05
Probability (TM ≤ 0.40 hours/activity day) = 0.025
Probability (TM ≤ 0.30 hours/activity day) = 0.01

This is a lognormal distribution with mean 2.19 and standard deviation 1.85. The ln[TM] has a normal distribution with mean 0.5156 and standard deviation of 0.7333. The mathematical development of this distribution is given in Section 3.1.3.

3.1.3 TM - Mathematical Development

The probability distribution for the duration TM (hours/day) of a regulated or casual visit to the Arsenal was determined by combining the probability distributions for the durations of individual activities and considering the possibility of multiple activities on the same day. The resulting probability distribution refers to the duration (hours/day) of a visit to the Arsenal on a day in which the regulated or casual visitor actually visits the Arsenal (not days in which the potential visitor does not visit the Arsenal). Duration probability distributions are developed for each individual activity and then combined on the basis of the regulated or casual visitors' relative preferences among those activities. The activities which received the greatest emphasis were

those which were preferred, based on participation rates, by many regulated or casual visitors and which were participated in frequently throughout the year.

Participation in multiple activities in a single day was incorporated by applying a probabilistic analysis to the data on activity durations and the preferences among these activities in the visitor population. No explicit data were available on the frequency of participation in multiple activities in a single day. Given the possibility of multiple activities, however, it was believed that the incorporation of multiple activities was important to the characterization of TM. Therefore, objective assumptions were made to enable a rigorous probabilistic estimation of the frequencies of this type of participation. These assumptions are presented under Step 3 below.

The development of the probability distribution for TM (hours/day) for a regulated or casual visitor to the Arsenal involves the following five steps:

1). Determine the probability distribution for the duration of each individual activity.

2). Determine the relative sizes of the subpopulations that participate in the different possible sets of activities.

3). For each possible subpopulation, determine the number of days per year of participation in each possible combination of single and multiple activities.

4). For the entire visitor population, determine the relative frequencies of the different combinations of activities on a given day by utilizing the information from Steps 2 and 3.

5). Determine the final probability distribution representing the sum of all activity durations occurring on the same day by combining the information from Steps 1 and 4.

Step 1. Determine the probability distribution for each individual activity duration.

The parameter TM (hours/day) for a regulated or casual visitor refers to the duration of regulated or casual activities on a day in which such an individual makes a visit to the Arsenal and participates in at least one such activity. Days in which there was no participation in these activities were not considered "activity days" and were not included. Walsh (1986, page 78) provides data on the average number of hours of participation per activity day in five regulated or casual visitor activities, representative of those identified in Volume I, Land Use, of the Human Health Exposure Assessment. These averages are referred to herein as "activity duration means" and refer only to activity days and do not include days in which the individual does not participate in the activity.

Activity	Activity Duration Mean (Average Number of Hours of Participation per Activity Day)
Picnicking	2.7
Walking for Pleasure	1.9
Nature Walks	2.0
Bird Watching	2.1
Wildlife and Bird Photography	1.6

Although the data only provide mean values and give no indication of distribution shape, it is reasonable to assume that the duration of each representative regulated or casual visitor activity could be described by a lognormal distribution. It is expected that the average hours/day reported by Walsh could be substantially exceeded by an occasional visitor. Therefore, the underlying distribution would likely be positively skewed. The lognormal distribution assigns probability only to positive durations and reflects that a few individuals have activity durations substantially above the mean. The parameters in the lognormal distribution are determined such that the mean of the lognormal distribution equals the activity duration means given by Walsh, with at least 95% of the activity durations exceeding 30 minutes. A 5th percentile of 30 minutes was chosen as it was expected to comprise a near minimum length visit. A sensitivity analysis of the impact of 30 minutes being the 5th percentile, 1th percentile, or 0.1th percentile was performed and is discussed in Appendix D. The lognormal distributions based on 30 minutes as the 5th percentile were judged to be in reasonable agreement with both the data and a general understanding of these activities.

The lognormal distributions for each of the five representative regulated or casual visitor activities are as follows:

Activity	Lognormal Distribution			
	Parameters 1	2	Mean	Std. Dev.
Picnicking	0.66	0.82	2.7	2.65
Walking for Pleasure	0.41	0.67	1.9	1.42
Nature Walks	0.45	0.70	2.0	1.59
Bird Watching	0.49	0.72	2.1	1.74
Wildlife and Bird Photography	0.29	0.60	1.6	1.05

For example, the mean duration of picnicking is 2.7 hours per picnic, the standard deviation is 2.65, and the mean and standard deviation of the natural logarithm of picnicking duration are 0.66 and 0.82, respectively. For the sake of clarity, the characteristics of the lognormal

distribution are given in terms of both duration and ln(duration). Both characterizations are equivalent.

Step 2. Determine the relative sizes of the subpopulations that participate in the different possible activity combinations.

People who participate in <u>at least one</u> of the five representative regulated or casual visitor activities may not necessarily participate in <u>all</u> five of the activities. Some people may participate in one activity, some in two activities, etc. There are 31 possible sets of activities that individuals might participate in at some time during a year. The 31 sets of activities partition the Arsenal regulated/casual visitor population into 31 subpopulations. For example, { Picnicking and Nature Walks} is one such set. The subpopulation corresponding to this set of activities include all people who picnic at least one day per year and participate in nature walks at least one day per year. They may do both activities on the same day as well but do <u>not</u> participate in the other three activities.

The 31 subpopulations defined by possible sets of activities are as follows, NW = Nature Walks, BW = Bird Watching, WBP = Wildlife and Bird Photography, P = Picnicking, and WP = Walking for Pleasure.

#	Set of Activities (Annual Participation)				
1.	P	WP	NW	BW	WBP
2.	P	WP	NW	BW	
3.	P	WP	NW		WBP
4.	P	WP	NW		
5.	P	WP		BW	WBP
6.	P	WP		BW	
7.	P	WP			WBP
8.	P	WP			
9.	P		NW	BW	WBP
10.	P		NW	BW	
11.	P		NW		WBP
12.	P		NW		
13.	P			BW	WBP
14.	P			BW	
15.	P				WBP
16.	P				
17.		WP	NW	BW	WBP
18.		WP	NW	BW	
19.		WP	NW		WBP
20.		WP	NW		
21.		WP		BW	WBP
22.		WP		BW	

23.	WP			WBP
24.	WP			
25.		NW	BW	WBP
26.		NW	BW	
27.		NW		WBP
28.		NW		
29.			BW	WBP
30.			BW	
31.				WBP

Because a regulated or casual visitor to the Arsenal participates in at least one activity, the set including no activities was not included.

The relative sizes or probabilities of the 31 subpopulations corresponding to the 31 sets of activities were determined from the following data on the participation rates in the five representative activities.

Activity	Percent of Population Participating
Picnicking	35% [a]
Walking for Pleasure	43% [a]
Nature Walks	9% [a]
Bird Watching	4% [a]
Wildlife and Bird Photography	2.9% [b]

[a] The proportion of the population who participate in the activities in population areas with more than one million people (National Park Service, 1986).

[b] National value given in Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20.

The proportion of Arsenal visitors in each of the 31 possible subpopulations was computed from the data on the "percent of population participating" in each activity. This proportion is equivalent to: The probability that an individual is in a particular subpopulation given that the individual participates in at least one of the five representative activities. Symbolically this can be written as P(A|B), where A is the event that the individual is in subpopulation A and B is the event that the individual participates in at least one of the five representative activities. Here, the event B is a surrogate for the event that a person is a regulated/casual visitor to the Arsenal, in that such a visitor is assumed to be participating in at least one regulated/casual activity and any such activity is being represented as if its TM, DW, or TE was the same as that for one of the five representative regulated/casual activities.

The definition of conditional probability states that

$$P(A|B) = P(\text{Both A and B}) / P(B).$$

For example, if event A is the event in which an individual participates annually in picnicking and nature walks but not walking for pleasure, bird watching, or wildlife and bird photography (subpopulation #12 in Step 2), then

$$P(\text{both A and B}) = P(P) * P(NW) * P(\text{not WP}) * P(\text{not BW}) * P(\text{not WBP})$$

$$= 0.35 * 0.09 * (1 - 0.43) * (1 - 0.04) * (1 - 0.029)$$

$$= 0.0167$$

and

$$P(B) = P(\text{person participates in at least 1 of the 5 representative activities})$$

$$= 1 - P(\text{person participates in none of the 5 representative activities})$$

$$= 1 - [\, P(\text{not P}) * P(\text{not NW}) * P(\text{not WP}) * P(\text{not BW}) * P(\text{not WBP}) \,]$$

$$= 1 - [\, (1 - 0.35) * (1 - 0.43) * (1 - 0.09) * (1 - 0.04) * (1 - 0.029)]$$

$$= 0.6857.$$

Therefore, the proportion of the regulated/casual visitor population in subpopulation #12 is

$$P(A|B) = P(\text{Both A and B}) / P(B).$$

$$= 0.0167/0.6857 = 0.0244.$$

This latter division by P(B) causes the 31 probabilities to reflect the assumption that the regulated or casual visitor participates in at least one activity. The probability of both A and B is the proportion of the general population which visit the Arsenal and have the set of visitor activities described for subpopulation A. The probability of P(A|B) is the proportion of Arsenal visitors who are in subpopulation A. Logically, P(A|B) is always larger than P(A and B).

The following 31 subpopulation proportions or probabilities sum to 1.0:

#	Set of Activities					Subpopulation Probability
1.	P	WP	NW	BW	WBP	0.0000229
2.	P	WP	NW	BW		0.0007672
3.	P	WP	NW		WBP	0.0005499
4.	P	WP	NW			0.0184129
5.	P	WP		BW	WBP	0.0002317
6.	P	WP		BW		0.0077573

7.	P	WP			WBP	0.0055604
8.	P	WP				0.1861757
9.	P		NW	BW	WBP	0.0000304
10.	P		NW	BW		0.0010170
11.	P		NW		WBP	0.0007290
12.	P		NW			0.0244079
13.	P			BW	WBP	0.0003071
14.	P			BW		0.0102830
15.	P				WBP	0.0073707
16.	P					0.0246790
17.		WP	NW	BW	WBP	0.0000426
18.		WP	NW	BW		0.0014248
19.		WP	NW		WBP	0.0010213
20.		WP	NW			0.0341955
21.		WP		BW	WBP	0.0004303
22.		WP		BW		0.0144065
23.		WP			WBP	0.0103264
24.		WP				0.3457549
25.			NW	BW	WBP	0.0000564
26.			NW	BW		0.0018887
27.			NW		WBP	0.0013538
28.			NW			0.0453289
29.				BW	WBP	0.0005731
30.				BW		0.0190970
31.					WBP	0.0136884

Step 3. **For each possible subpopulation, determine the number of days per year of participation in each possible combination of single and multiple activities.**

For each of the 31 subpopulations, the number of days of participation in different activity combinations was determined. "Activity combination" refers to the combination of activities participated in during a single day. As discussed previously, there are 31 different activity combinations. For example, a person who is a member of subpopulation #12 only participates in picnics and nature walks and therefore has three possible types of activity combinations: days involving only picnicking (type #16), days involving only nature walks (type #28), and days involving both picnicking and nature walks (type #12). Likewise, an individual in subpopulation #1 participates annually in all five activities and can, therefore, participate in any one of the 31 different activity combinations in a given day.

#	Type of Activity Combination (participation on the same day)				
1.	P	WP	NW	BW	WBP
2.	P	WP	NW	BW	
3.	P	WP	NW		WBP
4.	P	WP	NW		
5.	P	WP		BW	WBP
6.	P	WP		BW	
7.	P	WP			WBP
8.	P	WP			
9.	P		NW	BW	WBP
10.	P		NW	BW	
11.	P		NW		WBP
12.	P		NW		
13.	P			BW	WBP
14.	P			BW	
15.	P				WBP
16.	P				
17.		WP	NW	BW	WBP
18.		WP	NW	BW	
19.		WP	NW		WBP
20.		WP	NW		
21.		WP		BW	WBP
22.		WP		BW	
23.		WP			WBP
24.		WP			
25.			NW	BW	WBP
26.			NW	BW	
27.			NW		WBP
28.			NW		
29.				BW	WBP
30.				BW	
31.					WBP

The 31 types of activity combinations appear to be the same as the 31 different subpopulations (the notation is identical). However, the meaning is different. For the 31 different subpopulations, the notation refers to the activities an individual participates in at some time during the year (not necessarily in the same day). On the other hand, the 31 different types of activity days refer to the activities an individual participates in on the same day.

Because explicit data are not available on the frequency of participation in two or more activities in a given day, the incorporation of such combinations involves some uncertainty. The

derivation below is data based and statistically appropriate given the assumptions made. All assumptions required for this method are clearly stated.

The number of days of participation in each activity combination is dependent on the average annual number of days of participation in the following five single representative activities:

Activity	Average Annual Days for a Participant
Picnicking	6.6[a]
Walking for Pleasure	37.0[a]
Nature Walks	13.8[b]
Bird Watching	47.4[c]
Wildlife and Bird Photography	8.2[a]

[a] National values given in Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20.
[b] In Colorado, the number of days/year for Day Hiking is 13.8 (National Sporting Goods Association, 1989). Nationally, the average number of days/year for nature walks is 12.3 (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).
[c] In the Western United States, the number of days/year for Bird Watching/Nature is 47.4 (Table 9, National Park Survey, 1986).

The dependency between the above data and the number of days per activity combination is illustrated with an example. In subpopulation #12, an individual participates in picnics and nature walks. The average number of days involving picnicking is 6.6, and the average number of days involving nature walks is 13.8. These averages are rounded to 7 and 14, respectively. Obviously the number of days of participation in both activities on the same day cannot exceed 7. Probability theory is used to estimate the number of days involving only picnicking (type #16 activity days), the number of days involving only nature walks (type #28 activity days), and the number of days involving both picnicking and nature walks (type #12 activity days). All other types of activity days are impossible in this subpopulation and have zero relative frequency.

In applying probability theory to the estimation of the number of days of participation per activity combination, the assumption was made that the probability that an individual participates in a given activity on a given day is independent of the probability that they participate in any other activity. If visits to the Arsenal occurred completely randomly among the 365 days of a year (no seasons or parts of the week were preferred over others), then the probability of participating in activity A on a given day would be equal to the number of repeat visits for activity A divided by the total number of days in the year, e.g., 7 days of picnicking / 365. However, all days of the year are not equally preferable.

Walsh (1986, page 78) indicates that, for most activities, approximately 70% of the participation is on weekends. Additionally, winter months were assumed to be less preferable than summer months. If the selection of visits is restricted to a reduced number of days, the probability of

multiple activities on the same day increases, resulting in an conservative increase in the TM distribution. Therefore, for the purpose of estimating the number of days per activity combination, it was assumed that an individual must choose his or her visits from among the 52 weekend days occurring in a 6 month period. Note that one activity (bird watching) averages 47 days per year; therefore, the number of possible days cannot generally be reduced much below 52.

The effect of restricting the number of potential user days to 52 increases the probability of multiple activities on the same day and increases the protection afforded by the TM distribution. For example, restricting the choices of days for the 7 picnics and the 14 nature walks to only 52 weekend days increases the probability of participation in both activities on the same day. Therefore, TM (hours/day) is increased and the procedure is increasingly protective.

Monte Carlo simulation was used to determine the number of days spent in each activity combination for each subpopulation. For example, for subpopulation #12, 7 different picnic days were drawn at random (without replacement) from among 52 candidate days and 14 different nature walk days were drawn at random (without replacement) from among these same 52 candidate days. If a particular day appeared in both draws, then this day was associated with both activities. The number of days of activity combination #12, #16, and #28 were then counted to produce one sample of a visitation pattern (a triple). For example, such a process may result in a triple of {1, 6, 13}, i.e., 6 days spent picnicking, 13 days spent nature walking and 1 day spent both picnicking and nature walking.

The process results in a vector of 31 values, all of which are zero except for the triple corresponding to positions 12, 16, and 28, of the vector. This process was repeated 1000 times, each time representing the visitation pattern of an individual from subpopulation #12. The expected visitation pattern for subpopulation #12 is required in Step 4. It was obtained from the 1000 samples of visitation pattern by summing the 1000 values for each activity combination to produce one triple and then dividing by 1000. An analogous Monte Carlo simulation was performed for each of the 31 subpopulations to estimate the expected visitation pattern, i.e., expected numbers of days spent in each of the 31 possible activity combinations.

Step 4. **For the entire visitor population, determine the relative frequencies of the different combinations of activities on a given day by utilizing the information from Steps 2 and 3.**

In Step 3, the expected number of days spent in each activity combination was simulated for each of the 31 subpopulations. The relative frequency of a type of activity combination for the entire population was then calculated as illustrated in the following example for activity combination #12. First, the expected number of days for activity combination #12 was estimated by multiplying the number of days for combination #12 expected for subpopulation #1 (determined in Step 3) by the relative size (frequency) of subpopulation #1 (determined in Step 2), repeating this step for all subpopulations, and then summing the resulting values over the 31

subpopulations. The mathematics of multiplying each subpopulation estimate of the number of days for activity combination #12 by the frequency of that subpopulation, and then summing over subpopulations, is referred to statistically as taking the expected value over subpopulations.

The expected number of days for the other 30 activity combinations was estimated analogously. For each activity combination, the expected value was taken over all 31 subpopulations. The resulting vector of 31 expected values was interpreted as follows. Each position, 1 through 31, represents the expected value of the number of days of participation in the corresponding activity combination.

Following estimation of the expected number of days spent in each of the 31 activity combinations, the relative frequency of these activity combinations was defined as the number of days spent in each combination divided by the total number of days spent in any activity combination. The resulting frequencies were, equivalently, the probabilities that an individual who visits the Arsenal under the regulated/casual scenario will participate in each of the activity combinations.

The resulting frequencies associated with each of the 31 activity combinations are given below. Approximately 9.2% of the simulated activity days involved multiple activities. Days involving 2, 3, 4, and 5 activities were 8.86%, 0.33%, 0.005%, and 0.00002% respectively.

#	Type of Activity Combination (participation on the same day)					Probability
1.	P	WP	NW	BW	WBP	0.0000002
2.	P	WP	NW	BW		0.0000314
3.	P	WP	NW		WBP	0.0000054
4.	P	WP	NW			0.0008645
5.	P	WP		BW	WBP	0.0000063
6.	P	WP		BW		0.0012800
7.	P	WP			WBP	0.0001721
8.	P	WP				0.0337175
9.	P		NW	BW	WBP	0.0000003
10.	P		NW	BW		0.0000784
11.	P		NW		WBP	0.0000087
12.	P		NW			0.0019178
13.	P			BW	WBP	0.0000129
14.	P			BW		0.0030375
15.	P				WBP	0.0003963
16.	P					0.0819610
17.		WP	NW	BW	WBP	0.0000029
18.		WP	NW	BW		0.0006726
19.		WP	NW		WBP	0.0000801
20.		WP	NW			0.0175824

21.	WP		BW	WBP	0.0001228
22.	WP		BW		0.0268551
23.	WP			WBP	0.0031931
24.	WP				0.7173450
25.		NW	BW	WBP	0.0000063
26.		NW	BW		0.0014967
27.		NW		WBP	0.0001783
28.		NW			0.0405834
29.			BW	WBP	0.0002737
30.			BW		0.0608828
31.				WBP	0.0072345

Step 5. **Determine the probability distribution of the sum of all activity durations occurring on the same day by combining the information from Steps 1 and 4.**

Step 1 provides the probability distributions for the durations of each of the five representative regulated/casual visitor activities. Step 4 provides the probabilities that a visitor will participate in a particular combination of activities on a given day. If a visitor participates in more than one activity, the duration of the visit is equal to the sum of the durations of each activity. The results from these two steps were then combined in a Monte Carlo simulation to estimate the probability distribution of TM (hours/day), where TM is the sum of all regulated/casual visitor activities on an activity day. The duration of each activity was assumed to be independent of the duration of other activities. For example, a long nature walk has the same likelihood of being associated with a long picnic as does a short nature walk.

In the simulation, a particular activity combination was drawn from the 31 choices using the probabilities derived in Step 4. That is, approximately 0.082 (8.2%) of the time combination #16 was drawn (picnicking) and .0019 (0.19%) of the time combination #12 (picnicking and nature walking) was drawn. Next, a duration was drawn from the duration distributions of each of the individual activities involved in the chosen combination, and these durations are summed.

The frequency distribution of these sums is the simulated probability distribution for TM (hours/day).

Throughout this entire document several simulated or observed distributions are reported. The percentiles of these distributions are reported; so that, the reader is provided with the most reasonably complete description of these data. Depending upon the computational tools available to the user of such data, the probability distribution used to characterize these percentiles can be quite varied. The user with sufficient computational flexibility could use highly data-specific approximating distributions such as piecewise linear approximations to the cumulative distribution functions corresponding exactly to the reported percentiles. The user who desires to use a simpler smooth distribution such as the normal and lognormal distributions or other classical statistical distributions can also do so. This latter approach does simplify data reporting

and some computer implementations. Both types of users are accommodated in this report. The user who wants to use the most data-specific distributions can use the reported percentiles themselves. The user who wants to use only smoothed distributions can use the best fitting normal or lognormal distribution which provide quite reasonable approximations to the data herein. Graphical indications of the fit of the best fitting normal or lognormal distribution are given in the figures in Section 7. These figures are numbered according to the section to which they refer.

The percentiles of the simulated probability distribution for TM are listed below. Both normal and lognormal distributions were fit to these percentiles. The statistical fitting criterion was weighted least squares where the weights were proportional to the size of the population of activity durations involved, namely:

Percentage	WEIGHT: Incremental Proportion of Population of Durations
1	1
2.5	1.5
5	2.5
7.5	2.5
10	2.5
20	10
25	5
30	10
40	10
50	10
60	10
70	10
75	5
80	10
90	10
92.5	2.5
95	2.5
97.5	2.5
99	1.5

Here, for example, the weight on the fit at the 25th percentile is proportional to the incremental 15% of the activity durations between the 25th percentile and the previous percentile (the 10th percentile). The use of these weights insures that the fitted distribution fits most closely to the percentile increments where the largest proportions of values reside. Except where noted, all distribution fits for the TDVs were based on the weighted least squares criterion with weights proportional to the incremental percentage of activity durations in the data. Specifically, the weighted least squares procedures, minimizes the sum over all reported percentiles of

Weight for Percentile * [(Reported Percentile) - (Fitted Percentile)]^2.

The weights depend on the grid of reported percentiles. Where the percentiles were simulated by the authors, the same, reasonably comprehensive grid of percentiles was used throughout this document.

The best fit between the normal and lognormal distribution is used in the current implementation of the PPLV methodology to describe a smooth probability distribution for TM (hours/day). The best fitting probability distribution for TM is the lognormal distribution in which TM has mean 2.19 and standard deviation 1.85. Correspondingly, the ln(TM) has mean 0.5156 and standard deviation 0.7333. This probability distribution is described in Section 3.1.2.

The fit of the distribution to the simulated data is as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	9.28	9.22
97.5	7.00	7.05
95	5.60	5.59
92.5	4.82	4.81
90	4.28	4.29
80	3.12	3.10
75	2.76	2.75
70	2.47	2.46
60	2.02	2.02
50	1.67	1.67
40	1.39	1.39
30	1.14	1.14
25	1.02	1.02
20	0.91	0.90
10	0.66	0.65
7.5	0.59	0.58
5	0.52	0.50
2.5	0.41	0.40
1	0.32	0.30

A graphical indication of the fit is shown in Figure 3.1.3.

3.2 DW - DAYS PER YEAR: Regulated/Casual Visitors

3.2.1 DW - Rationale for Probability Distribution

It is assumed that residents of areas adjacent to or within walking distance of the Arsenal (the "neighborhood subpopulation") visit the Arsenal for regulated/casual activities at a higher frequency than the regional subpopulation. Therefore, two separate visitor subpopulations, herein referred to as the neighborhood visitor subpopulation and the regional visitor subpopulation, have been defined. As explained in Section 3.0, DW distributions have been developed for each visitor subpopulation, as well as for the combined or whole regulated/casual visitor population. These visitor subpopulations are assumed to participate in the same types, durations and multiplicity of activities, but with a higher frequency for the neighborhood participant than for the regional participant.

The introduction of two subpopulations having different frequencies allows a more detailed, defensible and rigorous analysis of exposures to the population as a whole and to the defined subpopulations.

3.2.1.1 Definition of Population and Subpopulations

The regional population was defined in the Final Human Health Exposure Assessment to be the residents within the six-county Metro area in 1990. Based on the U.S. Census Bureau data, the population in 1990 of this six-county area was 1,848,319 (Sue Piatt, DRCOG, 7-1-91). The exposure parameter probability distributions refer to the events occurring during the 70 year expected life spans of 1,848,319 people. This population of 1,848,319 people is the population upon which the probability distributions for the time dependent exposure parameters are focused.

The 1,848,319 people are assumed to be identical to the current Denver Metro area residents, with the exception that these 1,848,319 people are assumed to live for the next 70 years. For example, these 1,848,319 people are assumed to begin their 70 year life spans living in the same locations as the current Metro area residents do.

A combined visitor population and a number of subpopulations are defined in terms of the 70 year expected life spans of 1,848,319 people. By considering 70 year lifetimes for each individual rather than a population at a particular point in time, the exposure parameter characterization is more appropriate for lifetime human health assessment. The definition of neighborhood and the derivation of specific estimated numbers are discussed after this summary.

1. Neighborhood Subpopulation. This is the estimated portion of the 1,848,319 people who at some time in their life spans live in the neighborhood. These estimated 14,875 people include 6,291 people who begin their 70 year life spans living in the neighborhood plus an estimated 8,584 people who move into the neighborhood at some time after they move out of their initial residence. (Sections 3.2.1.3 and 3.2.1.4).

2. Neighborhood Visitor Subpopulation. This is the estimated 8,315 people in the neighborhood population who actually visit the Arsenal at some time during their 70 year life spans. (Section 3.2.1.5).

3. Regional Visitor Subpopulation. This is the estimated 118,624 people who are not part of the neighborhood subpopulation but do visit the Arsenal at some time during their 70 year life spans. (Section 3.2.1.2).

4. Population of All Regulated/Casual Visitors to the Arsenal. This is the combined population of neighborhood and regional visitors. There are 126,939 visitors in the combined visitor population (126,939 = 8,315 + 118,624).

Within the six-county Metro Denver population are people who do not visit Arsenal at any time during their 70 year life spans. These people do not belong to either the neighborhood visitor subpopulation or the regional visitor subpopulation. The probability distributions of the exposure parameters refer to Arsenal visitors and do not refer to or include non-visitors, as outlined below.

The visitor subpopulations refer to people who visit the Arsenal at any time during their 70 year life spans. Hence, the sizes of these subpopulations must reflect not just an individual's initial residence location and interest in the Arsenal but also that individual's subsequent residence locations and interests in the Arsenal following any moves that occur during the 70 year life span. The derivations of the visitor subpopulation sizes sequentially consider an individual's initial residence location and Arsenal interest, then the next residence location and the individual's interest in the Arsenal while residing at that location, then the next residence location and the individual's interest in the Arsenal while residing at that location, and so forth. The sequence continues until either the total duration at all residences exceeds 70 years or the individual moves out of the area (that is, out of Colorado in the context of the regional visitor subpopulation and out of the neighborhood in the context of the neighborhood visitor subpopulation).

3.2.1.2 Derivation of the Number of Regulated/Casual Visitors in the Regional Visitor Population

The probability that a particular individual among the 1,848,319 people in the regional population would be a member of the regional visitor subpopulation depends on that individual's 70 year history of residence locations and the probability that an individual would be an Arsenal visitor while living at a location. Individual 70 year histories were simulated; i.e., at each residence location two quantities were simulated; namely, (1) the duration of that residence from the individual residence duration distribution (Section 3.3.3) and (2) whether or not the individual would be a regulated/casual visitor to the Arsenal while at that location. At the end of that residence period, a move was simulated and the process repeated. The simulation stopped when either the cumulative duration at all residences exceeded 70 years or the move was out of State.

The results of the simulations are discussed first, and then the data base for the probabilities used in the simulations are discussed. In 10,000 simulations, 93.53% of the 70 year histories never included a residence duration for which the individual was an Arsenal visitor. In the simulations, 6.15% individuals had one residence duration in which they were Arsenal visitors, and 0.32% had two such residence durations. Thus, the percentage of the population that would be in the regional visitor population would be 6.47% (6.15%+0.32% = 6.47%). Because the estimated number of people in the neighborhood population is 14,875 (Section 3.2.1.4), the number of people in the regional visitor population is

$$118{,}624 = 6.47\% * (1{,}848{,}319 - 14{,}875).$$

Of the 118,624 people comprising the regional visitor subpopulation, 95.05% (6.15/6.47=0.9505) have only one residence duration in which they are Arsenal visitors. Similarly, 4.95% (0.32/6.47=0.0495) have two residence durations in which they are Arsenal visitors.

Within the six-county Metro Denver population, there are 14,875 members of the neighborhood population; 8,315 are expected to visit the Arsenal, and 6,560 are not expected to visit the Arsenal (14,875 - 8,315 = 6,560). There are also 1,833,444 members of the regional population (excluding the neighborhood population) (1,848,319 - 14,875 = 1,833,444); 118,624 are expected to visit the Arsenal, and 1,714,820 are <u>not</u> expected to visit the Arsenal [93.53% * (1,848,319 - 14,875) = 1,714,820].

In the simulation, the probability that, when a move occurs, it is a move out of Colorado is based on the data provided in Table 5-D, page 5-69 of the Exposure Factors Handbook. There, it is indicated that the mobility of the residential population in Colorado was among the highest in the nation. These data, from a 1984 U.S. Census Bureau Statistical Abstract, also indicate that in Colorado in 1980

39.8% were in the same house that they were in 1975,

22.7% were in a different house in the same county,

14.8% were in a different county in Colorado, and

20.6% were in a different state.

Only the last three of these probabilities refer to where a person moves, and, hence, only these three probabilities are used in the mathematical development. When a move occurs, the probability that it is a move out of Colorado is estimated to be 0.3546 [20.6/(22.7+14.8+20.6)=0.3546]. Because this estimate is a ratio and hence unaffected by rescaling, it is not necessary to rescale the components even though the reported percentages do not sum to 100% (39.8%+22.7%+14.8%+20.6% = 97.9%). Also, although these data refer to a particular five year period, the data are only used to indicate the relative probabilities of the

location of the new residence when a person moves. That is, the fact that the moves may have occurred over a five year period is immaterial; what is important is that, when moves occurred, approximately 35% were moves out of Colorado.

In the simulation, the probability that an individual would be *interested* in the Arsenal (that is, visit the Arsenal) while living at a particular non-neighborhood location can be estimated by considering the fraction of the current 1,848,319 Metro area residents who would be expected to visit the Arsenal if it were fully developed and open today. Only non-neighborhood locations are considered because people who have any of their residence locations in the neighborhood are part of the neighborhood population and not part of the regional visitor population. The fraction of the current Metro area residents who would be expected to visit the Arsenal can be estimated by

(1) estimating the total number of regulated/casual activity days at the Arsenal,

(2) using Barr Lake repeat visitation data to estimate the number of visitors corresponding to that estimated number of visitation days (Section 3.2.1.7), and

(3) dividing by that number of Arsenal visitors by the total number of people currently living in the Metro area, 1,848,319.

Step (1) is as follows:

Activity	Fraction of 1,848,319 People Who Participate[a]	Number of Participants (Fraction * 1,848,319)	Average # of Days per Year	Total # of Days per Year	Total Capture Rate for the Six Non-Reservoir Denver Metro Area Parks[e]	RMA Capture Rate[f]	RMA Regulated or Casual Visitor Days[g]
Picnicking	0.35[b]*0.815	527,233	6.6[c]	3,479,738	0.0279	1/7	13,869
Walking for Pleasure	0.43[b]*0.815	647,743	37.0[c]	23,966,491	0.0279	1/7	95,524
Nature Walks	0.09[b]*0.815	135,574	13.8[d]	1,870,921	0.0279	1/7	7,457
Bird Watching	0.04[b]*0.815	60,255	47.4[c]	2,856,087	0.0279	1/7	11,384
Wildlife & Bird Photography	0.029[c]*0.815	43,685	8.2[c]	358,217	0.0279	1/7	1,428
Total		1,414,490		32,531,454			129,662

[a] 0.815 is the estimated fraction of the total population that is non-institutionalized and 12 years old or older. National Park Service, 1986

[b] The proportion of the population who participate in the activities in population areas with more than one million people, National Park Service, 1986.

[c] National average (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).

[d] Participation in Selected Sports, Colorado, day hiking (National Sporting Goods Association, 1988, in THK, 1990).

[e] 0.0279 is the total 1989 attendance (908,208) at the six non-reservoir Denver Metropolitan Area Parks (Colorado Department of Parks and Outdoor Recreation, 1990) divided by 32,531,454.

[f] 1/7 assumes that the potential draw of the developed Arsenal will be equal to that of any of the existing six non-reservoir Denver Metro Area Parks.

[g] The total number of regulated/casual visitor days at the Arsenal is the product of the number of participants, average number of days per year, the non-reservoir Denver Metro Area Parks capture rate, and the RMA capture rate; e.g., 527,233*6.6*0.0279*1/7 = 13,869.

Thus, there are estimated to be 129,662 visitation days from regional regulated or casual visitors. To accomplish step (2), the Barr Lake repeat visitation frequency data are assumed to be predictive of Arsenal repeat visitation for regulated or casual visitors in the regional subpopulation, as discussed in Section 3.2.2.2. These frequencies are 2.3 days/year for a Daily Fee visitor, 4.6 days/year for a Annual Pass visitor, and 6.4 days/year for an Aspen Leaf Pass holder. The relative percentages of visitors who enter using Daily Fees, Annual Passes, and Aspen Leaf Passes are 81%, 13%, and 6%, respectively. Hence, if the regional visitors are expected to make 129,662 visits/year and

(# of Regional Visitors) * 2.3 days/year * 0.81 +
(# of Regional Visitors) * 4.6 days/year * 0.13 +
(# of Regional Visitors) * 6.4 days/year * 0.06 = 129,662 visitation days,

then it follows that the yearly number of regional visitors is 45,575. Finally, step (3) implies that the estimated probability that an individual would be *interested* in the Arsenal while living at a particular non-neighborhood location is 45,575/1,848,319 which equals 0.02466.

3.2.1.3 Definition of Neighborhood

The neighborhood is considered to be the area defined by an extension of the Arsenal perimeter 1/4 mile in all directions. This area falls within the National Parks Service definition of neighborhood parks and recreation areas (National Parks Service, 1986) and within the NRPA standards for the service area characteristics cited in the Commerce City Comprehensive Plan. In addition, all persons, after entering the Arsenal, will have to walk or bike for some additional distance, extending the effective travel time for the neighborhood subpopulation.

The number of residences in the neighborhood was determined by a house count of all residences or possible residences from a current aerial photograph. A housing unit population of approximately 3.1 persons/unit, based on 1990 U.S. Census data, was assumed. The estimated 1991 number of residents living within 1/4 mile of all Arsenal perimeters is 6,291 persons (THK, 1992). This number will be augmented by persons who may move into the neighborhood from outside of the neighborhood during their 70 year life spans, bringing the estimated total number of people in the neighborhood subpopulation to 14,875 as explained in Section 3.2.1.4.

Of course, the neighborhood subpopulation is within the six-county Metro area and is included in the 1,848,319 people defined as the population of interest in the Final Human Health Exposure Assessment.

3.2.1.4 Derivation of Neighborhood Subpopulation Size

Among the 1,848,319 people in the regional population, an estimated 6,291 have their initial residence in the neighborhood and hence are part of the neighborhood subpopulation. The remaining part of the neighborhood subpopulation is comprised of the estimated 8,584 individuals among the 1,842,028 (1,848,319 - 6,291 = 1,842,028) people who do not initially

live in the neighborhood but move into the neighborhood at some time later in their 70 year life span. Thus, the neighborhood subpopulation contains 14,875 individuals (6,291 + 8,584 = 14,875).

The number of individuals who do not initially live in the neighborhood but subsequently move into it, is estimated to be 8,584 by simulating a 70 year life span 100,000 times, determining the proportion (0.00466) of these life spans involving a move into the neighborhood, and then multiplying this proportion by 1,842,028 (0.00466 * 1,842,028 = 8,584). In the simulation, a 70-year sequence of residence locations was simulated (starting with an initial residence outside of the neighborhood). At each simulated residence location, the duration of that residence was simulated from the individual residence duration distribution (Section 3.3.3) and then at the end of that residence period a move was simulated. This process was repeated until either the cumulative duration at all residences exceeded 70 years, the move was out of State, or the move was into the neighborhood.

In the simulation of residence locations over a 70-year life span, the probability of a move out of Colorado was based on the data in the EPA Exposure Factors Handbook. There, in 1980

39.8% were in the same house that they were in 1975,

22.7% were in a different house in the same county,

14.8% were in a different county in Colorado, and

20.6% were in a different state.

Thus, the probability of a move out of Colorado was estimated to be 0.3546 [20.6%/(22.7%+14.8%+20.6) = 0.3546], the same as it was in the derivation of the regional visitor subpopulation. The probabilities of the other possible moves were based on the estimated probability of an intracounty move [22.7%/(22.7%+14.8%+20.6)], the estimated probability of a move out of the county but within the state [14.8%/(22.7%+14.8%+20.6)], and the relative sizes of the populations in the neighborhood, county, and region where the "combined county" was the combination of Adams and Denver counties which surround the Arsenal. The 1990 U.S. Bureau of Census population data are 265,038 for Adams county, 467,610 for Denver county, 732,648 for the "combined county" (265,038 + 467,610 = 732,648), and 1,848,319 for the region. As previously defined, the population living in the neighborhood in 1991 was estimated at 6,291 (THK, 1992). The probability that, when a person (in the region but not in the neighborhood) moves, the person moves into a residence in the neighborhood, involves the following probabilities:

1. The probability that a person moves from outside the "county" but within Metro Denver to the neighborhood is approximated by the probability that, a Metro Denver person moves from his or her county to some other county in the Metro Denver region times

the probability that the new residence is one of those in the neighborhood which is approximately equal to

[14.8/(22.7 + 14.8 + 20.6)] * [6,291/1,848,319] = 0.00087.

2. The probability that a person moves from within the "county" to the neighborhood is equal to the probability of an intracounty move times the probability that the new residence is one of those in the neighborhood which is approximately equal to:

[22.7/(22.7 + 14.8 + 20.6)] * [6,291/732,648] = 0.0034.

The conservative assumption has been made that a person in the region never moves outside of the region unless he or she moves out of Colorado. The probability that a particular person outside of the Metro Denver region moves into the neighborhood is extremely small, and is ignored herein.

3.2.1.5 Derivation of the Number of Regulated/Casual Visitors in the Neighborhood Visitor Population

The neighborhood subpopulation size (14,875) includes both the residents who do and do not participate in regulated or casual visitor activities at the Arsenal. The number of Arsenal visitors in this subpopulation is the number of neighborhood residents who participate in regulated or casual visitor activities at the Arsenal. This neighborhood visitor subpopulation and the corresponding regional visitor subpopulation are the subpopulations to which the DW (days/year) and TE (years/lifetime) distributions apply.

The number of people in the neighborhood visitor subpopulation depends on the number of people who live in the neighborhood at some point in their lifetime as well as the fraction of those people who participate in regulated or casual visitor activities. The fraction participating refers to the fraction participating among U.S. non-institutionalized population 12 years old and older, and was estimated in Step 1, Section 3.2.1.2.

The National Park Service (1986) estimated that there were 188 million people in the U.S. non-institutionalized population 12 years old and older in 1982-3. The total U.S. population in 1982-83 was estimated to be 231 million people based on a geometric interpolation between the 1980 and 1990 U.S. population sizes:

$$226{,}542{,}203 * (248{,}709{,}873 / 226{,}542{,}203)^{2/10} = 230{,}811{,}740.$$

Thus, the fraction of the entire U.S. population that is non-institutionalized and 12 years old or older has been estimated to be 0.815 (188 million / 231 million = 0.815 or 81.5%). This 81.5% is used herein to describe the percentage of a population who are potential participants in activities at the Arsenal.

The probability that a person participates in at least one activity is equal to

= 1 - Probability a person participates in no such activities

= 1 - (1-0.35)*(1-0.43)*(1-0.09)*(1-0.04)*(1-0.029) = 1 - 0.314 = 0.686

Thus, 69% of potential participant population would participate in at least one regulated or casual visitor activity, i.e., 69% of 81.5% of total population which is approximately, 56% of the total population (0.686 * 0.815 = 0.559). All of the people in this 56% of the neighborhood population are assumed to spend at least some of their regulated/casual activity participation time at the Arsenal. Thus, the number of people in the neighborhood visitor subpopulation is

0.559 * 14,875 = 8,315.

3.2.1.6 DW(neighborhood subpopulation)

The probability distribution for the frequency DW (days/year) of a regulated or casual visit to the Arsenal by a person in the neighborhood visitor subpopulation was determined by combining the probability distributions for the frequencies of individual types of activities (picnicking, walking for pleasure, nature walks, bird watching, and wildlife and bird photography). The possibility of multiple activities on the same day was also incorporated. Additional consideration was also given to the likelihood that an individual who spends some of his or her regulated/casual activity days at the Arsenal is not likely to spend all of his or her activity days at the Arsenal.

Basically, the determination of the DW (days/year) distribution parallels that used to derive the TM (hours/day) distribution. This parallel development is particularly appropriate because, whenever TM appears in the PPLV equations, it is multiplied by DW; hence, the development of the TM and DW distributions should be parallel. In simple terms, the assumptions about multiple activities that are made in the context of DW are the same as are made in the context of TM in Section 3.1.

An assumption that any given individual's participation would always take place at the Arsenal, and would never take place anywhere else, is considered highly improbable. The proximity of the Arsenal enhances the probability that a member of the neighborhood subpopulation would spend at least 10% of his or her activity days at the Arsenal. On the other hand, the large number of attractive alternative facilities for regulated/casual activities in the region makes it possible that less than 50% of an individual's activity days would be spent at the Arsenal. It is possible, although not probable, that a visitor may spend every one of his or her activity days at the Arsenal. Therefore, the fraction of activity days that would take place at the Arsenal was assumed to always follow a triangular distribution with minimum 0.1 (10%), mode 0.40 (40%), mean 0.50 (50%) and maximum, 1.0 (100%), based solely on professional judgment. This

distribution makes the conservative assumption that all members of the neighborhood subpopulation would spend at least 10% of his or her activity days at the Arsenal.

3.2.1.7 DW(regional subpopulation)

The frequency of visitation by the regional subpopulation would be expected to be less than that of the adjacent neighborhood subpopulation. National data on repeat visitation is not available, nor would such national data, if available, be expected to be more relevant than local data having geographic, climatic, or user preference significance as discussed below for the regional subpopulation.

Data on repeat visitation to Colorado state parks or recreational facilities were given in the THK 1990 report, and augmented by a more recent study (THK 1991). These reports examined Colorado visitor preferences, repeat visitation patterns, and the relationship of park amenities to those preferences and patterns. These studies provide data on visitation at eight outdoor parks or recreational facilities located in the Denver Metropolitan region: Chatfield Reservoir, Cherry Creek Reservoir, Roxborough Park, Castlewood Canyon Park, Golden Gate Park, Eldorado Canyon, Plains Conservation Center, and Barr Lake. As discussed below, Barr Lake was considered to provide an upper bound prediction of repeat visitation for the regional subpopulation at the Arsenal.

The use of area-specific recreational facilities to predict visitation patterns of the regional subpopulation at the Arsenal provides geographic and climatic relevance which cannot be determined through use of national data. The Denver metropolitan area facilities would be expected to have activity types and frequencies of visitation reflective of the area population. To assess the potential of these facilities to predict visitation patterns of the regional subpopulation at the Arsenal, the facilities were reviewed for their size, physical attributes, amenities, total number of visitors, and pattern of visitation and for possible correlation among these factors.

One important source document is a survey compiled by the Colorado Division of Parks and Outdoor Recreation (DPOR). It provides comprehensive and current data relevant to the pattern of visitation to Colorado outdoor park facilities. Every five years, DPOR conducts a survey of visitors to Colorado's State Parks and Recreation Areas. The data used in the development of the DW parameter is taken from the most recent of these surveys, *The 1988 Visitors Survey*. This document comments in its summary that "a pattern of increased visitation has been observed over the past several years", and predicts continued increases in (facility) acquisitions and visitation. Therefore, data compiled in previous surveys, i.e., lower visitation rates, were not used to avoid introduction of a non-conservative bias.

The following table, Denver Metropolitan Area Parks, Facility Attributes and Annual Attendance, provides a comparison of 1990 visitation, size, and main attributes for the eight facilities which are listed in order of attendance. Annual visitation in the ten preceding years is presented in the THK report (data for Plains Conservation Center are not available prior to

1986). It is apparent from this table and from the more detailed discussion in THK 1991 that the total number of visits is correlated more closely to main attributes and attractions of a facility than to its size. Figures 3-1, 3-2, and 3-3 in Section 7.0 illustrate this point.

Although park attributes cannot be easily be described on a quantitative scale, the correlation between general numbers of attributes and visitations can be seen in these figures. Figures 3-1, 3-2, and 3-3 illustrate scatter plots between attendance and park size (acreage), attendance and the number of amenities offered, and a three dimensional scatter plot for attendance by park size and number of amenities, respectively.

There is a strong correlation between park attendance and amenities ($r = .92$), and a marginal correlation between park attendance and park size ($r = .61$). The relative effect of both variables on attendance can be seen using a three dimensional plot. It is clear from this plot, that while there is an increase in attendance as the park size increases, the major increase in attendance is due to the number of amenities available. Therefore, main attributes and other amenities provide a basis for identifying which facilities are likely to be most representative of the Arsenal, and hence predictive of visitation.

The range of facilities is broad and includes mountain parks, recreational reservoirs, and rock climbing opportunities. Most of the facilities can be established as having either more attributes or less attributes than a park established at the Arsenal. Of the eight local recreational facilities, Barr Lake was considered to be the most representative of the Arsenal based on a comparison of attributes and amenities as indicated in the following Table and in subsequent discussion.

DENVER METROPOLITAN AREA PARKS FACILITY ATTRIBUTES AND AMENITIES AND ANNUAL ATTENDANCE			
FACILITY	**SIZE OF PARK** (approx. acres)	**ANNUAL ATTENDANCE** (1989-90)	**ATTRIBUTES**
Cherry Creek Reservoir	3900	1,247,174	Motor boating, water skiing, wind surfing and rowing concession, sailing, boat rentals, fishing, marina/mooring, boat ramps, swimming beaches, jet ski beach, picnic shelters, bicycle trails, horseback riding (stables), foot and nature trails, model airplane field, shooting range, overnight camping and RV dump area, showers, outdoor games areas and field dog trails
Chatfield Reservoir	7700	1,228,165	Motor boating, water skiing, wind surfing and rowing concession, sailing, boat rentals, fishing, marina/mooring, boat ramps, swimming beaches, jet ski beach, picnic shelters, bicycle trails, horseback riding (stables), foot and nature trails, model airplane field, shooting range, overnight camping and RV dump area, showers, outdoor games areas, dog trails, balloon launch, scenic overlook and a heron rookery

Golden Gate Park	9200	456,362	Highly scenic mountain park with mixed forest, rocks and open area hiking trails, stream and shoreline fishing, overnight camping, climbing
Eldorado Canyon	845	160,877	Scenic mountain park featuring mountain trails and sheer rock walls offering unique technical climbing opportunities. Very high repeat visitation rate amongst technical climbers. Swimming pool, picnicking
Barr Lake	2500	141,985	Non-motorized boating, sailing, fishing, wildlife sanctuary, bald eagle management area, hiking, picnicking, bicycle trails, horseback riding, waterfowl hunting, and Nature Center
Roxborough	1618	78,870	Scenic rock formations, Visitor' Center, 12+ miles of hiking trails
Castlewood	870	49,022	Historic homestead, hiking trails, scenic overlook, falls on Cherry Creek
Plains Conservation Center	1900	14,017	Wildlife refuge, Interpretive Center, historic homestead, educational tours, wagon rides

BARR LAKE PARK

In order to assess the representativeness of Barr Lake for the prediction of repeat visitation of the regional subpopulation at an Arsenal park, Barr Lake and the Arsenal are compared with respect to (existing or potential) activities related to water, trail, and open space. Barr Lake data were used in obtaining the DW distribution for the regional subpopulation for the recreational land use scenario as well as the regulated/casual land use scenario. Therefore, information on both types of activities is presented below. This information was obtained from the THK reports, as well as from verbal communication with DPOR representatives (Roy Fronczyk, 1991).

Water Activities. Barr Lake Park consists of 2,500 acres of prairie surrounding and inclusive of a constructed water reservoir of 1,940 surface acres. Permitted water activities at Barr Lake include wind surfing, non-motorized boating, motorized boating less than 10 hp, sailing, and fishing from the shoreline or from non-motorized boats. Swimming is not allowed as there are no beaches or lifeguards. The opportunities for water activities at Barr Lake are likely to be more numerous than those at the Arsenal lakes under the recreational scenario. The Arsenal lakes are much smaller than the reservoir; swimming and boating are currently prohibited. Waders for fishing are allowed.

Trail Activities. Trail related activities, such as hiking, biking, jogging and photography, are enhanced by the presence of the reservoir and wildlife refuge at Barr Lake. An unpaved trail suitable for walking or mountain biking extends around the reservoir. The landscape along this trail is natural vegetation, primarily open brush and marsh. However, some shade from trees exists along the south end of the lake. An irrigation canal borders the trail for about half of its length. At the south end of the reservoir, the trail skirts a wildlife sanctuary, the site for a nest of Bald Eagles. Picnic tables and a nature center are located in an area of open space area along the east side of the reservoir. Note that some of the potential Arsenal trails could presumably be built to focus on the wetlands, lakes and eagle sanctuary, and could be expected to draw visitation rates similar to those experienced by Barr Lake.

At the Arsenal, the majority of the grounds are dry land, with the lakes comprising a smaller proportion of the property than at Barr Lake. The Arsenal grounds are primarily dry prairie habitat, with few trees and limited marshlands. Park attendance figures from the preceding table suggest that mountain and near-water trails experience the greatest usage (attendance and repeat visits). Therefore, trail related visitation patterns at Barr Lake are expected to be similar or possibly more frequent than trail related visitation to the Arsenal.

Open Space Activities. The open space area at Barr Lake consists of infrequently cut native grasses. This area supports some sporting activities such as frisbee and informal soccer. There are no playing fields and no concessions except for several soda machines. Under the recreational scenario for the Arsenal, playing fields and concessions may be developed with the result that sports related visitation might be higher than that observed for Barr Lake. This is accounted for in Section 4.0 of this paper by the addition of an expanded recreational population which includes an organized sports scenario for both players and spectators.

Visibility to the Regional Subpopulation. Barr Lake is located immediately adjacent to and can be seen from Interstate Highway 76, a main access route into and out of Denver. Easily recognizable State Park signs are posted along Interstate 76. The Arsenal is located several miles from I-76 and will have less visibility to the regional subpopulation. However, a National Park status may compensate for its more isolated location. Based on visibility alone, Barr Lake appears to be comparable with the Arsenal.

The DPOR 1988 survey found that approximately 81.35% of the Barr Lake visitors use daily fees, 12.76% use an annual pass, and the remaining 5.89% use the Aspen Leaf pass (a senior

citizen's pass). Daily fee users visited Barr Lake an average of 2.3 times in a calendar year, annual pass holders an average of 4.6 times, and Aspen Leaf holders an average of 6.4 times. The data from the DPOR on Barr Lake provide current and area specific information on the number of visits (DW) expected to be made to the Arsenal in a calendar year by the regional regulated/casual visitor subpopulation.

The probability distribution for DW for the regional subpopulation is obtained by combining the probability distributions on the number of visits per year for daily fee users, annual pass users, and Aspen Leaf pass holders. The overall regulated/casual visitor population distribution is derived by combining the weighted neighborhood and regional subpopulations.

3.2.1.8 DW(combined population)

The distribution for the number (DW) of days per year of regulated/casual visitation to the Arsenal for the combined population of neighborhood and regional visitors is obtained by mathematically combining the DW(neighborhood subpopulation) distribution for 8,315 neighborhood visitors with the DW(regional subpopulation) distribution for 118,624 regional visitors.

3.2.2 DW - Probability Distribution

3.2.2.1 DW(neighborhood subpopulation)

The probability distribution for the number (DW) of days per year that a regulated or casual visitor in the neighborhood subpopulation visits the Arsenal is a normal distribution with the following percentiles:

Probability (DW ≤ 36.88 days/year) = 0.99
Probability (DW ≤ 33.35 days/year) = 0.975
Probability (DW ≤ 30.29 days/year) = 0.95
Probability (DW ≤ 28.30 days/year) = 0.925
Probability (DW ≤ 26.78 days/year) = 0.90
Probability (DW ≤ 22.52 days/year) = 0.80
Probability (DW ≤ 20.91 days/year) = 0.75
Probability (DW ≤ 19.46 days/year) = 0.70
Probability (DW ≤ 16.84 days/year) = 0.60
Probability (DW ≤ 14.39 days/year) = 0.50
Probability (DW ≤ 11.94 days/year) = 0.40
Probability (DW ≤ 9.32 days/year) = 0.30
Probability (DW ≤ 7.87 days/year) = 0.25
Probability (DW ≤ 6.25 days/year) = 0.20
Probability (DW ≤ 2.00 days/year) = 0.10
Probability (DW ≤ 0.47 days/year) = 0.075

Probability (DW ≤ 0.00 days/year) = 0.05
Probability (DW ≤ 0.00 days/year) = 0.025
Probability (DW ≤ 0.00 days/year) = 0.01

This normal distribution for DW has mean 14.39 and standard deviation 9.67. This is the DW distribution for regulated or casual neighborhood visitors to the Arsenal. The mathematical development of this probability distribution is in Section 3.2.3.1.

3.2.2.2 DW(regional subpopulation)

The probability distribution for the number (DW) of days per year that a regulated or casual visitor in the regional subpopulation visits the Arsenal is a normal distribution with the following percentiles:

Probability (DW ≤ 7.26 days/year) = 0.99
Probability (DW ≤ 6.56 days/year) = 0.975
Probability (DW ≤ 5.96 days/year) = 0.95
Probability (DW ≤ 5.57 days/year) = 0.925
Probability (DW ≤ 5.27 days/year) = 0.90
Probability (DW ≤ 4.44 days/year) = 0.80
Probability (DW ≤ 4.12 days/year) = 0.75
Probability (DW ≤ 3.83 days/year) = 0.70
Probability (DW ≤ 3.32 days/year) = 0.60
Probability (DW ≤ 2.84 days/year) = 0.50
Probability (DW ≤ 2.36 days/year) = 0.40
Probability (DW ≤ 1.84 days/year) = 0.30
Probability (DW ≤ 1.56 days/year) = 0.25
Probability (DW ≤ 1.24 days/year) = 0.20
Probability (DW ≤ 0.40 days/year) = 0.10
Probability (DW ≤ 0.10 days/year) = 0.075
Probability (DW ≤ 0.00 days/year) = 0.05
Probability (DW ≤ 0.00 days/year) = 0.025
Probability (DW ≤ 0.00 days/year) = 0.01

This normal distribution for DW has mean 2.84 and standard deviation 1.90. This is the DW distribution for regulated or casual regional visitors to the Arsenal. The mathematical development of this distribution is given in Section 3.2.3.2.

3.2.2.3 DW(combined population)

The probability distribution for the number (DW) of days per year that a regulated or casual visitor in the combined neighborhood and regional population visits the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW ≤ 21.15 days/year) = 0.99
Probability (DW ≤ 15.16 days/year) = 0.975
Probability (DW ≤ 11.39 days/year) = 0.95
Probability (DW ≤ 9.46 days/year) = 0.925
Probability (DW ≤ 8.19 days/year) = 0.90
Probability (DW ≤ 5.50 days/year) = 0.80
Probability (DW ≤ 4.72 days/year) = 0.75
Probability (DW ≤ 4.12 days/year) = 0.70
Probability (DW ≤ 3.22 days/year) = 0.60
Probability (DW ≤ 2.56 days/year) = 0.50
Probability (DW ≤ 2.03 days/year) = 0.40
Probability (DW ≤ 1.59 days/year) = 0.30
Probability (DW ≤ 1.39 days/year) = 0.25
Probability (DW ≤ 1.19 days/year) = 0.20
Probability (DW ≤ 0.80 days/year) = 0.10
Probability (DW ≤ 0.69 days/year) = 0.075
Probability (DW ≤ 0.58 days/year) = 0.05
Probability (DW ≤ 0.43 days/year) = 0.025
Probability (DW ≤ 0.31 days/year) = 0.01

This is a lognormal distribution with mean 3.86 and standard deviation 4.37. The ln[DW] has a normal distribution with mean 0.9399 and standard deviation of 0.9077. This is the DW distribution for regulated or casual visitors to the Arsenal. This DW distribution is for the whole population of regulated or casual visitors, that is, the distribution for the combined neighborhood and regional visitor subpopulations. The mathematical development of this distribution begins in Section 3.2.3.3.

3.2.3 DW - Mathematical Development

3.2.3.1 DW(neighborhood subpopulation)

The development of the DW distribution for the neighborhood visitor subpopulation is based on the same five representative activities and associated data as used in Section 3.1.3, namely, the participation rates in the five representative activities

Activity	Percent of Population Participating
Picnicking	35% [a]
Walking for Pleasure	43% [a]
Nature Walks	9% [a]
Bird Watching	4.0% [a]
Wildlife and Bird Photography	4.0% [b]

[a] The proportion of the population who participate in the activities from population areas with more than one million people (National Park Service, 1986).
[b] National value given in Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20.

and the average annual number of days of participation in each of the five representative activities

Activity	Average Annual Days for a Participant
Picnicking	6.6 [a]
Walking for Pleasure	37.0 [a]
Nature Walks	13.8 [b]
Bird Watching	47.4 [c]
Wildlife and Bird Photography	8.2 [a]

[a] National values given in Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20.
[b] In Colorado, the number of days/year for Day Hiking is 13.8 (National Sporting Goods Association, 1989). Nationally, the average number of days/year for nature walks is 12.3 (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).
[c] In the Western United States, the number of days/year for Bird Watching/Nature is 47.4 (Table 9, National Park Survey, 1986).

In Step 2 in Section 3.1.3, these data are used to derive the relative frequencies of the 31 subpopulations that participate in the 31 possible combinations of these activities. In Step 3 in Section 3.1.3, a Monte Carlo simulation of each subpopulation is used to determine, in each of the 31 subpopulations, the number of days per year of participation in each possible combination of single and multiple activities. Each of the 31 subpopulation simulations also generated the relative frequencies of the total number of days per year of regulated/casual visitor activity being 1, 2, 3, etc. days/year. Analogously to Step 4 in Section 3.1.3, these relative frequencies of days/year for each of the 31 subpopulations are combined by multiplying each subpopulation's relative frequencies of 1, 2, 3, etc. days/year by the frequency of that subpopulation, and then summing over the 31 subpopulations. In this manner, the estimated frequencies of 1, 2, 3, etc. days/year are obtained. Each of these estimated frequencies is the estimated probability of a specific number of regulated or casual activity days per year; this is a total number of days

including both days spent at the Arsenal and activity days spent at some location other than the Arsenal.

In Step 3, for example, if an individual participated in picnicking and walking for pleasure, then 7 picnicking days and 37 walking days were randomly distributed over the 52 weekend days in six months. If 3 of the 7 picnicking days were the same as 3 of the 37 walking days, then the total number of days/year of regulated/casual visitor days was 44 (i.e., 7 picnicking + 37 walking - 3 same = 44). These 44 days were all of the activity days including both days spent at the Arsenal and activity days spent at some location other than the Arsenal.

Because this probability distribution is for the total number of activity days and not necessarily the number of days spent at the Arsenal, consideration was also given to the likelihood that an individual who spends some of his or her regulated/casual activity days at the Arsenal may not spend all of his or her activity days at the Arsenal. The fraction of regulated/casual activity days/year spent at the Arsenal was assumed to follow a triangular distribution with minimum 0.1 (10%), mode 0.40 (40%), mean 0.50 (50%), and maximum 1.0 (100%), based solely on professional judgment. The 95th percentile of this distribution is 0.836; so that, approximately 5% of the regulated/casual neighborhood visitors to the Arsenal would spend at least 83% of their total activity days at the Arsenal.

Monte Carlo simulation was used to determine the probability distribution of

(Total Number of Activity Days) * (Fraction Spent at Arsenal).

This simulated distribution for the neighborhood subpopulation was reasonably well approximated by a normal distribution:

Percentage	Simulated Distribution (Days/Year)	Fitted Normal Distribution (Days/Year)
99	36.55	36.88
97.5	33.92	33.33
95	31.34	30.29
92.5	29.51	28.30
90	27.95	26.78
80	23.29	22.52
75	21.48	20.91
70	19.68	19.46
60	16.71	16.84
50	13.98	14.39
40	10.77	11.94
30	6.60	9.32
25	5.27	7.87

20	4.28	6.25
10	2.90	2.00
7.5	2.59	0.47
5	2.26	0.00
2.5	1.82	0.00
1	1.42	0.00

The best fitting normal distribution for DW has mean 14.39 and standard deviation 9.67. A graphical indication of the fit is shown in Figure 3.2.3.1.

3.2.3.2 DW(regional subpopulation)

The number of visits in a year made by a regulated or casual visitor is an integer valued discrete random variable with practically no upper bound. The most fundamental and most common probability distribution used to describe such random variables is the Poisson distribution. The Poisson distribution has a long history of successful applications in describing the frequencies of numbers of events in a fixed time period (Feller (1950) and Snedecor (1980)).

The Poisson probability distribution is completely specified by its mean. The probability that a Poisson random variable, say V, with mean m equals a particular integer v is

$$m^v * \exp(-m) / v! \quad \text{for } v = 0, 1, 2, \ldots .$$

Because a visitor to the Arsenal by definition has a number of visits $V \geq 1$, the Poisson probability distribution was conditioned on this requirement, i.e., individuals who make no visits are not considered. The conditional Poisson probability distribution for V given the condition $V \geq 1$ is such that the probability of V equaling a particular positive integer v is

$$[m^v * \exp(-m) / v!] / [1 - \exp(-m)] \quad \text{for } v = 1, 2, \ldots$$

The mean number of visits in a year given that there is at least one visit in a year is

$$m / [1 - \exp(-m)].$$

In order for this mean number of visits to be equal to the mean number of visits for daily fee users (2.3 visits per year),

$$2.3 = m / [1 - \exp(-m)]$$

or $m = 1.984$. Similarly, the values of the Poisson probability distribution parameter m for annual pass users with a mean of 4.63 is $m = 4.583$, and for Aspen Leaf holders with mean 6.4 the corresponding value of $m = 6.288$.

The component Poisson probability distributions for the number of visits given that the visitor

makes at least one visit in a year are shown in Appendix C for daily fee users, annual pass users, and Aspen Leaf holders.

The probability distribution for the number of visits per year for a regulated or casual visitor to the Arsenal was obtained by combining the probability distributions for daily fee visits per year, annual pass visits per year, and Aspen Leaf visits per year. For example, the probability that the number of visits/year is 4 visits/year is the sum of the following three probabilities:

1.) the probability that a daily fee visitor visits the Arsenal 4 times in a year given that the visitor visits the Arsenal at least once in that year times the probability that a visitor is a daily fee user,

2.) the probability that an annual pass visitor visits the Arsenal 4 times in a year given that the visitor visits the Arsenal at least once in that year times the probability that a visitor is an annual pass user, and

3.) the probability that an Aspen Leaf visitor visits the Arsenal 4 times in a year given that the visitor visits the Arsenal at least once in that year times the probability that a visitor is an Aspen Leaf holder.

The distributions for the three pass types were combined based on the proportion of visitors using each pass type. The Barr Lake data imply that 81.35% of the Barr Lake visitors use daily fees, 12.76% use an annual pass, and the remaining 5.89% use the Aspen Leaf pass. Mathematically, if V1, V2, and V3 are the random number of visits per year for a daily fee, an annual pass, and Aspen Leaf visitor respectively, then the probability distribution for visits/year given that the visitor visits the Arsenal at least once in a year is the probability distribution of a random variable that equals V1 with probability 0.8135, V2 with probability 0.1276, and V3 with probability 0.0589. This distribution was constructed using Monte Carlo simulation as follows.

First, the type of user (i.e., daily fee, annual pass, or Aspen Leaf) was selected based on the proportion of visitors for each pass type. Then the number of days for this type of user was drawn randomly from the distribution on repeat visitation corresponding to this pass type. By repeating this process a large number of times (10,000 times), the resulting probability distribution for DW (days/year) was simulated.

The distribution of simulated values for DW was fit using both normal and lognormal distributions. The best fit between the normal and lognormal distribution was used to describe the probability distribution of DW (days/year), and is the probability distribution described in Section 3.2.2.2. Using the sample mean and sample standard deviation as estimators, the best fitting probability distribution for DW is the normal distribution in which DW has mean 2.84 and standard deviation 5.96. Although the normal distribution provides a better fit than the lognormal, it must be truncated so that no negative values for DW are possible. Therefore, DW for the regulated/casual visitor was assigned a normal distribution truncated at DW=1.

Even though DW must be an integer in any one year, the average number of visitation days per year over several years would not necessarily be an integer. Hence, a normal distribution was considered a reasonable approximation for DW even though normal random variables are not, in general, integer valued.

3.2.3.3 DW(combined population)

The mathematical development of the DW(combined population) is postponed to Section 3.5. This postponement allows the necessary component results to be obtained first. Section 3.3 combines the visitor subpopulation distributions for TE(years/lifetime) to obtain the visitor population distribution for TE. Then, as the necessary next step in the development of a visitor population distribution for DW, Section 3.4 combines the component visitor subpopulation distributions for DW and TE to produce the visitor population distribution for DW*TE (days/lifetime). Section 3.5 develops the visitor population distribution for DW from the visitor population distributions for TE and DW*TE.

3.3 TE - YEARS PER LIFETIME: Regulated/Casual Visitors

3.3.1 TE - Rationale for Probability Distribution

The number of years in a lifetime in which a regulated or casual visitor actually visits the Arsenal is TE. Ideally, the probability distribution for TE would be determined from data on the number of years in which particular visitors return to the Arsenal. The 1988 Visitor Survey found that most visitation to Denver metropolitan area parks was made by Denver metropolitan area residents (Colorado DPOR, 1988). Generally, an individual's number of years in which there are visits to the Arsenal does not exceed the total number of years of residence in the area. The total number of years of residence in the Denver metropolitan area should therefore provide an upper bound on TE, the number of years in which there are Arsenal visits.

At the suggestion of EPA Region VIII, the U.S. West telephone company was contacted for residential mobility information that the company may track via telephone records (Brian Pavicic, U.S. West). Three categories of data are maintained on a monthly basis by U.S. West, i.e., number of new connects, number of moves within the same service area, and number of disconnects. However, none of this data is correlated, i.e., the length of time a household may have telephone service (taken to be the length of residence at a given location) is not deducible. For example, in the Commerce City zip code, there are approximately 100 transactions per month in the categories defined above. However, it is not known how frequently an individual household changes addresses.

Other potential sources of data were suggested by Mr. Pavicic. These sources included MCI, Sprint, and the Public Service Company. MCI and Sprint have only partial area market saturation in Adams County and do not track data of use in a residential mobility distribution.

However, the Public Service Company of Colorado (PSCo) was able to provide highly relevant data for the determination of TE. The company conducts a comprehensive biannual survey of its customers entitled the *Residential Energy Use Survey* (PSCo, 1989). PSCo provides electricity and natural gas to 80% of the residences in Colorado, and to virtually all of Adams County, the balance being provided utilities by rural cooperatives or self-sufficient families (residences who do not use utilities), etc. PSCo is the primary utility provider in the Metro Denver area.

The PSCo survey is sent to "every nth account" in the PSCo customer base (964,482 households in 1989) for the purpose of predicting energy demand in the future, characterizing the customer base, and gathering other information. In survey years 1985, 1987, and 1989, the question was asked "How long have you lived at this address?". The mean and median values for current average residence time reported by the respondents for 1985, 1987, and 1989 are tabled below. In addition, probability distributions ranging from < 1 to > 50 years were provided for these four survey years. In 1989, 5,380 surveys were sent and 2,998 were returned for a response rate of 55.7%. PSCo considers this response rate to be exceptionally high.

AVERAGE CURRENT RESIDENCE TIME
Public Service Company of Colorado

YEAR	MEAN VALUE	MEDIAN VALUE
1985	8.4 YRS	3.7 YRS
1987	9.6 YRS	4.3 YRS
1989	9.7 YRS	4.5 YRS
1991	10.1 YRS	4.8 YRS

A recently published paper entitled Duration and Expected Time of Residence for U.S. Households (Israeli and Nelson, USEPA, in *Risk Analysis*, 1992). This paper examined the common but erroneous practice of using "average current residence time" (time since moving into a current residence) as a surrogate for "average total residence time" (time between moving into and out of a residence). The paper presents a methodology which can be used to estimate total residence time distributions from current residence time data.

On May 13, 1992, the probability distribution of values from the 1991 *Residential Energy Use Survey* were provided verbally (Ron Fish, PSCo). There is a slight increase in the 1991 mean and median values over 1989 data. It is thought possible that the small increase in residency seen in the eight years of data tabled below might indicate a trend of decreasing mobility. Therefore, to avoid the introduction of a potential bias due to higher rates of mobility in 1985, 1987, and 1989, only 1991 data were used in developing the probability distribution for TE.

The PSCo 1991 current residence time data were analyzed using the Israeli and Nelson methodology to estimate the total residence time distribution. In the following table, mean and median values for average total residence time are given for 1985, 1987, and 1989 as well as 1991.

AVERAGE TOTAL RESIDENCE TIME Public Service Company of Colorado		
YEAR	MEAN VALUE	MEDIAN VALUE
1985	5.07 YRS	2.36 YRS
1987	5.31 YRS	2.21 YRS
1989	4.50 YRS	1.47 YRS
1991	5.48 YRS	1.98 YRS

As explained above, the total number of years of residence is usually an upper bound on the number of years of visitation at a particular park or recreation facility.

For members of the neighborhood visitor subpopulation, the total number of years of residence in the neighborhood incorporates not only the total residence duration at an Arsenal visitor's first residence in the neighborhood but also the possibility of a neighborhood resident making an intracounty move with the new residence also being in the neighborhood. The probability distribution on the number of neighborhood residences in a 70 year life span for a member of the neighborhood visitor subpopulation is developed in Section 3.3.3.1. The probability distributions on the number of such residences and the total residence duration at these residences are combined in Section 3.3.3.1 to provide a probability distribution on the upper bound for TE for the neighborhood subpopulation.

For the regional subpopulation, the probability distribution on the number of residences from which a person visits the Arsenal is derived in Section 3.3.3.2. The probability distributions on the number of such residences and the total residence duration at these residences are combined in Section 3.3.3.2 to provide a probability distribution on the upper bound for TE for the regional subpopulation.

The combined regulated/casual visitor population consists of 126,939 people of which 8,315 are neighborhood visitors and 118,624 are regional visitors. The probability distribution for TE for the combined population is the frequency distribution obtained by sampling the neighborhood visitor frequency distribution 6.55% of the time (8,315/126,939 = 0.0655) and sampling the regional visitor frequency distribution 93.45% of the time (118,624/126,939 = 0.9345).

There are aspects of the development of the TE distribution which tend to overestimate the years of Arsenal visitation in a 70 year life span. For example, the large number of opportunities for

outdoor pursuits in the Metro Denver area increases the probability that individuals will not visit the Arsenal every year that they reside at a given address. Currently, it is assumed that individuals who visit will do so every year of residence in the neighborhood or region. In addition to the Colorado State Park system, the U.S. Forest Service, the City and County of Denver, Jefferson County, and Boulder County maintain parks offering picnic sites, campgrounds, and hiking trails within a 30 to 45 minute driving time from most residential districts in the metropolitan area. (THK, 1990).

A second source of overestimation of TE is introduced by the greater response rate of the "more stable, higher income population", which is therefore over-represented compared to the "more transient, lower income population" which responded at a lower rate. This was determined in a subsequent PSCo analysis that correlates residence consumption history with the rate of response (Ron Fish, PSCo). The effect of this bias would be to overestimate the likelihood of medium and high TE values for the Commerce City population.

3.3.2 TE - Probability Distribution

3.3.2.1 TE(neighborhood subpopulation)

The probability distribution for the number (TE) of years that a regulated or casual visitor from the neighborhood subpopulation will visit the Arsenal in a lifetime is set equal to the probability distribution for total residence duration summed over all neighborhood residences. This distribution is expected to provide a potentially conservative estimate of the TE(neighborhood subpopulation) distribution, as previously discussed. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE $\leq$ 77.10 years/lifetime) = 0.99
Probability (TE $\leq$ 43.57 years/lifetime) = 0.975
Probability (TE $\leq$ 26.66 years/lifetime) = 0.95
Probability (TE $\leq$ 19.36 years/lifetime) = 0.925
Probability (TE $\leq$ 15.14 years/lifetime) = 0.90
Probability (TE $\leq$ 7.63 years/lifetime) = 0.80
Probability (TE $\leq$ 5.88 years/lifetime) = 0.75
Probability (TE $\leq$ 4.65 years/lifetime) = 0.70
Probability (TE $\leq$ 3.05 years/lifetime) = 0.60
Probability (TE $\leq$ 2.06 years/lifetime) = 0.50
Probability (TE $\leq$ 1.39 years/lifetime) = 0.40
Probability (TE $\leq$ 0.91 years/lifetime) = 0.30
Probability (TE $\leq$ 0.72 years/lifetime) = 0.25
Probability (TE $\leq$ 0.55 years/lifetime) = 0.20
Probability (TE $\leq$ 0.28 years/lifetime) = 0.10
Probability (TE $\leq$ 0.22 years/lifetime) = 0.075
Probability (TE $\leq$ 0.16 years/lifetime) = 0.05

Probability (TE ≤ 0.10 years/lifetime) = 0.025
Probability (TE ≤ 0.05 years/lifetime) = 0.01

This is a lognormal distribution with mean 6.92 and standard deviation 22.24. The ln[TE] has a normal distribution with mean 0.7204 and standard deviation of 1.5581. The mathematical development of this distribution is given in Section 3.3.3.1.

3.3.2.2 TE(regional subpopulation)

The probability distribution for the number (TE) of years that a regulated or casual visitor from the regional subpopulation will visit the Arsenal in a lifetime is set equal to the probability distribution for the total residence duration at all residences from which the person visits the Arsenal. This distribution is expected to provide a potentially conservative estimate of the TE(regional subpopulation) distribution, as previously discussed. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE ≤ 77.96 years/lifetime) = 0.99
Probability (TE ≤ 44.45 years/lifetime) = 0.975
Probability (TE ≤ 27.41 years/lifetime) = 0.95
Probability (TE ≤ 20.00 years/lifetime) = 0.925
Probability (TE ≤ 15.70 years/lifetime) = 0.90
Probability (TE ≤ 8.00 years/lifetime) = 0.80
Probability (TE ≤ 6.19 years/lifetime) = 0.75
Probability (TE ≤ 4.92 years/lifetime) = 0.70
Probability (TE ≤ 3.24 years/lifetime) = 0.60
Probability (TE ≤ 2.20 years/lifetime) = 0.50
Probability (TE ≤ 1.49 years/lifetime) = 0.40
Probability (TE ≤ 0.98 years/lifetime) = 0.30
Probability (TE ≤ 0.78 years/lifetime) = 0.25
Probability (TE ≤ 0.61 years/lifetime) = 0.20
Probability (TE ≤ 0.31 years/lifetime) = 0.10
Probability (TE ≤ 0.24 years/lifetime) = 0.075
Probability (TE ≤ 0.18 years/lifetime) = 0.05
Probability (TE ≤ 0.11 years/lifetime) = 0.025
Probability (TE ≤ 0.06 years/lifetime) = 0.01

This is a lognormal distribution with mean 7.13 and standard deviation 21.99. The ln[TE] has a normal distribution with mean 0.7885 and standard deviation of 1.5336. The mathematical development of this distribution is given in Section 3.3.3.2.

3.3.2.3 TE(combined population)

The probability distribution for the number (TE) of years that a regulated or casual visitor will visit the Arsenal in a lifetime is set equal to the probability distribution for the total residence duration at all residences from which the individual visits the Arsenal. This distribution is expected to provide a potentially conservative estimate of the TE(combined population) distribution, as previously discussed. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE ≤ 77.90 years/lifetime) = 0.99
Probability (TE ≤ 44.41 years/lifetime) = 0.975
Probability (TE ≤ 27.38 years/lifetime) = 0.95
Probability (TE ≤ 19.98 years/lifetime) = 0.925
Probability (TE ≤ 15.68 years/lifetime) = 0.90
Probability (TE ≤ 7.99 years/lifetime) = 0.80
Probability (TE ≤ 6.18 years/lifetime) = 0.75
Probability (TE ≤ 4.91 years/lifetime) = 0.70
Probability (TE ≤ 3.24 years/lifetime) = 0.60
Probability (TE ≤ 2.20 years/lifetime) = 0.50
Probability (TE ≤ 1.49 years/lifetime) = 0.40
Probability (TE ≤ 0.98 years/lifetime) = 0.30
Probability (TE ≤ 0.78 years/lifetime) = 0.25
Probability (TE ≤ 0.60 years/lifetime) = 0.20
Probability (TE ≤ 0.31 years/lifetime) = 0.10
Probability (TE ≤ 0.24 years/lifetime) = 0.075
Probability (TE ≤ 0.18 years/lifetime) = 0.05
Probability (TE ≤ 0.11 years/lifetime) = 0.025
Probability (TE ≤ 0.06 years/lifetime) = 0.01

This is a lognormal distribution with mean 7.12 and standard deviation 21.98. The ln[TE] has a normal distribution with mean 0.7865 and standard deviation of 1.5342. The mathematical development of this distribution is given in Section 3.3.3.3.

3.3.3 TE - Mathematical Development

The distribution for the total residence duration at a particular residence was derived from the data on years of current residence reported in the 1991 *PSCo Residential Energy Use Survey*. This survey indicates the following percentages of years of residence at their current address among the survey respondents:

Years at Current Address	Percent of Customers
<1	10.7
1	8.2
2-3	16.4
4-5	12.1
6-10	14.4
11-15	13.1
16-20	6.9
21-25	5.3
26-30	3.9
31-40	4.1
41-50	1.6
>50	0.5

The percentage of survey respondents who responded to the question "How long have you lived at this address?" was 97.2%. For example, on the average, 10.7 out of every 97.2 responses (which is 11.0% of every 100 responses) indicated that they had lived at their current address for less than one year. The probability distribution for the 2.8% that did not respond to this question, was assumed to be equal to the distribution for the respondents. Therefore, after dividing each of the above percentages by 0.972 to adjust for non-response to this particular question, the percentages reported above for the 97.2% of the survey respondents who responded to the question "How long have you lived at this address?" were adjusted to be as follows:

Years lived at current address	Percent of customers	Cumulative Percent
<1	11.0	11.0
1	8.4	19.4
2-3	16.9	36.3
4-5	12.4	48.8
6-10	14.8	63.6
11-15	13.5	77.1
16-20	7.1	84.2
21-25	5.5	89.6
26-30	4.0	93.6
31-40	4.2	97.8
41-50	1.6	99.5
>50	0.5	100.0

The residence data probability distribution identifies the following probabilities:

$$\text{Probability (Years} \leq 0.5 \text{)} = 0.110$$
$$\text{Probability (Years} \leq 1.5 \text{)} = 0.194$$

Probability (Years ≤ 3.5) = 0.363
Probability (Years ≤ 5.5) = 0.488
Probability (Years ≤ 10.5) = 0.636
Probability (Years ≤ 15.5) = 0.771
Probability (Years ≤ 20.5) = 0.842
Probability (Years ≤ 25.5) = 0.896
Probability (Years ≤ 30.5) = 0.936
Probability (Years ≤ 40.5) = 0.978
Probability (Years ≤ 50.5) = 0.995

This probability distribution for current residence duration was analyzed using the methodology reported in a recently published paper entitled Duration and Expected Time of Residence for U.S. Households (Israeli and Nelson, USEPA, 1992). This paper examined the common but erroneous practice of using "average current residence time" (time since moving into a current residence) as a surrogate for "average total residence time" (time between moving into and out of a residence). The paper presents a methodology which can be used to estimate total residence time distributions from current residence time data. That methodology was applied to the above 1991 PSCo data based current residence duration distribution. The resulting estimated probability distribution on the total residence duration had the following percentiles:

Probability (Years ≤ 0.12234) = 0.05
Probability (Years ≤ 0.25458) = 0.10
Probability (Years ≤ 0.39825) = 0.15
Probability (Years ≤ 0.55525) = 0.20
Probability (Years ≤ 0.72798) = 0.25
Probability (Years ≤ 0.91954) = 0.30
Probability (Years ≤ 1.13393) = 0.35
Probability (Years ≤ 1.37656) = 0.40
Probability (Years ≤ 1.65487) = 0.45
Probability (Years ≤ 1.97949) = 0.50
Probability (Years ≤ 2.36622) = 0.55
Probability (Years ≤ 2.83985) = 0.60
Probability (Years ≤ 3.44190) = 0.65
Probability (Years ≤ 4.24796) = 0.70
Probability (Years ≤ 5.41017) = 0.75
Probability (Years ≤ 7.26355) = 0.80
Probability (Years ≤ 10.49762) = 0.85
Probability (Years ≤ 16.03696) = 0.90
Probability (Years ≤ 25.63155) = 0.95

These probabilities were fit to the normal and lognormal distributions using the weighted least squares estimation procedure described in Step 5 near the end of Section 3.1.3. The best fitting distribution is a lognormal distribution. The best fitting lognormal distribution has mean 6.7833 and standard deviation 21.5036 which corresponds to the logarithm of a normal random variable

with mean 0.7133 and standard deviation 1.5500. The fit itself can be described as follows:

Percentage	Observed Percentile	Fitted Percentile
95	25.63	26.12
90	16.04	14.87
85	10.50	10.17
80	7.23	7.52
75	5.41	5.80
70	4.25	4.60
65	3.44	3.71
60	2.84	3.02
55	2.37	2.48
50	1.98	2.04
45	1.65	1.68
40	1.38	1.38
35	1.13	1.12
30	0.92	0.91
25	0.73	0.72
20	0.56	0.55
15	0.40	0.41
10	0.25	0.28
5	0.12	0.16

A graphical indication of the fit is shown in Figure 3.3.3.

3.3.3.1 TE(neighborhood subpopulation)

The probability distribution for TE (years/lifetime) of regulated or casual visitation to the Arsenal for the neighborhood visitor subpopulation was approximated by the probability distribution of the total residence duration in years summed over all of the individual's residences in the neighborhood. This cumulative total residence duration distribution was determined by a Monte Carlo simulation. In that simulation (which is discussed in more detail below), 1.69% of the TE(neighborhood subpopulation) values corresponded to the 1.69% of the neighborhood visitor subpopulation who were estimated to have two residence durations in the neighborhood. These 1.69% of the TE values were equal to the sum of two independently sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. The other 97.42% (100%-1.69%) of the TE(neighborhood subpopulation) values were equal to randomly sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. Ten thousand simulated TE values were generated. The observed distribution of simulated values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	77.35	77.10
97.5	43.37	43.57
95	26.39	26.66
92.5	19.41	19.36
90	15.12	15.14
80	7.76	7.63
75	5.92	5.88
70	4.73	4.65
60	3.10	3.05
50	2.08	2.06
40	1.41	1.39
30	0.92	0.91
25	0.73	0.72
20	0.56	0.55
10	0.28	0.28
7.5	0.22	0.22
5	0.16	0.16
2.5	0.10	0.10
1	0.06	0.05

A graphical indication of the fit is shown in Figure 3.3.3.1.

The fitted lognormal distribution for TE(neighborhood subpopulation) has mean 6.92 and standard deviation 22.24, and the ln(TE) has mean 0.7204 and standard deviation 1.5581. This is the TE (years/lifetime) distribution for the subpopulation of neighborhood regulated or casual visitors to the Arsenal.

Simulation

As discussed in Section 3.2.1.4, the neighborhood subpopulation size is 14,875. This subpopulation includes 6,291 people whose initial residence is in the neighborhood and 8,584 people who move into the neighborhood at some time during their 70 year life span (6,291 + 8,584 = 14,875). Among the 14,875 members of the neighborhood subpopulation, there were estimated to be 8,315 visitors to the Arsenal (Section 3.2.1.5). All of these 8,315 people were assumed to visit the Arsenal every year they live in the neighborhood. A portion (1.69%) of these people were estimated to have two residence durations in the neighborhood.

The probability that a person moves from within the neighborhood to another residence in the neighborhood is the probability of an intracounty move times the probability that the new residence is one of those in the neighborhood which is approximately equal to

$$[22.7/(22.7 + 14.8 + 20.6)] * [6,291/732,648] = 0.391 * 0.0086 = 0.0034.$$

Thus, the probability of a person having two residence durations in the neighborhood is likely to be quite small even if the person's initial residence is in the neighborhood. Hence, only people who have their initial residence in the neighborhood were assumed to have a non-negligible chance of having two residence durations in the neighborhood.

In the above calculation, the probability that such a person has two residences in the neighborhood was estimated to be 0.0034. A check on the reasonableness of this estimate can by obtained from the relative proportions of Adams and Denver counties within 1/4 mile of the Arsenal; these proportions are as follows:

1990 Proportional Estimates for Adams and Denver Counties

Distance	Number of People	Adams	Denver	% of Adams	% of Denver
1/4 mile	6291*	2657	3634	0.0001	0.00008
1990 County Population		265,038	467,610	1.00	1.00

* Determined from a recent aerial photograph, Landis Photography, in THK, 1992.

It can be easily seen that the 1/4 mile surrounding areas comprise a small percentage of the balance of the county populations. Therefore, the likelihood that a person making an intracounty move would choose a home within the neighborhood as compared to elsewhere in the county is probably also small, as most of the residential possibilities are elsewhere in the county. In the derivation of the estimated probability of 0.0034 that a person with one residence duration in the neighborhood would also have a second residence duration in the neighborhood, the probability that, when a neighborhood resident moves within the county, the new residence will be in the neighborhood was estimated to be 6,291/732,648 or 0.0086. However, when a neighborhood resident moves within the county, if that resident has a preference to stay in the neighborhood over the rest of the county, then the probability of 0.0086 or 0.86% may be somewhat low. Therefore, in the determination of the likelihood of a person having two residences in the neighborhood, a percentage of 10% (instead of the smaller 0.86%) was chosen on the basis of professional judgment as a conservative upper bound estimate of intracounty moves within the neighborhood. Thus, a person beginning in the neighborhood would have 0.04 probability (approximately 0.391 * 0.1000) as an upper bound on the probability of having two residences in the neighborhood.

Based on these probabilities, the number of people in the 1990 Denver Metro area population that will have one or more residence durations in the neighborhood in their lifetime was determined as follows:

Two residences: $6,291 * 0.04 = 252$

One residence: $0.00466 * (1,848,319 - 6,291) - 252 = 14,875 - 252 = 14,623$

Total population size with one or more residence durations in the neighborhood:
$252 + 14,623 = 14,875.$

Therefore,

$$252/14,875 = 0.0169$$

was the proportion of the neighborhood subpopulation that have a TE (years/lifetime) corresponding to two "total residence durations," and

$$14,623/14,875 = 0.9831$$

was the proportion of the neighborhood subpopulation that have a TE (years/lifetime) corresponding to one "total residence duration." These proportions were used to characterize the estimated number of neighborhood residences in the 70 year life span of the 8,315 members of the neighborhood visitor subpopulation.

3.3.3.2 TE(regional subpopulation)

The probability distribution for TE (years/lifetime) of regulated or casual visitation to the Arsenal for the regional visitor subpopulation was approximated by the probability distribution of the total residence duration in years summed over all of the individual's residences from which the Arsenal was visited. This cumulative total residence duration distribution was determined by a Monte Carlo simulation. In that simulation (which was discussed in Section 3.2.1.2), 93.53% of the TE values corresponded to the 93.53% of the regional visitor subpopulation who were estimated to have only one residence duration during which they visited the Arsenal. Further, 6.15% of the TE values corresponded to the 6.15% of the regional visitor subpopulation who were estimated to have two residence durations during which they visited the Arsenal. These 6.15% of the TE values were equal to the sum of two independently sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. Similarly, the remaining 0.32% of the TE values corresponded to the 0.32% of the regional visitor subpopulation who were estimated to have three residence durations during which they visited the Arsenal. No simulated 70 year time span had more than three such residence durations. Ten thousand simulated TE values were generated. The observed distribution of simulated values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	78.31	77.96
97.5	44.13	44.45
95	26.96	27.41
92.5	20.02	20.01
90	15.76	15.70
80	8.13	8.00
75	6.28	6.19
70	5.00	4.92
60	3.30	3.24
50	2.21	2.20
40	1.49	1.49
30	0.98	0.98
25	0.77	0.78
20	0.59	0.61
10	0.30	0.31
7.5	0.23	0.24
5	0.17	0.18
2.5	0.10	0.11
1	0.06	0.06

A graphical indication of the fit is shown in Figure 3.3.3.2.

The lognormal distribution for TE(regional subpopulation) has mean 7.13 and standard deviation 21.99, and the ln(TE) has mean 0.7885 and standard deviation 1.5336. This is the TE (years/lifetime) distribution for the subpopulation of regional regulated or casual visitors to the Arsenal.

3.3.3.3 TE(combined population)

The probability distribution for TE (years/lifetime) of regulated or casual visitation to the Arsenal for the combined population of neighborhood and regional visitors is approximated by the probability distribution of the total residence duration in years of the combined population. There are 8,315 people in the neighborhood visitor subpopulation and 118,624 in the regional visitor subpopulation, and 126,939 people in the combined regulated/casual visitor population (126,939=8,315+118,624). The total residence duration distribution is determined by a Monte Carlo simulation.

In the Monte Carlo simulation, a fraction (8,315/126,939) of the simulated total residence duration values corresponded to the neighborhood visitor subpopulation. Within this fraction of simulations, 1.69% of the TE values corresponded to the 1.69% of the neighborhood visitor

subpopulation who are estimated to have two residence durations in the neighborhood. These 1.69% of the TE values are equal to the sum of two independently sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. The other 98.31% (100%-1.69%) of this fraction of the TE values are equal to randomly sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence.

In the Monte Carlo simulation, the other fraction (118,624/126,939) of the simulated total residence duration values corresponded to the regional visitor subpopulation. Within this fraction of simulations, 93.53%, 6.15%, and 0.32% of the TE values corresponded to the regional visitors who were estimated to have one, two, and three residence durations, respectively, during which they visited the Arsenal.

Ten thousand simulated TE values were generated. The observed distribution of simulated values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	78.31	77.90
97.5	43.99	44.41
95	26.96	27.38
92.5	20.02	19.98
90	15.76	15.68
80	8.11	7.99
75	6.27	6.18
70	5.00	4.91
60	3.28	3.24
50	2.21	2.20
40	1.48	1.49
30	0.97	0.98
25	0.77	0.78
20	0.59	0.60
10	0.29	0.31
7.5	0.23	0.24
5	0.17	0.18
2.5	0.10	0.11
1	0.06	0.06

A graphical indication of the fit is shown in Figure 3.3.3.3.

The lognormal distribution for TE(combined) has mean 7.12 and standard deviation 21.98, and the ln(TE) has mean 0.7865 and standard deviation 1.5342. This is the TE (years/lifetime)

distribution for the combined population of neighborhood and regional regulated or casual visitors to the Arsenal.

3.4 DW*TE - DAYS PER LIFETIME: Regulated/Casual Visitors

3.4.1 DW*TE - Rationale for Probability Distribution

As a preliminary step to the development of a distribution for DW for the combined population of neighborhood and regional visitors to the Arsenal, Section 3.4 combines the component visitor subpopulation distributions for DW and TE to produce the visitor population distribution for DW*TE(days/lifetime). Section 3.5 develops the combined population distribution for DW from this distribution for DW*TE and the TE distribution developed in Section 3.3 for the combined population.

The distributions of DW and TE for a neighborhood visitor are different than the distributions of DW and TE for a regional visitor. In order to reflect these differences and maximize the information obtained from each of these subpopulations, the data on neighborhood visitor activity frequencies (DW(neighborhood)) are combined only with the data on total years of residence in the neighborhood (TE(neighborhood)) while the data on regional visitor activity frequencies (DW(regional)) are combined only with the data on total years of residence in the region (TE(regional)).

The total number of days per lifetime spent on the Arsenal by a regulated/casual visitor is denoted by DW*TE where DW denotes days/year and TE denotes years/lifetime. If a regulated/casual visitor is a member of the neighborhood subpopulation, then the number (DW*TE) of days per lifetime spent on the Arsenal is equal to

DW(neighborhood)*TE(neighborhood)

If a regulated/casual visitor is a member of the regional subpopulation, then the number (DW*TE) of days per lifetime spent on the Arsenal is equal to

DW(regional)*TE(regional)

The distribution for DW(neighborhood) and DW(regional) are developed in Section 3.2. The probability distributions for TE(neighborhood) and TE(regional) are developed in Section 3.3.

In Section 3.4, a Monte Carlo simulation procedure is used to develop a distribution for DW*TE for the combined population. The distribution represents the most accurate estimate of the distribution of days per lifetime for the combined population that can be obtained from the data.

The Monte Carlo simulation of the distribution of DW*TE fully utilizes the distinct information on neighborhood and regional visitor subpopulations and avoids inappropriate calculations such as

DW(neighborhood) * TE(regional),

and

DW(regional) * TE(neighborhood).

3.4.2 DW*TE - Probability Distribution

The probability distribution for the number (DW*TE) of days per lifetime of regulated or casual visitor activities at the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW*TE ≤ 355.42 days/lifetime) = 0.99
Probability (DW*TE ≤ 184.97 days/lifetime) = 0.975
Probability (DW*TE ≤ 105.48 days/lifetime) = 0.95
Probability (DW*TE ≤ 73.15 days/lifetime) = 0.925
Probability (DW*TE ≤ 55.20 days/lifetime) = 0.90
Probability (DW*TE ≤ 25.20 days/lifetime) = 0.80
Probability (DW*TE ≤ 18.70 days/lifetime) = 0.75
Probability (DW*TE ≤ 14.31 days/lifetime) = 0.70
Probability (DW*TE ≤ 8.83 days/lifetime) = 0.60
Probability (DW*TE ≤ 5.62 days/lifetime) = 0.50
Probability (DW*TE ≤ 3.58 days/lifetime) = 0.40
Probability (DW*TE ≤ 2.21 days/lifetime) = 0.30
Probability (DW*TE ≤ 1.69 days/lifetime) = 0.25
Probability (DW*TE ≤ 1.25 days/lifetime) = 0.20
Probability (DW*TE ≤ 0.57 days/lifetime) = 0.10
Probability (DW*TE ≤ 0.43 days/lifetime) = 0.075
Probability (DW*TE ≤ 0.30 days/lifetime) = 0.05
Probability (DW*TE ≤ 0.17 days/lifetime) = 0.025
Probability (DW*TE ≤ 0.09 days/lifetime) = 0.01

This lognormal distribution for DW*TE has mean 27.53 and standard deviation 131.98, and the ln(DW*TE) has mean 1.7264 and standard deviation 1.7826.

3.4.3 DW*TE - Mathematical Development

The probability distribution for the number (DW*TE) of days per lifetime that a person in the combined population of neighborhood and regional regulated/casual visitors would visit the Arsenal was determined by Monte Carlo simulation. The number of regulated or casual visitors to the Arsenal in the neighborhood and regional visitor subpopulations was 8,315 and 118,624, respectively, as derived in Section 3.2.1. The combined population has 126,939 regulated/casual visitors to the Arsenal. The subpopulation distributions for DW and TE were randomly sampled in the simulation and DW*TE was set equal to

DW(neighborhood)*TE(neighborhood)

in a fraction (8,315/126,939) of the simulations and was set equal to

DW(regional)*TE(regional)

in the remaining fraction (118,624/126,939) of the simulations. Thus, the fraction of simulated DW*TE values computed using the neighborhood subpopulation DW and TE distributions was equal to the fraction of the combined population corresponding to the neighborhood subpopulation. Similarly, the fraction of simulated DW*TE values computed using the regional subpopulation DW and TE distributions was equal to the fraction of the combined population corresponding to the regional subpopulation.

Ten thousand values of DW*TE were simulated. The observed distribution of simulated DW*TE values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Days/Lifetime)	Fitted Lognormal Distribution (Days/Lifetime)
99	357.31	355.42
97.5	182.61	184.97
95	104.94	105.48
92.5	72.14	73.15
90	55.45	55.20
80	25.53	25.20
75	19.23	18.70
70	14.91	14.31
60	9.34	8.83
50	6.09	5.62
40	3.99	3.58
30	2.53	2.21
25	1.98	1.69
20	1.44	1.25
10	0.69	0.57
7.5	0.53	0.43
5	0.36	0.30
2.5	0.21	0.17
1	0.12	0.09

A graphical indication of the fit is shown in Figure 3.4.3.

The fitted lognormal distribution for DW*TE(combined subpopulation) has mean 27.53 and standard deviation 131.98, and the ln(DW*TE) has mean 1.7264 and standard deviation 1.7826.

3.5 DW(Combined Population) - DAYS PER YEAR: Regulated/Casual Visitors

3.5.1 DW(Combined Population) - Rationale for Probability Distribution

Section 3.5 develops the visitor population distribution for DW(combined population) from the distribution for DW*TE(combined population) derived in Section 3.4 and the distribution for TE(combined population) developed in Section 3.3.

3.5.2 DW(Combined Population) - Probability Distribution

The probability distribution for the number (DW) of days per year of regulated or casual visitor activities at the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW ≤ 21.15 days/year) = 0.99
Probability (DW ≤ 15.16 days/year) = 0.975
Probability (DW ≤ 11.39 days/year) = 0.95
Probability (DW ≤ 9.46 days/year) = 0.925
Probability (DW ≤ 8.19 days/year) = 0.90
Probability (DW ≤ 5.50 days/year) = 0.80
Probability (DW ≤ 4.72 days/year) = 0.75
Probability (DW ≤ 4.12 days/year) = 0.70
Probability (DW ≤ 3.22 days/year) = 0.60
Probability (DW ≤ 2.56 days/year) = 0.50
Probability (DW ≤ 2.03 days/year) = 0.40
Probability (DW ≤ 1.59 days/year) = 0.30
Probability (DW ≤ 1.39 days/year) = 0.25
Probability (DW ≤ 1.19 days/year) = 0.20
Probability (DW ≤ 0.80 days/year) = 0.10
Probability (DW ≤ 0.69 days/year) = 0.075
Probability (DW ≤ 0.58 days/year) = 0.05
Probability (DW ≤ 0.43 days/year) = 0.025
Probability (DW ≤ 0.31 days/year) = 0.01

This lognormal distribution for DW has mean 3.86 and standard deviation 4.37, and the ln(DW) has mean 0.9399 and standard deviation 0.9077.

3.5.3 DW(Combined Population) - Mathematical Development

The probability distribution for the number (DW) of days per year that a person in the combined population of neighborhood and regional regulated/casual visitors would visit the Arsenal was determined mathematically from the distributions for DW*TE(combined population) and

TE(combined population), derived in Sections 3.4 and 3.3, respectively.

It can be shown mathematically, that the product of two lognormal random variables is itself lognormally distributed. Furthermore, if DW, TE, and [DW*TE] are lognormally distributed and

(1) ln(DW) is normally distributed with mean A and standard deviation B,

(2) ln(TE) is normally distributed with mean C and standard deviation D, and

(3) ln([DW*TE]) is normally distributed with mean E and standard deviation F,

then, $E = A + C$ and $F^2 = B^2 + D^2$

and $A = E - C$ and $B^2 = F^2 - D^2$.

Hence, the lognormal distribution for DW(combined population) was derived by solving the above two equations for A and B as follows. Because TE(combined population) is lognormally distributed with mean 7.12 and standard deviation 21.98, ln(TE) has a mean of 0.7865 (C=0.78657) and standard deviation 1.5342 (D=1.5342). Also, because [DW*TE](combined population) is lognormally distributed with mean 27.53 and standard deviation 131.98, ln([DW*TE]) has a mean of 1.7264 (E=1.7264) and standard deviation 1.7826 (F=1.7826). These distributions imply that

$A = 1.7264 - 0.7865 = 0.9399$ and

$B^2 = (1.7826)^2 - (1.5342)^2 = (0.9077)^2$;

so that, DW(combined population) is lognormally distributed with mean 3.86 and standard deviation 4.37, and ln(DW) has mean 0.9399 and standard deviation 0.9077.

4.0 RECREATIONAL VISITORS

Recreational activities at the Arsenal might include fishing and other recreational activities such as bicycling, jogging, walking, and informal outdoor sports. These activity groups are referred to as the anglers and general visitors, respectively. General visitors are subdivided into the neighborhood general visitors who live in close proximity to the Arsenal and regional general visitors who live further away. The three visitors groups are referred to as the angler, neighborhood general visitor, and regional general visitor subpopulations. The whole or total visitor population is referred to as the recreational visitor population.

If the recreational scenario were to include construction of facilities for organized team sports at the Arsenal, then the recreational visitor population would be expanded to include an organized sports visitor subpopulation as well as the angler and general visitor subpopulations. The combined population of all four subpopulations (angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations) is referred to as the expanded recreational visitor population. The analysis of and probability distribution for the expanded recreational scenario assumes that the Arsenal will have an athletic complex for organized sports, e.g., baseball diamonds, football fields, etc. The organized sports visitor subpopulation includes both players of organized sports and attenders (spectators).

4.0.1 Definition of Population and Subpopulations

As in the regulated/casual scenario (Section 3.2.1.1), the regional population was defined in the Final Human Health Exposure Assessment to be the residents within the six-county Metro area in 1990. Based on the U.S. Census Bureau data, the population in 1990 of this six-county area was 1,848,319 (Sue Piatt, DRCOG, 7-1-91). The exposure parameter probability distributions refer to the events occurring during the 70 year expected life spans of 1,848,319 people. This population of 1,848,319 people is the population upon which the probability distributions for the time dependent exposure parameters are focused.

The 1,848,319 people are assumed to be identical to the current Denver Metro area residents, with the exception that these 1,848,319 people are assumed to live for the next 70 years. For example, these 1,848,319 people are assumed to begin their 70 year life spans living in the same locations as the current Metro area residents do.

Combined visitor populations and a number of subpopulations are defined in terms of the 70 year expected life spans of 1,848,319 people. By considering 70 year lifetimes for each individual rather than a population at a particular point in time, the exposure parameter characterization is more appropriate for lifetime human health assessment. The definitions of the subpopulations and the derivation of specific estimated numbers are discussed after this summary.

1. Neighborhood Subpopulation. This is the estimated portion of the 1,848,319 people who at some time in their life spans live in the neighborhood and is the same subpopulation as in the regulated/casual scenario. These estimated 14,875

people include 6,291 people who begin their 70 year life spans living in the neighborhood plus an estimated 8,584 people who move into the neighborhood at some time after they move out of their initial residence. (Section 4.1.1.2).

2. Neighborhood General Visitor Subpopulation. This is the estimated 9,649 people in the neighborhood population who actually visit the Arsenal at some time during their 70 year life spans. (Section 4.1.1.2).

3. Regional General Visitor Subpopulation. This is the estimated 296,101 people who are not part of the neighborhood subpopulation but do visit the Arsenal at some time during their 70 year life spans. (Section 4.1.1.3).

4. Angler Subpopulation. This is the estimated 602 people who have permits to fish at the Arsenal. (Section 4.1.1.1).

5. Organized Sports Subpopulation. This is the estimated 3,376 people who participate in or attend organized sports activities at the Arsenal. (Section 4.1.1.4).

6. Recreational Visitor Population. This is the combined population of anglers, neighborhood general visitors, and regional general visitors. There are 306,352 visitors in the combined visitor population (306,352 = 602 + 9,649 + 296,101).

7. Expanded Recreational Visitor Population. This is the combined population of anglers, neighborhood general visitors, regional general visitors, and organized sports visitors. There are 309,728 visitors in the combined visitor population (309,728 = 602 + 9,649 + 296,101 + 3,376).

Within the six-county Metro Denver population are people who do not visit Arsenal at any time during their 70 year life spans. These people do not belong to any of the visitor subpopulations. The probability distributions of the exposure parameters refer to Arsenal visitors and do not refer to or include non-visitors, as outlined below.

4.0.2 Guide to Development of the Exposure Parameter Distributions

Probability distributions for TM (duration of a visit in hours/day), DW (frequency of visits in days/year), and TE (years/lifetime) are developed for each of the four possible subpopulations (angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations) as well as for both the recreational visitor population and the expanded recreational visitor population, i.e., the recreational visitor population plus the organized sports visitors. The probability distribution for the recreational visitor population is more appropriate than the probability distribution for the expanded recreational visitor population if the construction of facilities for organized team sports is not built at the Arsenal and/or the

organized sports scenario does not evolve. That such facilities would not be built is considered to be a realistic possibility, as explained in Section 4.2.3.3.

The four probability distributions for TM for the four subpopulations (angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations) are developed in Section 4.1. Similarly, the four probability distributions for DW for the four subpopulations are developed in Section 4.2. In Section 4.3, two probability distributions for TE are presented and discussed, one for neighborhood visitors and one for regional visitors.

Section 4.4 develops the TM, DW, and TE distributions for the recreational visitor population comprised of the angler, neighborhood general visitor, and regional general visitor subpopulations.

Section 4.5 develops the TM, DW, and TE distributions for the expanded recreational visitor population comprised of the angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations.

The derivations in Sections 4.4 and 4.5 of the probability distributions for TM, DW, and TE for recreational and expanded recreational visitor populations are parallel. For example, for the recreational visitor population, the population distributions of TM, DW, and TE are derived in such a way that the frequency distribution for DW*TE (days/lifetime) in the combined population is the same as the combined frequency distributions for

days/lifetime for anglers:
DW(angler)*TE(angler)

days/lifetime for neighborhood general visitors:
DW(neighborhood general visitor)*TE(neighborhood general visitor)

days/lifetime for regional general visitors:
DW(regional general visitor)*TE(regional general visitor)

and the frequency distribution TM*DW*TE (hours/lifetime) in the combined population is the same as the combined frequency distributions for

hours/lifetime for anglers:
TM(angler)*DW(angler)*TE(angler)

hours/lifetime for neighborhood general visitors:
TM(neighborhood general visitor)*DW(neighborhood general visitor)*TE(neighborhood general visitor)

hours/lifetime for regional general visitors:

TM(regional general visitor)*DW(regional general visitor)*TE(regional general visitor).

The derivations in Sections 4.4 and 4.5 avoid inappropriate calculations such as

TM(angler)*DW(neighborhood general visitor)*TE(regional visitor)

which does not correspond to any visitor.

The sequential development in both Sections 4.4 and 4.5 consists of the following three steps:

Step 1. The TE distributions for the component subpopulations are combined to provide a distribution of TE for the whole population.

Step 2. The DW*TE distributions for the component subpopulations are combined to provide a distribution for DW*TE for the whole population. A population DW distribution is identified such that the population DW distribution times the population TE distribution derived in Step 1 equals the distribution for DW*TE for the whole population.

Step 3. The TM*DW*TE distributions for the component subpopulations are combined to provide a distribution for TM*DW*TE for the whole population. A population TM distribution is identified such that the population TM distribution times the population DW distribution derived in Step 2 times the population TE distribution derived in Step 1 equals the distribution for TM*DW*TE for the whole population.

The developments in Sections 4.4 and 4.5 for the recreational and expanded recreational visitor populations appropriately reflect that the data and corresponding probability distributions for TM, DW, and TE for a particular subpopulation are generally distinct from the data and probability distributions for TM, DW, and TE for a different subpopulation.

By developing separate distributions for TM, DW, and TE, Sections 4.4 and 4.5 reflect the current structure of the PPLV computations. Currently, TM and DW are not always multiplied together in the PPLV equations; so that, separate distributions for TM and DW are required, rather than a single TM*DW distribution. In particular, while TM is always multiplied by DW in the PPLV equations, DW is currently not always multiplied by TM.

The definitions and sizes of the neighborhood and regional subpopulations in the recreational scenario are the same as developed in Section 3 for the regulated/casual scenario. The sizes of the neighborhood and regional general visitor subpopulations are developed in Sections 4.1.1.2 and 4.1.1.3, respectively.

4.1 TM - Recreational Visitor Subpopulations

Probability distributions for the following durations are determined in Section 4.1:

1) TM(angler), the duration (number of hours) of a fishing visit at the Arsenal,

2) TM(neighborhood general visitor), the duration (number of hours) of a visit to the Arsenal by a general visitor who is a member of the neighborhood subpopulation,

3) TM(regional general visitor), the duration (number of hours) of a visit to the Arsenal by a general visitor who is a member of the regional subpopulation,

4) TM(organized sports visitor), the duration (number of hours) spent at an organized sports event at the Arsenal by a player or spectator at this event.

4.1.1 TM - Rationale

The derivation of probability distributions for TM in the recreational scenario is different than in the regulated/casual visitor scenario. The reason is that in the regulated or casual visitor scenario, the two visitor subpopulations engaged in the same types of activities and had the same TM distributions. However, in the recreational scenario, the four visitor subpopulations (anglers, neighborhood general visitors, regional general visitors, and organized sports visitors) do not all engage in the same types of activities and, hence, have different TM distributions.

Representative activities for recreational visitors are considered to be picnicking, walking for pleasure and exercise, bicycling, fishing, organized sports (players and attenders), and jogging. While these activities do not comprise an exhaustive list of possible activities, the probability distributions of hours of participation per activity day for these activities should provide a representative sample of the corresponding probability distributions for the possible activities.

4.1.1.1 TM(angler)

The fishing program at the Arsenal is currently managed through a permit system. During 1990, 602 Arsenal angler permits were issued on a first come first served basis (501 public permits, 34 Senior and handicap permits, and 67 military personnel permits).

Fishing is assumed to be an activity of interest to the general population. However, the distance an angler would be willing to travel for the purpose of fishing appears to be important, inasmuch as almost all of the permit applicants are residents of adjacent counties. The angler is considered, therefore, to be a member of the regional subpopulation. Bright and Manfredo also report that "As a rule, anglers visit the Arsenal to fish only. They are seldom interested in going just to the visitor center or to view wildlife only."

Site-specific data on the frequency (DW) of fishing events at the Arsenal have been researched by Colorado State University in cooperation with the USFWS (Bright and Manfredo, 1991). Data were collected using a mail-back questionnaire sent to 485 anglers who had received a 1990 permit to fish at the Arsenal. Of these, 324 usable questionnaires were returned, resulting in a response rate of 67%.

The data of importance to the development of the TM(angler) probability distribution for fishing were "use hours", i.e., how long the angler fished, and whether the anglers participated in any other activities during fishing visits to the Arsenal. The mean value for duration of fishing reported by Bright and Manfredo was 3.803 hours per visit. A frequency distribution of "use hours" was also provided by the authors. This mean and frequency distribution were fit to determine the probability distribution for TM(angler).

Regarding a different entry system or an increase in the number of permittees, Bright and Manfredo found that the "...most highly supported option (for permit allocation systems) was to keep the present system with no changes." While the model of social carrying capacity utilized by Bright and Manfredo indicated that permit numbers could be increased from 500 to 700, the USFWS is concerned with pressure on the fisheries with the goal of a self-sustaining fishery at the Arsenal, and recommends "...maintenance of 500 public fishing permits" in its 1991 Fisheries Management Recommendations (Langer, 1990). Therefore, a significant increase in the number of fishing permits issued is not foreseen.

Additional sources of duration information that were comparable to the Bright and Manfredo data used for TM(angler). On source is the USFWS report entitled Water Resources and Sport Fishery Management on the Rocky Mountain Arsenal (Langer, 1990). The Butler-Borgenson roving clerk creel survey was used wherein anglers are interviewed in the field. The average duration of a (completed) fishing visit at the Arsenal was found to be 2.75 hours at Lake Ladora. Lake Mary anglers averaged only 1.89 hours per completed fishing visit. Only mean values have been reported in this survey but some data on incomplete fishing visits also was gathered.

A third data source was the Colorado Division of Wildlife. They provided data on fishing duration and frequency in the Denver Metro area. The Division conducts surveys of participation in fishing in the State (1989 Fisherman Questionnaire). Although these data were not site-specific, they were examined for comparability with Arsenal-specific data. This survey found that anglers in the three counties surrounding the Arsenal (Adams, Arapahoe, and Denver) fished an average of 4.31 hours per visit in warm water lakes and reservoirs. The probability distribution for the product of TM and DW determined from the Division data was very comparable to the corresponding probability distribution determined from the Arsenal-specific data, and is discussed in the DW(angler) narrative.

4.1.1.2 TM(neighborhood general visitor)

Derivation of the Hours/Day of Recreational Activity for a General Visitor

The general visitor population includes individuals who participate in all recreational activities defined for the Arsenal except those related to fishing and organized sports. Representative activities for general visitors were modeled after those provided in Volume I of the Human Health Exposure Assessment and were considered to be bicycling, walking, running or jogging, and playing or attending informal outdoor team sports. A distinction was made between informal sport events, including frisbee, pickup games of soccer, softball, etc., and organized sport leagues which are characterized in the Section 4.1.1.4. These representative activities do not necessarily comprise an exhaustive list of possible general recreational activities at the Arsenal. However, the probability distributions of hours of participation per activity day for these five activities provide a representative sample of the corresponding probability distributions for other possible activities.

General visitor activities and the probability distribution for visitation duration TM(hours/day) are the same for the neighborhood and regional general visitor subpopulations. However, the number of such visitors in each subpopulation differ, and the probability distributions for both visitation frequency DW(days/year) and years of visitation TE(years/lifetime) differ. Even though TM(neighborhood general visitor) and TM(regional general visitor) have the same probability distributions, for clarity, each distribution is presented explicitly and separately.

The probability distribution of the number of hours that a recreational visitor to the Arsenal would spend participating in non-fishing and non-organized sports activities at the Arsenal was derived from several data sources: "Estimates of Visitations to Alternative Recreational Surface Uses Proposed for the Rocky Mountain Arsenal" (THK, 1991); the National Sporting Goods Association (1988 and 1990); the Gallup Leisure Activities Index, 1986; the National Park Service (1986); Walsh (1986); and the U.S. Bureau of Outdoor Recreation (1972).

The development of the TM(general visitor) distribution involved characterizing distributions for the hours of participation for each of the five representative activities.

Although there are data on the preferences among activities that are specific to Colorado or the Western regions, no data were available on the average duration of those activities in an environment specifically comparable or nearly comparable to that at the Arsenal. National data on the average number of hours of participation per activity day are given on page 78 in Walsh (1986) for four of the activities. For running or jogging, data were used from the Gallup Leisure Activities Index (1986).

The data used in developing the TM(general visitor) distribution, and the specific sources for these data are:

Activity	Average Number of Hours of Participation per Activity Day
Bicycling	2.0[a]
Playing Outdoor Sports	2.6[a]
Attending Outdoor Sports	4.2[a]
Walking	1.9[a]

[a] U.S. Bureau of Outdoor Recreation, 1972, page 78 in Walsh (1986)

For running or jogging, a distribution was developed from Gallup data providing the percentage of joggers (15% of the adult population) who would jog discrete mileage increments up to > 10. An average jogging speed of 8.5 minutes/mile plus an estimated total warm-up and cool-down time of 15 minutes/jog was used to derive TM(hours/day), as follows:

Percentage of Joggers	Miles Jogged	Time Spent (minutes)
20%	1	23.5
44%	2	32.0
68%	3	40.5
79%	4	49.0
86%	5	57.5
92%	6	66.0
97%	10	100.0
98%	> 10	> 100.0
100%	Not Sure	

For each of the representative general recreational activities, a normal or lognormal probability distribution was used to describe the activity duration on an activity day.

The five activity-specific duration distributions are combined based on their relative contribution to the total number of activity days. The relative contributions are derived from the available data on the number of days of activity participation per participant and the percentage of the population that participate in the activity:

Activity	Average Annual Days for a Participant	Percent of Population Participating
Bicycling	54.8[a]	26%[d]
Playing Outdoor Sports	44.6[b]	23%[d]
Attending Outdoor Sports	10.6[b]	26%[d]
Walking for Exercise	96.6[c]	43%[d]
Running or Jogging	57.6[c]	15%[e]

[a] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1988).
[b] National Average (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20)
[c] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1990).
[d] Percent participation in population areas with more than one million people (National Park Survey, 1986).
[e] Gallup Leisure Activities Index, 1986. Gallup also cited in development of TM and DW distributional shape.

It is assumed that general recreational visitors would tend to participate in only one activity on a given day. For example, a person would not normally run 5 miles and then participate in a team sporting event like soccer or softball. However, a person might combine one of these representative recreational activities with some leisure time such as a picnic. Therefore, the probability distribution for the total number of hours per activity day for recreational visitors is calculated assuming the possibility of either a single recreational activity or a single recreational activity plus a picnic.

Derivation of the Number of General Recreational Visitors in the Neighborhood Visitor Subpopulation

The neighborhood subpopulation size (14,875 as derived in Section 3.1.2) includes both the residents who do and do not participate in general recreational activities at the Arsenal. The number of Arsenal visitors in this subpopulation is the number of neighborhood residents who participate in general recreational activities at the Arsenal. This neighborhood general visitor subpopulation and the corresponding regional general visitor subpopulation are the subpopulations to which the DW (days/year) and TE (years/lifetime) distributions apply.

The number of people in the neighborhood general visitor subpopulation depends on the number (14,875) of people who live in the neighborhood at some point in their lifetime as well as the fraction of those people who participate in general visitor activities. For the following estimated proportions of the potential neighborhood participants in general recreational activities at the Arsenal,

Activity	Fraction Participating
Bicycling	0.26[a]
Playing Outdoor Sports	0.23[a]
Attending Outdoor Sports	0.26[a]
Walking for Exercise	0.43[a]
Running or Jogging	0.15[b]

[a] Percent participation in population areas with more than one million people (National Park Survey, 1986).
[b] Gallup Leisure Activities Index, 1986. Gallup also cited in the development of TM and the DW distributional shape.

the probability that a potential participant participates in at least one activity is equal to the following, under the assumption of independence,

= 1 - Probability a potential participant participates in no such activities

= 1 - (1-0.26)*(1-0.23)*(1-0.26)*(1-0.43)*(1-0.15) = 1 - 0.204 = 0.796

That is, 79.6% of the potential participant population is estimated to participate in at least one general recreational activity. Here, as in the regulated/casual scenario, the potential participants are non-institutionalized people 12 years old and older, which is approximately 81.5% of the population. Thus, approximately 79.6% of 81.5% of the total population, which is approximately 65% of the total population (0.796 * 0.815 = 0.6487), is expected to participate in at least one general recreational activity at the Arsenal. Therefore, the number of general recreational visitors in the neighborhood visitor subpopulation is

0.6487 * 14,875 = 9,649.

4.1.1.3 TM(regional general visitor)

Derivation of the Hours/Day of Recreational Activity for a General Visitor

Regional general visitor activities and the probability distribution for visitation duration TM(hours/day) are the same as they are for the neighborhood general visitor subpopulation. However, the number of regional general visitors and their probability distributions for both visitation frequency DW(days/year) and years of visitation TE(years/lifetime) are different than they are for the neighborhood general visitor. Even though TM(neighborhood general visitor) and TM(regional general visitor) have the same probability distributions, for clarity, each distribution is presented explicitly and separately.

Derivation of the Number of General Recreational Visitors in the Regional Visitor Population

The probability that a particular individual among the 1,848,319 people in the regional population would be a member of the regional visitor subpopulation depends on that individual's 70 year history of residence locations and the probability that an individual would be a general recreational visitor to the Arsenal while living at a location. Individual 70 year histories were simulated; i.e., at each residence location two quantities were simulated; namely, (1) the duration of that residence from the individual residence duration distribution (Section 3.3.3) and (2) whether or not the individual would be a general recreational visitor to the Arsenal visitor while at that location. At the end of that residence period, a move was simulated and the process repeated. The simulation stopped when either the cumulative duration at all residences exceeded 70 years or the move was out of State. The simulation is the same as that in Section 3.2.1 for the number of regulated/casual visitors in the regional visitor population except that the probability determining (2), i.e., whether or not the individual would be an Arsenal visitor while at that location, is different for a general recreational visitor than it was for a regulated/casual visitor.

The results of the simulations are discussed first, and then the data base for the probabilities used in the simulations are discussed. In 10,000 simulations, 83.85% of the 70 year histories never included a residence duration for which the individual was a general recreational visitor to the Arsenal. That is, approximately 84% of the people in the regional population (who were not part of the neighborhood population) would not be expected to be a general recreational visitor to the Arsenal. In the simulations, 14.31% individuals had one residence duration in which they were Arsenal visitors, 1.65% had two such residence durations, 0.15% had three, and 0.04% had four. Thus, the percentage of the population that would be in the regional general visitor population would be 16.15% (14.31% + 1.65% + 0.15% + 0.04% = 16.15%). Because the estimated number of people in the neighborhood population is 14,875 (see Section 4.1.1.2), the number of people in the regional general visitor population is

$$296{,}101 = 16.15\% * (1{,}848{,}319 - 14{,}875).$$

Of these 296,101 people comprising the regional general visitor subpopulation, 88.6% (14.31/16.15 = 0.886) have only one residence duration in which they are Arsenal visitors. Similarly, 10.2% (1.65/16.15 = 0.102) have two residence durations in which they are Arsenal visitors. Finally, smaller percentages, namely 0.9% (0.15/16.15 = 0.009) and 0.2% (0.04/16.15 = 0.002) have 3 and 4 residence durations in which they are general recreational visitors to the Arsenal. The information on multiple moves is utilized in the development of the distribution of TE(years/lifetime).

In the simulation, the probabilities associated with moves are the same as in the regional simulation in Section 3.1.2.

In the simulation, the probability that an individual would be *interested* in the Arsenal, i.e., make a general recreational visit to the Arsenal, while living at a particular non-neighborhood location can be estimated by considering the fraction of the current 1,848,319 Metro area residents who would be expected to make a general recreational visit to the Arsenal if it were fully developed and open today. Only non-neighborhood locations are considered because people who have any of their residence locations in the neighborhood are part of the neighborhood population and not part of the regional visitor population. The fraction of the current Metro area residents who would be expected to make a general recreational visit to the Arsenal can be estimated by

(1) estimating the total number of general recreational activity days at the Arsenal,

(2) using Barr Lake repeat visitation data to estimate the number of visitors corresponding to that estimated number of visitation days (Section 3.2.1.7), and

(3) dividing by that number of Arsenal visitors by the total number of people currently living in the Metro area, 1,848,319.

Step (1) is as follows:

Activity	Fraction of 1,848,319 People Who Participate[a]	Number of Participants (Fraction * 1,848,319)	Average # of Days per Year	Total # of Days per Year	Total Capture Rate for All Eight Denver Metro Area Parks[g]	RMA Capture Rate[h]	RMA Recreational Visitor Days[i]
Bicycling	0.26[b]*0.815	391,659	54.8[d]	21,462,913	0.0277	1/9	66,058
Playing Outdoor Sports	0.23[b]*0.815	346,467	44.6[e]	15,452,428	0.0277	1/9	47,559
Attending Outdoor Sports	0.26[b]*0.815	391,659	10.6[e]	4,151,585	0.0277	1/9	12,778
Walking for Pleasure and/or Exercise	0.43[b]*0.815	647,743	96.6[f]	62,571,974	0.0277	1/9	192,583
Running or Jogging	0.15[c]*0.815	225,957	57.6[f]	13,015,123	0.0277	1/9	40,058
Total		2,003,485		116,654,023			359,036

[a] 0.815 is the estimated fraction of the total population that is non-institutionalized and 12 years old or older.

[b] The proportion of the population who participate in the activities in population areas with more than one million people, National Park Service, 1986. The participation rate for walking includes both pleasure and exercise purposes, using professional judgement based on several references.

[c] Gallup Leisure Activities Index, 1986.

[d] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1988).

[e] National Average (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).

[f] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1990).

[g] 0.0277 is the total 1989 attendance (3,229,184) at the eight Denver Metropolitan Area Parks (Colorado Department of Parks and Outdoor Recreation, in THK, 1990) divided by 116,654,023. Because a large proportion of the 1989 attendance took place at the two parks with several amenities (including large reservoirs) (Section 3.2.2.2), assuming that all of 3,229,184 is due to the five tabled activities makes the capture rate (0.0277) very conservative.

[h] 1/9 assumes that the potential draw of the developed Arsenal will be equal to that of any of the existing eight Denver Metro Area Parks.

[i] The total number of general recreational visitor days at the Arsenal is the product of the number of participants, average number of days per year, the Denver Metro Area Parks capture rate, and the RMA capture rate; e.g., 391,659*54.8*0.0277*1/9 = 66,058.

Thus, there are estimated to be 359,036 visitation days from regional general recreational visitors. To accomplish Step 2), the Barr Lake repeat visitation frequency data are assumed to be predictive of Arsenal repeat visitation for regulated or casual visitors in the regional subpopulation (Section 3.2.2.2). These frequencies are 2.3 days/year for a Daily Fee visitor, 4.6 days/year for a Annual Pass visitor, and 6.4 days/year for an Aspen Leaf Passholder. The relative percentages of visitors who enter using Daily Fees, Annual Passes, and Aspen Leaf Passes are 81%, 13%, and 6%, respectively. Hence, if the regional visitors are expected to make 359,036 visits/year and

(# of Regional Visitors) * 2.3 days/year * 0.81 +
(# of Regional Visitors) * 4.6 days/year * 0.13 +
(# of Regional Visitors) * 6.4 days/year * 0.06 = 359,036 visitation days,

then it follows that the yearly number of regional visitors is 126,199. Finally, step (3) implies that the estimated probability of an individual would be *interested* in making a general recreational visit to the Arsenal while living at a particular non-neighborhood location is 126,199/1,848,319 which equals 0.0683.

4.1.1.4 TM(organized sports visitor)

If an athletic complex were constructed at the Arsenal and made available to organized sports leagues, then recreational visitors to the Arsenal would include organized sports visitors. These visitors would include both players and spectators.

Data on organized sports participation in Commerce City have been provided by Tim Moore, Athletic Coordinator for the City of Commerce City. These data regard the number of participants and description of participation in sports programs offered by the City. Because these data pertain more directly to DW (days per year) than to TM (hours per day), these data are discussed in detail in Section 4.2.1.4.

Data on the duration (hours per day) of playing outdoor team sports are provided by the U.S. Bureau of Outdoor Recreation (1972) cited on page 78 in Walsh (1986). The average number of hours of participation per activity day is 2.6 hours. A lognormal probability distribution with mean 2.6 hours and a specified 5th percentile of 30 minutes is used to describe the organized sports participation duration. This is the same probability distribution used for the "playing outdoor sports" component of TM(neighborhood general visitors) and TM(regional general visitor). Players and spectators are assumed to be at the Arsenal for the same number of hours per visit.

4.1.2 TM - Probability Distributions

4.1.2.1 TM(angler)

The probability distribution for the duration TM(angler) in hours/day of fishing has the following percentiles:

Probability (TM(angler) ≤ 8.58 hours/ activity day) = 0.99
Probability (TM(angler) ≤ 7.27 hours/ activity day) = 0.975
Probability (TM(angler) ≤ 6.31 hours/ activity day) = 0.95
Probability (TM(angler) ≤ 5.75 hours/ activity day) = 0.925
Probability (TM(angler) ≤ 5.36 hours/ activity day) = 0.90
Probability (TM(angler) ≤ 4.40 hours/ activity day) = 0.80
Probability (TM(angler) ≤ 4.08 hours/ activity day) = 0.75
Probability (TM(angler) ≤ 3.81 hours/ activity day) = 0.70
Probability (TM(angler) ≤ 3.37 hours/ activity day) = 0.60
Probability (TM(angler) ≤ 3.01 hours/ activity day) = 0.50
Probability (TM(angler) ≤ 2.68 hours/ activity day) = 0.40
Probability (TM(angler) ≤ 2.38 hours/ activity day) = 0.30
Probability (TM(angler) ≤ 2.22 hours/ activity day) = 0.25
Probability (TM(angler) ≤ 2.06 hours/ activity day) = 0.20
Probability (TM(angler) ≤ 1.69 hours/ activity day) = 0.10
Probability (TM(angler) ≤ 1.57 hours/ activity day) = 0.075
Probability (TM(angler) ≤ 1.43 hours/ activity day) = 0.05
Probability (TM(angler) ≤ 1.24 hours/ activity day) = 0.025
Probability (TM(angler) ≤ 1.06 hours/ activity day) = 0.01

This is a lognormal distribution with mean 3.33 and standard deviation 1.58. The ln[TM(angler)] has a normal distribution with mean 1.1015 and standard deviation of 0.4504. The mathematical development of this distribution is given in Section 4.1.3.1.

4.1.2.2 TM(neighborhood general visitor)

The probability distribution for the duration TM(neighborhood general visitor) in hours/day of non-fishing and non-organized sports recreational activities has the following percentiles:

Probability (TM(neighborhood general visitor) ≤ 9.18 hours/ activity day) = 0.99
Probability (TM(neighborhood general visitor) ≤ 8.10 hours/ activity day) = 0.975
Probability (TM(neighborhood general visitor) ≤ 6.13 hours/ activity day) = 0.95
Probability (TM(neighborhood general visitor) ≤ 4.95 hours/ activity day) = 0.925
Probability (TM(neighborhood general visitor) ≤ 4.44 hours/ activity day) = 0.90
Probability (TM(neighborhood general visitor) ≤ 2.64 hours/ activity day) = 0.75
Probability (TM(neighborhood general visitor) ≤ 1.54 hours/ activity day) = 0.50
Probability (TM(neighborhood general visitor) ≤ 0.85 hours/ activity day) = 0.25

Probability (TM(neighborhood general visitor) ≤ 0.51 hours/ activity day) = 0.10
Probability (TM(neighborhood general visitor) ≤ 0.44 hours/ activity day) = 0.075
Probability (TM(neighborhood general visitor) ≤ 0.39 hours/ activity day) = 0.05
Probability (TM(neighborhood general visitor) ≤ 0.29 hours/ activity day) = 0.025
Probability (TM(neighborhood general visitor) ≤ 0.21 hours/ activity day) = 0.01

This distribution includes the possibility of the neighborhood general visitor activities being combined with picnics. This is a lognormal distribution with mean 2.46 and standard deviation 3.026. The ln[TM(organized sports visitor)] has a normal distribution with mean 0.44 and standard deviation of 0.96.

The probability distribution for TM(neighborhood general visitor) and TM(regional general visitor) are identical. The mathematical development of this distribution is given in Section 4.1.3.2.

4.1.2.3 TM(regional general visitor)

The probability distribution for TM(regional general visitor) is the same as that for TM(neighborhood general visitor) given in Section 4.1.2.2. The mathematical development of this distribution is given in Section 4.1.3.2.

4.1.2.4 TM(organized sports visitor)

The probability distribution for the duration TM(organized sports visitor) in hours/day of participation has the following percentiles:

Probability (TM(organized sports visitor) ≤ 14.48 hours/ activity day) = 0.99
Probability (TM(organized sports visitor) ≤ 10.18 hours/ activity day) = 0.975
Probability (TM(organized sports visitor) ≤ 7.53 hours/ activity day) = 0.95
Probability (TM(organized sports visitor) ≤ 6.18 hours/ activity day) = 0.925
Probability (TM(organized sports visitor) ≤ 5.31 hours/ activity day) = 0.90
Probability (TM(organized sports visitor) ≤ 2.96 hours/ activity day) = 0.75
Probability (TM(organized sports visitor) ≤ 1.55 hours/ activity day) = 0.50
Probability (TM(organized sports visitor) ≤ 0.81 hours/ activity day) = 0.25
Probability (TM(organized sports visitor) ≤ 0.45 hours/ activity day) = 0.10
Probability (TM(organized sports visitor) ≤ 0.39 hours/ activity day) = 0.075
Probability (TM(organized sports visitor) ≤ 0.32 hours/ activity day) = 0.05
Probability (TM(organized sports visitor) ≤ 0.24 hours/ activity day) = 0.025
Probability (TM(organized sports visitor) ≤ 0.17 hours/ activity day) = 0.01

This is a lognormal distribution with mean 2.46 and standard deviation 3.026. The ln[TM(organized sports visitor)] has a normal distribution with mean 0.44 and standard deviation of 0.96. The mathematical development of this distribution is given in Section 4.1.3.4.

4.1.3 TM - Mathematical Development

4.1.3.1 TM(angler)

The probability distribution for TM(angler) involves only one activity and only one type of visitor, namely, a person with a fishing permit. Hence, the mathematical development was not complicated by the necessity to combine several component probability distributions. Site-specific data on the duration (TM) of fishing events at the Arsenal have been researched by Colorado State University in cooperation with the USFWS (Bright and Manfredo, 1991). These site-specific data are as follows:

Value	Frequency	Percent	Percent Among Valid Responses	Cumulative Percent Among Valid Responses
0	9	2.8	2.9	2.9
1	6	1.9	1.9	4.8
2	51	15.7	16.2	21.0
3	77	23.8	24.4	45.4
4	89	27.5	28.3	73.7
5	40	12.3	12.7	86.3
6	23	7.1	7.3	93.7
7	3	0.9	1.0	94.6
8	13	4.0	4.1	98.7
9	0	0.0	0.0	98.7
10	4	1.2	1.3	100.00
Invalid	9	2.8	Invalid	
Total	324	100.00	100.00	

The values for "Cumulative Percent Among Valid Responses" were fit to the lognormal and normal distributions using the weighted least squares fitting procedure described at the end of Section 3.1.3. The best fitting distribution for TM(angler) is a lognormal distribution with mean 3.33 and standard deviation 1.58. Although the fitted mean 3.33 is slightly lower than the sample mean 3.803, the sample mean is only a single number description of the sample whereas the 11 sample percentages corresponding to 0, 1, 2, ..., 10 hours are a much more complete description of the sample and the fitted distribution corresponds closely to this more complete description. In the fitting procedure, the percentage corresponding to the maximum sample

value 10 is considered to be 99.7% instead of 100% because the 100th percentile of both the normal and lognormal distributions is plus infinity. The 99.7% value corresponds to the expected percentage of a continuous distribution not exceeding the largest value in a sample of size 315 (324 - 9 invalid values = 315 values);i.e, 99.7% = 100% * n/(n+1) when the sample size n equals 315 (Wilks, 1962). A comparison of the observed and fitted percentiles is as follows:

Percentage	Observed (Bright and Manfredo, 1991) (Hours)	Fitted Lognormal Distribution (Hours)
99.7	10.00	10.37
98.7	8.00	8.20
94.6	7.00	6.21
93.7	6.00	5.99
86.3	5.00	4.92
73.7	4.00	4.00
45.4	3.00	2.86
21.0	2.00	2.09
4.8	1.00	1.42
2.9	0.00	1.28

A graphical indication of the fit is given in Figure 4.1.3.1.

4.1.3.2 TM(neighborhood general visitor)

The probability distribution for TM(neighborhood general visitor) and TM(regional general visitor) are identical. The development of the probability distribution for TM(neighborhood general visitor) for a recreational visitor to the Arsenal involves the following three steps:

1. Determine the probability distributions for each individual activity duration.

2. Determine the relative frequency of each activity among recreational activity days.

3. Determine the general visitor activity duration distribution by combining the individual activity duration distributions on the basis of the relative frequencies of the different activities and by including picnics.

Step 1. Determine the probability distributions for each individual activity duration.

The durations of the five representative recreational activities vary from individual to individual. For each of the first four representative activities, a normal or lognormal probability distribution

with a specified mean number of hours and a specified 5th percentile was used to describe the activity duration on an activity day. For running and jogging, the "Not Sure" category was dropped, the remaining percentages were rescaled to sum to 100%, and the lognormal distribution provided a good fit to the results, as follows:

Rescaled Percentages	Miles Jogged	Time Spent (hours)	Fitted Time (hours)
20.4%	1	0.392	0.372
44.9%	2	0.533	0.516
69.4%	3	0.667	0.695
80.6%	4	0.817	0.822
87.8%	5	0.958	0.946
93.9%	6	1.100	1.132
99.0%	10	1.667	1.632

For the first four representative general recreational activities, the average durations are as follows:

Activity	Average Number of Hours of Participation per Activity Day
Bicycling	2.0[a]
Playing Outdoor Sports	2.6[a]
Attending Outdoor Sports	4.2[a]
Walking for Exercise	1.9[a]

[a] U.S. Bureau of Outdoor Recreation, 1972, page 78 in Walsh (1986).

The following duration distributions were assigned for these four activities by equating the mean of each distribution to the data based means given above and applying professional judgment to obtain the distribution shape and 5th percentile. The duration distribution for running or jogging was obtained as described above.

Activity	Distribution Type	Parameters 1	Parameters 2	Mean	Std. Dev.
Attending Outdoor Sports	Normal	—	—	4.2	1.628
Bicycling	Lognormal	0.45	0.70	2.0	1.59
Playing Outdoor Sports	Lognormal	0.63	0.81	2.6	2.51
Walking for Exercise	Lognormal	0.41	0.67	1.9	1.42
Running or Jogging	Lognormal	-0.60	0.47	0.61	0.30

The mean duration for attending outdoor sports events is somewhat large (4.2 hours) and falls approximately in the middle of reasonable lower and upper bounds (0 and 8 hours) for attendance at such an event. Because of this symmetry, the duration distribution for attending sports events was assumed to be approximately normal with a mean of 4.2. The 5th percentile of this distribution was assumed to be 1.5 hours to reflect that most sports events last at least one hour and a person attending an hour long event might reasonably arrive 15 minutes before the event and leave 15 minutes after the event. This person would spend 1.5 hours attending that outdoor sports event. The 99th percentile of this distribution is 8 hours. The data on which this distribution is based presumably reflects a significant portion of attendance at major professional sports events which tend to have longer durations than the informal team sports activities expected at the Arsenal. Therefore, this distribution provides a conservative upper bound for the distribution of duration for individuals attending informal sports events.

Lognormal distributions were assigned to each of the other activities. The distributions for bicycling, playing outdoor sports, and walking for exercise were assumed to have 5th percentiles equal to 30 minutes.

Step 2. Determine the relative frequency of each activity among recreational activity days.

The relative frequency of each activity depends on average number of days of participation per year for each activity and the percentage of the population participating in each of the five representative activities for general recreational visitors to the Arsenal. These data are given in the first two columns below.

Activity	Annual Days for an Average Activity Participant	Percent of Population Participating	Annual Days for an Average General Visitor	Fraction of Total Days
Bicycling	54.8[a]	26%[d]	14.25[f]	0.184[g]
Playing Outdoor Sports	44.6[b]	23%[d]	10.26	0.132
Attending Outdoor Sports	10.6[b]	26%[d]	2.76	0.036
Walking for Exercise	96.6[c]	43%[d]	41.54	0.536
Running or Jogging	57.6[c]	15%[e]	8.64	0.112
Total			77.45	1.000

[a] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1988, in THK, 1990).
[b] National Average (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).
[c] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1990).
[d] The proportion of the population who participate in activities in population areas with more than one million people, National Park Service, 1986.
[e] Gallup Leisure Activities Index, 1986. Gallup also cited in the development of TM and the DW distributional shape.
[f] 54.8 * 26% = 14.25
[g] 14.25 / 77.45 = 0.184

These figures are interpreted as follows. An average individual in the bicycling portion of the population (26% of the entire population) spends 54.8 days bicycling each year. It follows that when the entire population is considered (including non-bikers), an average individual spends 54.8*0.26 + 0.0*0.74 = 14.25 days bicycling each year. Similarly, an average individual from the entire population spends 10.26 days per year playing outdoor sports and so on. These figures imply that the average person in Colorado participates in some recreational activity 77.45 days per year. The important information is not the total number of recreational days, which are spread over many different parks or other facilities. Rather, the important information is that, of those 77.45 days, the proportion of days involving bicycling is 0.184, the proportion of days involving playing outdoor sports is 0.132, etc. This means, for example, that the probability is 0.184 that a randomly selected recreational day involves bicycling.

The probabilities corresponding to the "fraction of total days" are important to the calculation of TM(neighborhood general visitor). These probabilities imply how often the TM(neighborhood general visitor) for a recreational activity day should be calculated from the bicycling duration distribution, the playing outdoor sports duration distribution, etc.

Step 3. Determine the general visitor activity duration distribution by combining the individual activity duration distributions on the basis of the relative frequencies of the different activities and by including picnics.

The probability distribution for the number of hours participating in some general recreational visitor activity in a day that an individual participates in some such activity is determined by combining the probability distributions for hours per day for individual activities together with the relative frequency of the different activities. That is, the individual activity probability distributions are combined on the basis of the recreational visitors's relative preferences among those activities. The activities preferred the most by recreational visitors receive the greatest emphasis. The estimated relative frequencies of the different representative recreational activities are the fractions of total days tabled in Step 2.

The probability distribution for TM(neighborhood general visitor) can be estimated by simulation techniques using the probability distributions for the individual activity durations, the relative frequencies of the different activities, and the probability distribution for the duration of a picnic that might be combined with a recreational activity. The TM(neighborhood general visitor) on a recreational day is simulated by the following sequence of actions:

1.) Randomly select one of the five representative recreational activities. The probabilities of selecting bicycling, playing outdoor sports, attending outdoor sports, walking for exercise, or running/jogging are 0.184, 0.132, 0.036, 0.536, and 0.112, respectively.

2.) Randomly select an activity duration from the activity duration distribution corresponding to the activity selected in action (1). Set TM(neighborhood general visitor) equal to this duration.

3.) Randomly determine if the selected recreational activity is to be combined with a picnic. If it is, then randomly select the picnic duration from the probability distribution for picnic durations, and add the picnic duration to TM(neighborhood general visitor).

In action (3), 50% of all picnics are assumed to be combined with <u>each</u> type of recreational activity. The national average number of picnicking days is 6.6 days per year among people who picnic. Therefore, 3.3 picnicking days per year are combined with each type of recreational activity. For example, the average number of bicycling days per year for a bicyclist is 54.8 days. Thus, in action (3), if the selected recreational activity is bicycling, then the probability of adding a picnic duration to the recreational activity duration is 3.3/54.8 because this is the proportion of overlap of 3.3 picnicking days among 54.8 days of bicycling. Picnic durations are assumed to have the same distribution as they had for regulated/casual visitors, i.e., a lognormal distribution with mean 2.7 hours and standard deviation 2.65 hours.

This sequence of actions is repeated numerous times. The percentiles of the resulting frequency distribution of simulated neighborhood general visitation duration values are an estimate of the percentiles of the probability distribution for TM(neighborhood general visitor).

The simulated percentiles were fit to the normal and lognormal distributions using the weighted least squares estimation procedure described in Step 5 near the end of Section 3.1.3. The best fitting distribution is a lognormal distribution. The best fitting lognormal distribution has mean 6.7833 and standard deviation 21.5036 which corresponds to the logarithm of a normal random variable with mean 0.7133 and standard deviation 1.5500. The fit itself can be described as follows:

Percentage	Observed Percentile	Fitted Percentile
95	25.63	26.12
90	16.04	14.87
80	7.23	7.52
75	5.41	5.80
70	4.25	4.60
65	3.44	3.71
60	2.84	3.02
55	2.37	2.48
50	1.98	2.04
45	1.65	1.68
40	1.38	1.38
35	1.13	1.12
30	0.92	0.91
25	0.73	0.72
20	0.56	0.55
15	0.40	0.41
10	0.25	0.28
5	0.12	0.16

A graphical indication of the fit is shown in Figure 4.1.3.2.

4.1.3.3 TM(regional general visitor)

The probability distribution for TM(regional general visitor) is the same as that for TM(neighborhood general visitor) derived in Section 4.1.3.2.

4.1.3.4 TM(organized sports visitor)

The probability distribution for TM(organized sports visitor) is expected to be skewed in that values much larger than the mean may occasionally occur. Therefore, lognormality was assumed. This distribution can be estimated based on the mean duration reported by U.S.

Bureau of Outdoor Recreation (USBOR 1972), which is 2.6 hours for participation in team sports. Based on this mean and an assumed 5th percentile of 30 minutes, the corresponding lognormal distribution would have a mean of 2.6, standard deviation 2.51, and 95th percentile of 7.12 hours, which is consistent with nearly a full day of participation in or attendance at organized sports activities. The logarithmic durations would have a mean of 0.63 and standard deviation of 0.81. However, this distribution was not assigned to TM(organized sports visitor). Instead, as described below, TM(organized sports visitor) was assigned an adjusted lognormal distribution which is more appropriate when the DW(organized sports visitor) distribution is approximated by a lognormal distribution.

The distribution for TM(organized sports visitor) was determined by estimating the distribution for TM*DW (organized sports visitor) and then back-calculating the TM(organized sports visitor) distribution. The reason for this back calculation was to ensure that the product of the TM and DW distributions most closely represents the information contained in the data and the stated assumptions. Additional explanation is found below. Specifically, the following steps were involved in the estimation of the final TM(organized sports visitor) distribution (See also Figure 4-1, Section 7.0):

Step 1. Derive a first estimate of distribution of the duration for organized sports visitors (TM_1) based on USBOR data and professional judgement. As explained in the preceding paragraph, the lognormal distribution was used to characterize this first estimate of the duration distribution.

Step 2. Develop a first estimate of distribution of the number of visits/year for organized sports visitors (DW_1). This step is fully described in Section 4.2.3.4.

Step 3. Estimate the distribution of hours/year. In this step, simulated data for hours/year are generated by repeatedly sampling from TM_1 and DW_1 and calculating the product of the sample values. The numerical results of this step are described below. Samples from TM_1 are drawn by sampling the corresponding lognormal distribution, while samples from DW_1 are simulated using the procedure described in Section 4.2.3.4. In this way, the TM*DW distribution is based on the simulated data for DW rather than a lognormal approximation of the DW distribution, thus increasing the accuracy of the distribution of hours/year. The resulting simulated data for TM_1*DW_1 are fit with a lognormal distribution, which is given at the end of this section. This lognormal distribution ($TM*DW_{final}$) is the distribution which is most reflective of the available data.

Step 4. Determine a final estimate of the distribution of the number of visits/year for organized sports visitors (DW_{final}) by fitting a lognormal distribution to the simulated data for DW_1.

Step 5. Estimate the final duration distribution for organized sports visitors (TM_{final}) by solving the mathematical formulas which insure that the distribution of TM_{final} * DW_{final} equals the distribution of $TM*DW_{final}$.

The reason that TM_{final} is used instead of TM_1 is that the product of the distributions for TM_{final} and DW_{final} equals the lognormal distribution fit to TM_1*DW_1, which is most accurate characterization of hours per year. The distribution of TM*DW incorporates the simulated data for DW directly and avoids the use of a lognormal approximation of this data. For other subpopulations, a back calculation was not necessary because both TM and DW were assumed to be lognormal. In the PPLV equations, the TM parameter is always multiplied by DW. Therefore, as long as the TM*DW distribution is accurate, the distribution of TM itself is arbitrary. In contrast, DW currently occurs alone in some of the PPLV equations. Therefore, it is important to characterize as accurately as possible the distributions of TM*DW and DW and then, based on these distributions, to back-calculate the distribution for TM.

In step 3, the distribution of TM_1*DW_1 was simulated. This distribution was best fit by a lognormal distribution with a mean of 25.819 and standard deviation 51.793. The ln(TM*DW) values are normally distributed with mean 2.4440 and standard deviation 1.2705. The fit of this lognormal distribution to the simulated data is as follows:

Percentage	Estimated Distribution for TM*DW (Hours/Year)	Fitted Lognormal Distribution for TM*DW (Hours/Year)
99	214.06	221.34
97.5	140.07	138.96
95	96.34	93.11
92.5	74.20	71.73
90	61.97	58.69
80	35.14	33.56
75	27.64	27.14
70	21.91	22.43
60	14.37	15.89
50	8.83	11.52
40	4.71	8.35
30	1.12	5.92
25	0	4.89
20	0	3.95
10	0	2.26
7.5	0	1.85
5	0	1.43
2.5	0	0.95
1	0	0.60

A graphical indication of the fit is shown in Figure 4.1.3.4.

The upper percentiles of the estimated distribution of TM*DW are fit quite well by the lognormal distribution. Hence, the product TM*DW is reasonably well approximated by the fitted lognormal distribution. It is important that this estimated distribution of TM*DW be reflected in the characterization of TM*DW for the organized sports visitor and ultimately be represented in the PPLV equations for the expanded recreational population. Therefore, the separate distributions for TM(organized sports visitor) and DW(organized sports visitor) were developed in steps 4 and 5 below, so that their product equals the above fitted lognormal distribution for TM*DW.

Step 4 utilizes the lognormal distribution for DW(organized sports visitor) presented in Section 4.2.2.4.

In Step 5, the distribution of TM(organized sports visitor) was back-calculated. If TM*DW and DW are lognormally distributed, then the best fitting lognormal distribution of TM can be determined exactly using a result from the statistical theory for lognormal distributions. In short, the product of two lognormal random variables is itself lognormal and has a log mean and log standard deviation which can be easily calculated from the log means and log standard deviations of the original two random variables. This calculation is the same as that indicated in detail in Section 4.4.2.3.

This statistical result implies that, if TM*DW is lognormally distributed with mean 25.819 and standard deviation 51.793, DW is lognormally distributed with mean 10.496 and standard deviation 10.492, and TM is lognormally distributed, then TM has mean 2.460 and standard deviation 3.026. Therefore, TM(organized sports visitor) was assigned a lognormal distribution with mean 2.460 and standard deviation 3.026. The ln [TM(organized sports visitor)] has mean 0.44 and standard deviation 0.96.

As mentioned in the first paragraph of this section, the TM distribution directly based on the USBOR data has a mean of 2.600 and standard deviation 2.510. The difference between this distribution and that assigned to TM(organized sports visitor) is relatively small. For example, the 95th percentile increases from 7.12 hours (USBOR) to 7.53 hours and the 50th percentile decreases from 1.88 hours (USBOR) to 1.55. However, the change allows the product of the distributions of TM(organized sports visitor) and DW(organized sports visitor) to better fit the simulated data on TM*DW.

4.2 DW - Recreational Visitor Subpopulations

Probability distributions for the following visitation frequencies (days/year) are determined in this section.

1) DW(angler), the number of days per year spent fishing on the Arsenal,

2) DW(neighborhood general visitor population), the number of days per years spent in general recreational activities at the Arsenal by members of the neighborhood population,

3) DW(regional general visitor), the number of days per year spent in non-fishing and non-organized sports activities on the Arsenal, and

4) DW(organized sports participation), the number of days per year spent as a player or spectator in organized sports leagues on the Arsenal.

4.2.1 DW - Rationale

4.2.1.1 DW(Angler)

As in TM, fishing is assumed to be an activity in which the regional subpopulation participates (Section 4.1.1.1).

Site-specific data for the duration (TM) and frequency (DW) of fishing events at the Arsenal have been researched by Colorado State University in cooperations with the USFWS (Bright and Manfredo, 1991). Data were collected using a mail-back questionnaire sent to 485 anglers who had received a 1990 permit to fish at the Arsenal. Of these, 326 usable questionnaires were returned, resulting in a response rate of 67%.

The data of importance to the development of the DW(angler) probability distribution for fishing were "the number of times been to Arsenal in 1990 to fish {sic}". The mean value for frequency of fishing reported by Bright and Manfredo was 12.246 times per fishing season (April 1 to September 30). The mode of these data was two visits per season. A frequency distribution was also provided by the authors.

An additional source of duration information supports the Bright and Manfredo results. It is the USFWS report entitled Water Resources and Sport Fishery Management on the Rocky Mountain Arsenal (Langer, 1990). This report also cites a mean value for fishing frequency of 12.25 days/years. Only the mean value was reported in this survey.

A third data source was provided by the Colorado Division of Wildlife on fishing duration and frequency on the Denver Metro area. The Division conducts surveys of participation in fishing in the State (1989 Fisherman's Questionnaire). Although these data were not site-specific, the

product of TM and DW determined from the Division data was less conservative than the corresponding probability distribution determined from Arsenal-specific data. For example, the Arsenal-specific means for TM(angler) and DW(angler) were 3.803 hours/day and 12.25 days/years, respectively, resulting in a product of 46.6 hours/year. The corresponding product using the Division of Wildlife data is 4.31 hours/day times 7.89 days/year, which results in a product of 34.0 hours/year.

Anglers in the Denver Metro area have a great number of choices for fishing. The 1991 Colorado Fishing Map, produced by the Department of Wildlife, lists 48 sites in the six county Metro area. Of these sites, 41 are warm water lakes or reservoirs and 14 of the 41 are similar to the Arsenal in that they do not permit boating. The number of times that a person participates in fishing during the year was considered most likely to be distributed among various sites that are within the vicinity of the Arsenal.

4.2.1.2 DW(neighborhood general visitor)

Recreational activities in which members of the neighborhood might participate include bicycling, walking for pleasure and exercise, and running or jogging. As discussed in Section 4.1.1.1, fishing is assumed to be an activity of interest to the regional population, as participation is not necessarily a function of neighborhood proximity to the Arsenal. Similarly, organized sports participants registered in Commerce City leagues live throughout Commerce City and adjacent surrounding areas. Therefore, these activities are considered to be of interest to the regional population, which includes, of course, the Arsenal neighborhood.

Bicycling

Bicycling participation rates for metropolitan areas (> 1,000,000 population) are used for development of this parameter and are reported to be 0.26 by the National Parks Service, 1986. However, this source does not report data regarding the number of days of participation in bicycling. Comparable participation rates can also be derived from the National Sporting Goods Association (NSGA) for Colorado by dividing the number of participants by the total population for that year. For example in 1988, the participation rate was approximately 0.24. In addition, NSGA reports the average number of days of participation in bicycling to be 54.8, which was used in the development of this parameter.

Walking for Pleasure and Exercise

Within the recreational scenario, both walking for pleasure and exercise walking are anticipated. According to the National Park Service, walking for pleasure is roughly equivalent to "taking walks" and was tied with swimming as the most widespread activity in the 1982-1983 Nationwide Recreation Survey. The participation rate for metropolitan areas is reported to be 0.43. However, this source does not report data regarding the number of days of participation in walking for pleasure.

Walking for exercise is surveyed annually by the National Sporting Goods Association. According to the NSGA, participation in jogging is decreasing because "the population is aging and turning to other sports, for example, exercise walking" (Dan Kasen, 05-20-92). In Colorado, a 1990 participation rate of 0.35 for walking for exercise can be derived by dividing the number of participants by the total population for that year. The NSGA reports the average number of days of participation in walking for exercise to be 96.6, which was used in the development of this parameter. The 95th percentile of the DW distribution is 207 days per year. On the basis of professional judgment, this was regarded as a reasonable upper bound of total participation in walking for pleasure and exercise.

Jogging

A number of data sources were reviewed for jogging and an effort made to minimize the sources cited for information necessary to develop distributions. The Gallup Leisure Activities Index (1986), cited in the development of the TM distribution (Section 4.1.1.2), also provided nationwide participation rates for "those describing themselves as joggers" to be 15%, somewhat lower than the 23% who claim to "have gone running at least once in the past year". Because the distribution for this parameter estimates a mean of 57.6 days/per year (NSGA, 1990), the "joggers" participation rate was used. It is comparable to and slightly more conservative than the 1990 Colorado participation rate of 11.4%, derived by dividing the number of participants by the total Colorado population in 1990.

As discussed above, NSGA reports that jogging is "losing popularity" as the population ages and turning to other sports, e.g., exercise walking. Gallup similarly reports "The current 15% participation level shows no significant movement since 1982 and only marginal growth from a decade ago....Not surprisingly, jogging bears a direct relationship to age with decreasing involvement as one gets older."

The 1982-82 Nationwide Recreation Survey provided a jogging participation rate of 0.26 for metropolitan areas, but did not provide the detailed frequency and characteristics of participation that are found in Gallup. A lower level of involvement in jogging, as well as other sports, is noted in Gallup, page 12:

> Although generally less important than youth, the factors of high household income and high education and occupation status have a direct--and remarkably consistent--relationship to high levels of sports participation. For example, persons with a college degree or working in business or the professions or in high income households are about twice as likely to participate in all of these sports activities than are their less well-off counterparts.

Gallup specifically reports the "same relationship" (decreasing involvement in jogging with age) that is noted in the case of education and occupation.

The Gallup Index also reported data regarding the frequency of participation in jogging, with a mean value of three times per week. The shape of this distribution was similar to that for bicycling. Therefore, this shape was estimated to be representative of walking as well, using the data-based average values for each activity.

The number of people in the neighborhood subpopulation is 14,875 (Section 3.1.2). The number of people in this subpopulation who participate in at least one of the general recreational activities is estimated to be 9,649 which is approximately 65% of the 14,875 people in the neighborhood subpopulation (Section 4.1.1.2). These 9,649 people comprise the neighborhood general visitor subpopulation.

The probability distribution for DW(neighborhood general visitor) corresponds to the number of days/year that these 9,649 people participate in general recreational activities at the Arsenal. The number of days/year of general recreational activities at the Arsenal is equal to the total number of days spent participating in general recreational activities at all locations times the fraction of that total spent at the Arsenal. The 9,649 members of the neighborhood general visitor subpopulation are assumed to spend an average of 50% of their general recreational activity days at the Arsenal. Each member is assumed to spend at least 10% of his or her participation days at the Arsenal and possibly as much as 100%.

4.2.1.3 DW(regional general visitor)

The total number of visits to the Arsenal per year for general recreational activity was estimated in Section 4.1.1.3 to be 359,036 visits on the basis of the estimated fraction of the regional population who participate in general recreational activities (bicycling, playing outdoor sports, attending outdoor sports, walking, running, or jogging), the average number of days/year of these activities, the total capture rate of the Metro area parks, and the Arsenal's relative capture rate among these parks.

The number of different individuals in a year who would make these 359,036 visits was estimated to be 126,199 on the basis of the Barr Lake repeat visitation frequencies. The rationale supporting the use of the Colorado Division of Parks and Outdoor Recreation (DPOR) data from Barr Lake on repeat visitation frequency for activities other than angling or organized sports or neighborhood activities is given in Section 3.2.1.2. The total number of visits per year was estimated independently of the Barr Lake data. The Barr Lake data were used only to convert the estimated number of visits to the estimated number of visitors.

The expected number of individuals per mode of entry was estimated from Barr Lake data on the total number of visits, the relative frequency of the different modes of entry, and the average numbers of visits by mode of entry (DPOR, 1988). Based on the total number of visits and the Barr Lake repeat visitation data, it was projected that, on the average in a year, 81% of the visitors (102,221 people) will pay daily fees to make a total of 235,108 to the Arsenal, 13% of the visitors (16,406 people) with an annual pass will make 75,467 visits, and 6% of the visitors (7,572 people) will be Aspen Leaf holders and make 48,460 visits. The average number of

Arsenal visits per person was estimated to be 2.3, 4.6, and 6.4 days/year for daily fee users, annual pass users and Aspen Leaf holders, respectively.

The number of visits for a person using a specific mode of entry is clearly not the same for all individuals. The distribution of the number of visits around the average number of visits per mode of entry is approximated by a Poisson probability distribution. The Poisson distribution was modified to reflect the condition that a visitor to Arsenal visits at least one day per year. That is, the probability of zero visits was set to zero.

A separate Poisson distribution was used to approximate the visitation frequency data for DW(regional general visitor) for each mode of entry (daily fee, annual pass, and Aspen Leaf). These probability distributions were then combined on the basis of the relative number of people using the different modes of entry. The most popular mode of entry has the greatest impact on DW(regional general visitor). The Poisson probability distribution for each pass type is shown in Appendix C.

4.2.1.4 DW(organized sports visitor)

In a telephone conversation with the Athletic Coordinator for the City of Commerce City, considerable site-specific data on organized sports participation were obtained (Tim Moore, 12-12-91). These data concern the number of participants and character of participation in sports programs offered by the City. Mr. Moore is responsible for organizing and scheduling these athletic programs and has provided the following specific information concerning the experience in his community's programs.

SPORT	AGE	SEASON	NUMBER OF PLAYERS	NUMBER OF GAMES
SOFTBALL				
	Adult	Summer	720	14
	Adult	Fall	120	14
	Adult	6 Weekend Tournaments	180	3-5 per Tournament
	Seniors (≥ 50 yrs)		30	14 (50% away)
BASEBALL				
	6-8	Summer	96-120	15
	9-10	Summer	96-120	15
	11-12	Summer	72-90	15
	13-14	Summer	24-30	15
FLAG FOOTBALL				
	2&3 Grades	Sept.-Oct.	64	4
	4&5 Grades	Sept.-Oct.	64	4
TACKLE FOOTBALL				
	8-9	Aug.-Sept.	50	6
	10	Aug.-Sept.	50	6
	11	Aug.-Sept.	25	6
	12	Aug.-Sept.	25	6

The softball games are all played at the Adams City High School field, which is lighted and located at 4625 E. 68th Ave., Commerce City (2.5 miles west of the Arsenal). The youth baseball and flag football games are held at Fairfax Park. The youth tackle football is offered through a parent-run organization. There is a one day doubles outdoor volleyball tournament in May and a co-ed (6 per team) tournament on another day in May. These activities are held at the sand volleyball courts on the grounds of the City recreation center. A soccer and girls softball program have been offered for several years, but have not had sufficient registrants.

If an athletic complex was to be built at the Arsenal that would attract all of the organized sports participants currently registered by Commerce City, there would be 1688 players: 1020 (720 + 120 + 180) adult softball players, 30 senior softball players, 360 (120 + 120 + 90 + 30) youth baseball players, 128 flag football players, and 150 tackle football players. If a player participated in more than one season/league, then 1688 may overestimate the number of organized sports players, because an individual registered in two leagues is included twice in the total count of 1688.

In U.S. Bureau of Outdoor Recreation (1972) cited on page 78 of Walsh (1986), the percent of the population "playing outdoor team sports" and "attending outdoor sports events" are 35.7% and 35.4%, respectively. Hence, if there were 1688 players of organized sports at the Arsenal, it was considered reasonable to assume that there would also be an equal number (1688) of attenders/spectators of organized sports at the Arsenal if an athletic complex was built there.

4.2.2 DW - Probability Distribution

4.2.2.1 DW(angler)

The probability distribution for the number [DW(angler)] of days per year that an angler with an Arsenal fishing permit visits the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW(angler) $\leq$ 66.40 days / year) = 0.99
Probability (DW(angler) $\leq$ 47.43 days / year) = 0.975
Probability (DW(angler) $\leq$ 35.51 days / year) = 0.95
Probability (DW(angler) $\leq$ 29.41 days / year) = 0.925
Probability (DW(angler) $\leq$ 25.43 days / year) = 0.90
Probability (DW(angler) $\leq$ 16.98 days / year) = 0.80
Probability (DW(angler) $\leq$ 14.56 days / year) = 0.75
Probability (DW(angler) $\leq$ 12.69 days / year) = 0.70
Probability (DW(angler) $\leq$ 9.89 days / year) = 0.60
Probability (DW(angler) $\leq$ 7.84 days / year) = 0.50
Probability (DW(angler) $\leq$ 6.21 days / year) = 0.40
Probability (DW(angler) $\leq$ 4.84 days / year) = 0.30
Probability (DW(angler) $\leq$ 4.22 days / year) = 0.25
Probability (DW(angler) $\leq$ 3.62 days / year) = 0.20
Probability (DW(angler) $\leq$ 2.42 days / year) = 0.10
Probability (DW(angler) $\leq$ 2.09 days / year) = 0.075
Probability (DW(angler) $\leq$ 1.73 days / year) = 0.05
Probability (DW(angler) $\leq$ 1.30 days / year) = 0.025
Probability (DW(angler) $\leq$ 0.93 days / year) = 0.01

This is a lognormal distribution with mean 11.95 and standard deviation 13.75. The ln[DW(angler)] has a normal distribution with mean 2.0592 and standard deviation of 0.9184.

The mathematical development of this distribution is given in Section 4.2.3.1.

4.2.2.2 DW(neighborhood general visitor)

The probability distribution for the number [DW(neighborhood general visitor)] of days per year that a general recreational visitor in the neighborhood visitor subpopulation visits the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW(neighborhood general visitor) ≤ 150.59 days / year) = 0.99
Probability (DW(neighborhood general visitor) ≤ 110.07 days / year) = 0.975
Probability (DW(neighborhood general visitor) ≤ 84.06 days / year) = 0.95
Probability (DW(neighborhood general visitor) ≤ 70.52 days / year) = 0.925
Probability (DW(neighborhood general visitor) ≤ 61.60 days / year) = 0.90
Probability (DW(neighborhood general visitor) ≤ 42.28 days / year) = 0.80
Probability (DW(neighborhood general visitor) ≤ 36.64 days / year) = 0.75
Probability (DW(neighborhood general visitor) ≤ 32.23 days / year) = 0.70
Probability (DW(neighborhood general visitor) ≤ 25.56 days / year) = 0.60
Probability (DW(neighborhood general visitor) ≤ 20.58 days / year) = 0.50
Probability (DW(neighborhood general visitor) ≤ 16.57 days / year) = 0.40
Probability (DW(neighborhood general visitor) ≤ 13.14 days / year) = 0.30
Probability (DW(neighborhood general visitor) ≤ 11.55 days / year) = 0.25
Probability (DW(neighborhood general visitor) ≤ 10.01 days / year) = 0.20
Probability (DW(neighborhood general visitor) ≤ 6.87 days / year) = 0.10
Probability (DW(neighborhood general visitor) ≤ 6.00 days / year) = 0.075
Probability (DW(neighborhood general visitor) ≤ 5.04 days / year) = 0.05
Probability (DW(neighborhood general visitor) ≤ 3.85 days / year) = 0.025
Probability (DW(neighborhood general visitor) ≤ 2.81 days / year) = 0.01

This is a lognormal distribution with mean 29.67 and standard deviation 30.83. The ln[DW(neighborhood general visitor)] has a normal distribution with mean 3.0242 and standard deviation of 0.8556. The mathematical development of this distribution is given in Section 4.2.3.2.

4.2.2.3 DW(regional general visitor)

The probability distribution for the number [DW(regional general visitor)] of days per year that a general recreational visitor in the regional general visitor subpopulation visits the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW(regional general visitor) ≤ 14.12 days / year) = 0.99
Probability (DW(regional general visitor) ≤ 12.34 days / year) = 0.975
Probability (DW(regional general visitor) ≤ 11.00 days / year) = 0.95
Probability (DW(regional general visitor) ≤ 10.20 days / year) = 0.925
Probability (DW(regional general visitor) ≤ 9.63 days / year) = 0.90

Probability (DW(regional general visitor) ≤ 8.19 days / year) = 0.80
Probability (DW(regional general visitor) ≤ 7.70 days / year) = 0.75
Probability (DW(regional general visitor) ≤ 7.29 days / year) = 0.70
Probability (DW(regional general visitor) ≤ 6.60 days / year) = 0.60
Probability (DW(regional general visitor) ≤ 6.02 days / year) = 0.50
Probability (DW(regional general visitor) ≤ 5.48 days / year) = 0.40
Probability (DW(regional general visitor) ≤ 4.96 days / year) = 0.30
Probability (DW(regional general visitor) ≤ 4.70 days / year) = 0.25
Probability (DW(regional general visitor) ≤ 4.42 days / year) = 0.20
Probability (DW(regional general visitor) ≤ 3.76 days / year) = 0.10
Probability (DW(regional general visitor) ≤ 3.55 days / year) = 0.075
Probability (DW(regional general visitor) ≤ 3.29 days / year) = 0.05
Probability (DW(regional general visitor) ≤ 2.93 days / year) = 0.025
Probability (DW(regional general visitor) ≤ 2.56 days / year) = 0.01

This is a lognormal distribution with mean 6.43 and standard deviation 2.44. The ln[DW(regional general visitor)] has a normal distribution with mean 1.7943 and standard deviation of 0.3668. The mathematical development of this distribution is given in Section 4.2.3.3.

4.2.2.4 DW(organized sports visitor)

The probability distribution for the number [DW(organized sports visitor)] of days per year that a visitor in the organized sports visitor subpopulation visits the Arsenal is a lognormal distribution with the following percentiles:

Probability (DW(organized sports visitor) ≤ 51.46 days / year) = 0.99
Probability (DW(organized sports visitor) ≤ 37.94 days / year) = 0.975
Probability (DW(organized sports visitor) ≤ 29.19 days / year) = 0.95
Probability (DW(organized sports visitor) ≤ 24.60 days / year) = 0.925
Probability (DW(organized sports visitor) ≤ 21.57 days / year) = 0.90
Probability (DW(organized sports visitor) ≤ 14.96 days / year) = 0.80
Probability (DW(organized sports visitor) ≤ 13.01 days / year) = 0.75
Probability (DW(organized sports visitor) ≤ 11.48 days / year) = 0.70
Probability (DW(organized sports visitor) ≤ 9.17 days / year) = 0.60
Probability (DW(organized sports visitor) ≤ 7.42 days / year) = 0.50
Probability (DW(organized sports visitor) ≤ 6.01 days / year) = 0.40
Probability (DW(organized sports visitor) ≤ 4.79 days / year) = 0.30
Probability (DW(organized sports visitor) ≤ 4.23 days / year) = 0.25
Probability (DW(organized sports visitor) ≤ 3.68 days / year) = 0.20
Probability (DW(organized sports visitor) ≤ 2.56 days / year) = 0.10
Probability (DW(organized sports visitor) ≤ 2.24 days / year) = 0.075
Probability (DW(organized sports visitor) ≤ 1.89 days / year) = 0.05

Probability (DW(organized sports visitor) ≤ 1.45 days / year) = 0.025
Probability (DW(organized sports visitor) ≤ 1.07 days / year) = 0.01

This is a lognormal distribution with mean 10.496 and standard deviation 10.492. The ln[DW(organized sports visitor)] has a normal distribution with mean 2.0047 and standard deviation of 0.8323. The mathematical development of this distribution is given in Section 4.2.3.4.

4.2.3 DW - Mathematical Development

4.2.3.1 DW(angler)

Site-specific data for the frequency (DW) of fishing events at the Arsenal have been researched by Colorado State University in cooperations with the USFWS (Bright and Manfredo, 1991). A sample frequency distribution for the number of Arsenal fishing visits made by the survey respondents was also provided by the researchers. The observed percentiles from that sample frequency function were fit to the normal and lognormal distributions using the weighted least squares estimation procedure described in Step 5 of Section 3.1.3. The best fitting distribution is a lognormal distribution. The best fitting lognormal distribution for DW(angler) has mean 11.95 and standard deviation 13.75 which corresponds to the ln[DW(angler)] having a normal distribution with mean 2.0592 and standard deviation of 0.9184. The fit itself can be described as follows:

Percentage	Observed Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99.7	80.00	97.78
99.4	75.00	78.75
99.1	66.00	68.84
98.8	65.00	62.31
98.4	60.00	56.18
97.8	50.00	49.84
96.6	45.00	41.90
96.3	42.00	40.45
96.0	40.00	39.13
93.8	35.00	32.20
92.2	30.00	28.85
87.5	25.00	22.55
84.7	24.00	20.07
84.4	23.00	19.84
83.8	22.00	19.39
82.9	20.00	18.76
76.9	19.00	15.40

76.6	18.00	15.27
76.0	17.00	15.00
75.1	16.00	14.61
73.8	15.00	14.07
68.8	14.00	12.30
68.5	13.00	12.20
67.9	12.00	12.01
63.6	11.00	10.79
63.2	10.00	10.68
57.0	9.00	9.22
55.5	8.00	8.90
49.8	7.00	7.80
48.3	6.00	7.54
43.9	5.00	6.81
38.0	4.00	5.92
31.5	3.00	5.04
21.8	2.00	3.83
11.8	1.00	2.64

A graphical indication of this fit is given in Figure 4.2.3.1.

4.2.3.2 DW(neighborhood general visitor)

The probability distribution for DW(neighborhood general visitor) was determined by fitting both normal and lognormal distributions to 10,000 simulated values of DW(neighborhood general visitor). These values were simulated by repeating the following steps 10,000 times:

1. Select the individual's general recreational activity from among bicycling, playing outdoor sports, attending outdoor sports, walking, and running/jogging.

2. Determine a value for the individual's total number of days of participation in this activity summed over all possible locations, i.e., at the Arsenal as well as at other sites.

3. Calculate the individual's number (DW) of days of activity participation at the Arsenal by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

Step 1.

In step (1), the probability of selecting a specific activity is proportional to the relative popularity of that activity. The estimated proportions of the potential neighborhood participants in general recreational activities at the Arsenal are:

Activity	Fraction Participating
Bicycling	0.26[a]
Playing Outdoor Sports	0.23[a]
Attending Outdoor Sports	0.26[a]
Walking for Exercise	0.43[a]
Running or Jogging	0.15[b]

[a] Percent participation in population areas with more than one million people (National Park Survey, 1986).
[b] Gallup Leisure Activities Index, 1986. Gallup also cited in the development of TM and the DW distributional shape.

Hence, the corresponding probabilities of selecting a specific recreational activity are

Activity	Probability of Selection
Bicycling	0.26/1.33[a] = 0.20
Playing Outdoor Sports	0.23/1.33 = 0.17
Attending Outdoor Sports	0.26/1.33 = 0.20
Walking for Exercise	0.43/1.33 = 0.32
Running or Jogging	0.15/1.33 = 0.11

[a] 1.33 = 0.26+0.23+0.26+0.43+0.15

Step 2.

In step (2), the individual's total number of days of participation in a selected activity summed over all possible locations is determined by first selecting a value for the number of days per week that the individual will participate in the activity and then, second, multiplying this selected days/week value by the number of weeks of such participation.

The individual variability in participation days/week is assumed to be well characterized by the data on such variability for jogging. This variability is reported in the Gallup Leisure Activities Index, 1986, to be as follows:

Frequency	Joggers	All Adults
Less than once a week	18%	3%
Once or twice a week	31%	5%
3 or 4 times a week	28%	4%
Every day or almost every day	21%	3%
Not sure	2%	
Total	100%	15%
Average times per week	3	

If the 18%, 31%, 28%, and 21% are increased proportionately to account for the 2% "Not sure", then the Gallup data suggest that the probability distribution on participation days/week can be estimated to have the following percentiles:

Frequency	Percentile	Cumulative Probability
Less than once a week	1	0.1837
Once or twice a week	2.5	0.5000
3 or 4 times a week	4.5	0.7857
Every day or almost every day	7	1.0000

If the percentiles are linearly interpolated between these percentiles, then the probability distribution on participation days/week can be estimated to have the following percentiles:

Percentage	Percentile (Days/Week)
99%	6.88
97.5%	6.71
95%	6.42
92.5%	6.13
90%	5.83
80%	4.67
75%	4.25
70%	3.90
60%	3.20
50%	2.50
40%	2.03
30%	1.55
25%	1.31
20%	1.08
10%	0.54
7.5%	0.41
5%	0.27
2.5%	0.14
1%	0.05

The mean total number of days per year summed over all locations for each general recreational activity and the number of weeks to reach that mean if the average number of participation days per week is 3 are as follows:

Activity	Mean Number of Days/Year at All Locations	Number of Weeks to Reach the Mean at an Average of 3 Days/Week
Bicycling	54.8[a]	54.8/3 = 18.27
Playing Outdoor Sports	44.6[b]	44.6/3 = 14.87
Attending Outdoor Sports	10.6[b]	10.6/3 = 3.53
Walking for Exercise	96.6[c]	96.6/3 = 32.20
Running or Jogging	57.6[c]	57.6/3 = 19.20

[a] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1988).
[b] National Average (U.S. Bureau of Outdoor Recreation, 1972, in Walsh, 1986, page 20).
[c] Participation in Selected Sports, Colorado (National Sporting Goods Association, 1990).

The mean numbers of days/year are the same for both neighborhood and regional general recreational participants; however, the fraction of those participation days spent at the Arsenal is not the same for neighborhood and regional visitors (as discussed in more detail under step (3)).

When the percentiles of the number of participation days per week is multiplied by the number of weeks indicated above, the percentiles of the estimated probability distribution for the total number of participation days/year summed over all possible locations for each general recreational activity are as follows:

Percentage	Bicycling	Playing Outdoor Sports	Attending Outdoor Sports	Walking	Running or Jogging
99%	125.70	102.31	24.29	221.54	132.10
97.5%	122.59	99.78	23.69	216.06	128.83
95%	117.29	95.47	22.66	206.72	123.26
92.5%	112.00	91.15	21.64	197.39	117.70
90%	106.51	86.69	20.58	187.73	111.94
80%	85.32	69.44	16.49	150.37	89.66
75%	77.65	63.20	15.00	136.85	81.60
70%	71.25	57.99	13.77	125.58	74.88
60%	58.46	47.58	11.30	103.04	61.44
50%	45.68	37.17	8.82	80.50	48.00
40%	37.09	30.19	7.17	65.37	38.98
30%	28.32	23.05	5.47	49.91	29.76
25%	23.93	19.48	4.62	42.18	25.15
20%	19.73	16.06	3.81	34.78	20.74
10%	9.87	8.03	1.91	17.39	10.37
7.5%	7.49	6.10	1.45	13.20	7.87
5%	4.93	4.01	0.95	8.69	5.18

2.5%	2.56	2.08	0.49	4.51	2.69
1%	0.91	0.74	0.18	1.61	0.96

Step 3.

In step (3), the individual's number (DW) of days of activity participation at the Arsenal was calculated by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

The members of the neighborhood general visitor subpopulation are assumed to spend an average of 50% of their general recreational activity days at the Arsenal. Each member is assumed to spend at least 10% of his or her participation days and as much as 100% at the Arsenal. The fraction of general recreational activity days spent at the Arsenal is assumed, on the basis of professional judgement, to have a triangular distribution with minimum 0.1, maximum 1.0, and mean 0.5. The corresponding mode of this Arsenal capture rate for individual activity participation days is 0.4.

Simulation Results

The distribution of the 10,000 simulated values was fit to both the normal and lognormal distributions. The best fitting distribution for DW(neighborhood general visitor) has mean 29.67 and standard deviation 30.83. The ln[DW(neighborhood general visitor)] has a normal distribution with mean 3.0242 and standard deviation of 0.8556. The simulated and fitted percentiles were as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	134.19	150.59
97.5	107.89	110.07
95	87.19	84.06
92.5	75.96	70.52
90	67.67	61.60
80	46.29	42.28
75	39.15	36.64
70	33.80	32.23
60	24.74	25.56
50	17.56	20.58
40	12.43	16.57
30	8.20	13.14
25	6.37	11.55
20	4.91	10.01

10	2.35	6.87
7.5	1.75	6.00
5	1.14	5.04
2.5	0.55	3.85
1	0.23	2.81

A graphical indication of this fit is given in Figure 4.2.3.2.

The number of people in the neighborhood subpopulation is 14,875 (Section 3.1.2). The number of people in this subpopulation who participate in at least one of the general recreational activities is estimated to be 9,649 which is approximately 65% of the 14,875 people in the neighborhood subpopulation (Section 4.1.1.2). These 9,649 people comprise the neighborhood general visitor subpopulation.

The probability distribution for DW(neighborhood general visitor) corresponds to the number of days/year that these 9,649 people participate in general recreational activities at the Arsenal. These 9,649 members of the neighborhood general visitor subpopulation are assumed to spend an average of 50% of their general recreational activity days at the Arsenal. Each member is assumed to spend at least 10% of his or her participation days and possibly as much as 100%. The fraction of general recreational activity days spent at the Arsenal is assumed, on the basis of professional judgement, to have a triangular distribution with minimum 0.1, maximum 1.0, and mean 0.5. The corresponding mode is 0.4.

The neighborhood subpopulation size (14,875 as derived in Section 3.1.2) includes both the residents who do and do not participate in general recreational activities at the Arsenal. The number of Arsenal visitors in this subpopulation is the number of neighborhood residents who participate in general recreational activities at the Arsenal. This neighborhood general visitor subpopulation and the corresponding regional general visitor subpopulation are the subpopulations to which the DW (days/year) and TE (years/lifetime) distributions apply.

The number of people in the neighborhood general visitor subpopulation depends on the number (14,875) of people who live in the neighborhood at some point in their lifetime as well as the fraction of those people who participate in general visitor activities. For the following estimated proportions of the potential neighborhood participants in general recreational activities at the Arsenal,

Activity	Fraction Participating
Bicycling	0.26[a]
Playing Outdoor Sports	0.23[a]
Attending Outdoor Sports	0.26[a]
Walking for Exercise	0.43[a]
Running or Jogging	0.15[b]

[a] Percent participation in population areas with more than one million people (National Park Survey, 1986).
[b] Gallup Leisure Activities Index, 1986. Gallup also cited in the development of TM and the DW distributional shape.

the probability that a potential participant participates in at least one activity is equal to the following, under the assumption of independence,

= 1 - Probability a potential participant participates in no such activities

= 1 - (1-0.26)*(1-0.23)*(1-0.26)*(1-0.43)*(1-0.15) = 1 - 0.204 = 0.796

That is, 79.6% of the potential participant population is estimated to participate in at least one general recreational activity. Here, as in the regulated/casual scenario, the potential participants are non-institutionalized people 12 years old and older, which is approximately 81.5% of the population. Thus, approximately 79.6% of 81.5% of the total population, which is approximately 65% of the total population (0.796 * 0.815 = 0.6487), is expected to participate in at least one general recreational activity at the Arsenal. Therefore, the number of general recreational visitors in the neighborhood visitor subpopulation is

0.6487 * 14,875 = 9,649.

4.2.3.3 DW(regional general visitor)

The probability distribution for DW(regional general visitor) was determined by fitting both normal and lognormal distributions to 10,000 sample values of DW(regional general visitor). These sample values were simulated by repeating the following steps 10,000 times:

1. Randomly select the individual's mode of entry to the Arsenal. The probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf are assumed to be 0.81, 0.13, and 0.06, respectively, which are the relative frequencies of the Barr Lake visitors who use these three modes of entry.

2. Determine a value for DW(regional general visitor) corresponding to the individual's selected mode of entry.

   a. If the mode of entry is daily fee, then select DW from a modified Poisson distribution with mean 2.3 days/year.

b. If the mode of entry is annual pass, then select DW from a modified Poisson distribution with mean 4.6 days/year.

c. If the mode of entry is Aspen Leaf, then select DW from a modified Poisson distribution with mean 6.4 days/year.

In Step 1), the probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf were based on the data for Barr Lake in DPOR, 1988; namely,

Subpopulation (Mode of Entry)	Number in Subpopulation	Proportion
Daily Fees	102,221*	0.81
Annual Pass	16,406	0.13
Aspen Leaf	7,572	0.06
Total	126,199	1.0000

* 102,221 = 0.81 * 126,199

In Steps 2a)-2c), modified Poisson distributions reflect the given condition that for each of these three modes of entry the number of visits per year is at least one. The probabilities in the modified Poisson distributions are the conditional Poisson probabilities corresponding to this given condition.

The distribution of the 10,000 simulated values was fit to both the normal and lognormal distributions. The best fitting distribution for DW(regional general visitor) has mean 6.43 and standard deviation 2.44. The ln[DW(regional general visitor)] has a normal distribution with mean 1.7943 and standard deviation of 0.3668. The simulated and fitted percentiles were as follows:

Percentage	Simulated Distribution (Days/Year)	Fitted Lognormal Distribution (Days/Year)
99	13.00	14.12
97.5	12.00	12.34
95	11.00	11.00
92.5	10.00	10.20
90	10.00	9.63
80	8.00	8.19
75	8.00	7.70

70	7.00	7.29
60	7.00	6.60
50	6.00	6.02
40	6.00	5.48
30	5.00	4.96
25	5.00	4.70
20	4.00	4.42
10	3.00	3.76
7.5	3.00	3.55
5	3.00	3.29
2.5	2.00	2.93
1	1.00	2.56

A graphical indication of this fit is given in Figure 4.2.3.3.

4.2.3.4 DW(organized sports visitor)

Simulation was used to estimate the probability distribution of DW(organized sports visitor). The steps in simulating a value of DW are depicted in Figure 4-1. These steps were:

1. Randomly determine whether the organized sports visitor is a player or a spectator.

2. Randomly determine the number of organized sports leagues in which the individual will participate.

3. For each organized sports league, randomly determine whether that league will play its games at the Arsenal.

4. For each league that plays at the Arsenal, randomly determine the total number of games (including practices) in which the individual will participate.

5. DW is the sum, over the leagues that play at the Arsenal, of the number of games per league in which an individual is assumed to participate.

In Step 1), the population of organized sports visitors was assumed to contain equal numbers of players and spectators. Hence, the probability that an organized sports visitor is a player is 0.5. Similarly, the probability that an organized sports visitor is a spectator is 0.5.

In Step 2), a person was assumed to participate in at least one organized sports league per year. An adult softball participant might participate in the summer season, the fall season, and the tournaments. Although somewhat less likely, a youth might participate in baseball, flag football, and tackle football. In order to reflect the possibility of a participant in one league also participating in a second or third league, each participant was assumed to have a 50% chance

of participating in a second league and a 50% chance of participating in a third league. Thus, each organized sports person participates in either 1, 2, or 3 leagues with probabilities 0.25, 0.50, and 0.25, respectively.

In Step 3), each league is assumed to have a 50% chance of having all of its games at the Arsenal and a 50% chance of having all of its games at some other athletic fields. These probabilities broadly reflect the current Commerce City athletic facilities as described below.

In April, 1984, Commerce City and the School District entered into an agreement which incorporated the recreational program into the City's organizational structure as an individual department. In an analysis of the City's existing facilities in comparison to the National Recreation and Parks Association (NRPA) Standards, the City found that it had a total of 17 baseball/softball fields available, which is an excess of nine fields in comparison to NRPA Standards. Of these 17 baseball/softball fields, 8 fields were suitable for adult city league use, with the remaining fields lacking the appropriate size, lighting, and/or parking. The assumption that 50% of the baseball/softball leagues would play at the Arsenal, given the number of other field available, is likely to be a conservative upper bound. The 50% value implies that the Arsenal would have to have roughly 8 baseball/softball fields available. If baseball/softball fields were to be constructed at the Arsenal, it is likely that the number of fields would be less than 8. In addition, the City had 7 football/soccer fields available which is a deficit of 1 field in comparison to NRPA Standards. The assumption that 50% of the City soccer leagues play at the Arsenal, implies that the Arsenal would have to have roughly 7 football/soccer fields available. Again, the 50% is likely to be an overestimate of the probability of a league playing at the Arsenal.

In step (4), a league is assumed to consist of a total of 16 games and practices. For baseball and softball, this allows for one or two practices at the same site as the games, and other practices at other sites, which is common for such leagues. For flag and tackle football, the number of games and practices may be overestimated as a consequence of treating all leagues alike. A player may not always attend every game or practice. The number of games and practices a player attends (per league) was assumed to be binomially distributed with 16 possible games/practices and the probability of 0.9 of attending a game/practice. The 95th percentile of the number of games and practices a player attends in a given league is 16; the mean is 14.4; and the 5th percentile is 12.

Similarly, a spectator may not always attend every game or practice. According to the U.S. Bureau of Outdoor Recreation (1972) cited on page 20 of Walsh (1986), the average annual days (summed over all locations) for a person "playing outdoor team sports" is 44.6 and for a person "attending outdoor sports events" is 10.6. Thus, based on these data, spectators attend only a fraction (approximately 10.6/44.6) of the games and practices that players do. Hence, the number of games and practices a spectator attends (per league) is assumed to be binomially distributed with 16 possible games/practices and the probability of $0.9*(10.6/44.6) = 0.21$ of attending a game/practice. The 95th percentile of the number of games and practices a spectator would attend in a given league is 6; the mean is 3.42; and the 5th percentile is 1.

In 10,000 repetitions of steps (1)-(5), the frequency distribution of simulated DW values was as follows:

P(DW = 46) = 0.0021	P(DW = 22) = 0.0000
P(DW = 45) = 0.0018	P(DW = 21) = 0.0000
P(DW = 44) = 0.0034	P(DW = 20) = 0.0000
P(DW = 43) = 0.0031	P(DW = 19) = 0.0000
P(DW = 42) = 0.0020	P(DW = 18) = 0.0001
P(DW = 41) = 0.0009	P(DW = 17) = 0.0001
P(DW = 40) = 0.0005	P(DW = 16) = 0.0447
P(DW = 39) = 0.0008	P(DW = 15) = 0.0778
P(DW = 38) = 0.0002	P(DW = 14) = 0.0634
P(DW = 37) = 0.0001	P(DW = 13) = 0.0369
P(DW = 36) = 0.0001	P(DW = 12) = 0.0144
P(DW = 35) = 0.0000	P(DW = 11) = 0.0106
P(DW = 34) = 0.0000	P(DW = 10) = 0.0099
P(DW = 33) = 0.0000	P(DW = 9) = 0.0138
P(DW = 32) = 0.0029	P(DW = 8) = 0.0175
P(DW = 31) = 0.0143	P(DW = 7) = 0.0260
P(DW = 30) = 0.0239	P(DW = 6) = 0.0333
P(DW = 29) = 0.0262	P(DW = 5) = 0.0452
P(DW = 28) = 0.0200	P(DW = 4) = 0.0621
P(DW = 27) = 0.0144	P(DW = 3) = 0.0589
P(DW = 26) = 0.0073	P(DW = 2) = 0.0468
P(DW = 25) = 0.0029	P(DW = 1) = 0.0233
P(DW = 24) = 0.0002	P(DW = 0) = 0.2873
P(DW = 23) = 0.0003	

The simulated distribution was very skewed, with one major mode and several smaller modes and valleys (zero frequencies) in the upper tail. The smaller modes and valleys are due to the realistic circumstance that a league either plays all of its games or no games at the Arsenal. Therefore, in a given year the underlying distribution of DW(organized sports visitor) may well have multiple modes. However, if DW for each individual were to be tracked over many years, the modes and valleys would be averaged and thus would tend to flatten. Therefore, it is reasonable to characterize DW(organized sports visitor) with a unimodal distribution such as the normal or lognormal.

The percentiles of this simulated distribution were fit to the lognormal and normal distributions. The best fitting distribution for DW is a lognormal distribution with mean 10.496 and standard deviation 10.492. This distribution implies that ln[DW(organized sports visitor)] is normally distributed with mean 2.005 and standard deviation 0.8323. Although the assumptions underlying the simulated data imply a significant probability for no visits to the Arsenal in a year, the lognormal approximation shifts this probability from 0 visits to 1-4 visits. The percentiles from the simulated distribution and the fitted distribution were as follows:

Percentage	Simulated Distribution (Days)	Fitted Lognormal Distribution (Days)
99	43	51.46
97.5	31	37.94
95	30	29.19
92.5	29	24.60
90	28	21.57
80	15	14.96
75	15	13.01
70	14	11.48
60	8	9.17
50	5	7.42
40	3	6.01
30	1	4.79
25	0	4.23
20	0	3.68
10	0	2.56
7.5	0	2.24
5	0	1.89
2.5	0	1.45
1	0	1.07

A graphical indication of this fit is given in Figure 4.2.3.4.

4.3 TE - YEARS PER LIFETIME: Recreational Visitors

4.3.1 TE - Rationale for Probability Distribution

The number of years in a lifetime in which a recreational visitor actually visits the Arsenal is TE. The probability distribution for TE for recreational visitors to the Arsenal was developed analogously to the way in which TE for regulated/casual visitors was developed in Section 3.3. Both developments incorporate residence duration and the number of residence durations during which a person will visit the Arsenal. The residence durations are the same for regulated/casual and recreational visitors.

However, the fraction of the population participating in regulated/casual activities is different than the fraction of the population participating in recreational activities. The probability that a person will visit the Arsenal from a residence is assumed to be proportional to the fraction of the population participating in the specified activities. It is also assumed that a person chooses independently at each new residence whether or not to be interested in visiting the Arsenal. Hence, the number of residence durations during which a person would choose to visit the Arsenal in a regulated/casual scenario is different than it is for the recreational scenario. The

only difference between the TE developments for regulated/casual and recreational visitors is the difference between the probability of being a regulated/casual visitor to the Arsenal while at a residence and the probability of being a recreational visitor to the Arsenal while at a residence.

Among the recreational visitors, the anglers, regional general visitors, and organized sports visitors have the same estimated TE distribution while the neighborhood general visitors have a different estimated TE distribution. The difference is due to the probability of an intra-neighborhood move being smaller than the probability of an intra-region move.

Ideally, the probability distribution for TE would be determined from data on the number of years in which particular visitors return to the Arsenal. The 1988 Visitor Survey found that most visitation to Denver metropolitan area parks was made by Denver metropolitan area residents (Colorado DPOR, 1988). Generally, an individual's number of years in which there are visits to the Arsenal does not exceed the total number of years of residence in the area. The total number of years of residence in the Denver metropolitan area provides an upper bound on TE, the number of years in which there are Arsenal visits.

As discussed in Section 3.3.1, several data sources were reviewed. The most relevant data source was the Public Service Company of Colorado (PSCo) which was able to provide highly relevant data for the determination of TE. The company conducts a comprehensive biannual survey of its customers entitled the *Residential Energy Use Survey* (PSCo, 1989). PSCo provides electricity and natural gas to 80% of the residences in Colorado, and to virtually all of Adams County, the balance being provided utilities by rural cooperatives or self-sufficient families (residences who do not use utilities), etc. PSCo is the primary utility provider in the Metro Denver area.

The PSCo survey is sent to "every nth account" in the PSCo customer base (964,482 households in 1989) for the purpose of predicting energy demand in the future, characterizing the customer base, and gathering other information. In survey years 1985, 1987, 1989 and 1991, the question was asked "How long have you lived at this address?". The mean and median values for current average residence time reported by the respondents for 1985, 1987, 1989 and 1991 are tabled below. In addition, probability distributions ranging from < 1 to > 50 years were provided for these four survey years. In 1989, 5,380 surveys were sent and 2,998 were returned for a response rate of 55.7%. PSCo considers this response rate to be exceptionally high.

AVERAGE CURRENT RESIDENCE TIME Public Service Company of Colorado		
YEAR	MEAN VALUE	MEDIAN VALUE
1985	8.4 YRS	3.7 YRS
1987	9.6 YRS	4.3 YRS
1989	9.7 YRS	4.5 YRS
1991	10.1 YRS	4.8 YRS

A recently published paper entitled Duration and Expected Time of Residence for U.S. Households (Israeli and Nelson, USEPA, in *Risk Analysis*, 1992). This paper examined the common but erroneous practice of using "average current residence time" (time since moving into a current residence) as a surrogate for "average total residence time" (time between moving into and out of a residence). The paper presents a methodology which can be used to estimate total residence time distributions from current residence time data.

On May 13, 1992, the probability distribution of values from the 1991 *Residential Energy Use Survey* were provided verbally (Ron Fish, PSCo). There is an increase in the 1991 mean and median values over previous years. Therefore, to avoid the introduction of a potential bias due to higher rates of mobility in 1985, 1987, and 1989, only 1991 data were used in developing the probability distribution for TE.

The PSCo 1991 current residence time data were analyzed using the Israeli and Nelson methodology to estimate the total residence time distribution. In the following table, mean and median values for average total residence time are given for 1985, 1987, and 1989 as well as 1991.

AVERAGE TOTAL RESIDENCE TIME Public Service Company of Colorado		
YEAR	MEAN VALUE	MEDIAN VALUE
1985	5.07 YRS	2.36 YRS
1987	5.31 YRS	2.21 YRS
1989	4.50 YRS	1.47 YRS
1991	5.48 YRS	1.98 YRS

The possibility of an individual being an Arsenal visitor at more than one residence was incorporated by explicitly evaluating the entire 70 year life span of an individual. A probability distribution on the number of residence durations for which an individual would be an Arsenal visitor was developed. One probability distribution was developed for the neighborhood subpopulation, and a second probability distribution was developed for the angler, regional general visitor, and organized sports visitor. In the distribution for the neighborhood, both one and two residence durations with Arsenal visitation have significant probabilities. In the simulation for anglers, regional general visitors, and organized sports visitors, only one, two, three, and four residence durations with Arsenal visitation had non-zero frequencies.

There are several conservative aspects in the development of the TE distribution. For example, the large number of opportunities for outdoor pursuits in the Metro Denver area increases the probability that individuals will not visit the Arsenal every year that they reside at a given address. Currently, it is assumed that individuals who visit will do so every year of residence in the neighborhood or region. In addition to the Colorado State Park system, the U.S. Forest Service, the City and County of Denver, Jefferson County, and Boulder County maintain parks offering picnic sites, campgrounds, and hiking trails within a 30 to 45 minute driving time from most residential districts in the metropolitan area. (THK, 1990).

A second conservative aspect is introduced by the greater response rate in the PSCo survey from the "more stable, higher income population", which is therefore over-represented compared to the "more transient, lower income population" which responded at a lower rate. This was determined in a subsequent PSCo analysis that correlates residence consumption history with the rate of response (Ron Fish, PSCo). The effect of this bias would be to overestimate the likelihood of medium and high TE values for the Commerce City population.

4.3.2 TE - Probability Distribution

4.3.2.1 TE(angler)

The probability distribution for the number [TE(angler)] of years of fishing at the Arsenal is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE(angler) $\leq$ 84.28 years/ lifetime) = 0.99
Probability (TE(angler) $\leq$ 48.35 years/ lifetime) = 0.975
Probability (TE(angler) $\leq$ 29.99 years/ lifetime) = 0.95
Probability (TE(angler) $\leq$ 21.96 years/ lifetime) = 0.925
Probability (TE(angler) $\leq$ 17.28 years/ lifetime) = 0.90
Probability (TE(angler) $\leq$ 8.87 years/ lifetime) = 0.80
Probability (TE(angler) $\leq$ 6.88 years/ lifetime) = 0.75
Probability (TE(angler) $\leq$ 5.48 years/ lifetime) = 0.70
Probability (TE(angler) $\leq$ 3.63 years/ lifetime) = 0.60

Probability (TE(angler) ≤ 2.48 years/ lifetime) = 0.50
Probability (TE(angler) ≤ 1.69 years/ lifetime) = 0.40
Probability (TE(angler) ≤ 1.12 years/ lifetime) = 0.30
Probability (TE(angler) ≤ 0.89 years/ lifetime) = 0.25
Probability (TE(angler) ≤ 0.69 years/ lifetime) = 0.20
Probability (TE(angler) ≤ 0.35 years/ lifetime) = 0.10
Probability (TE(angler) ≤ 0.28 years/ lifetime) = 0.075
Probability (TE(angler) ≤ 0.20 years/ lifetime) = 0.05
Probability (TE(angler) ≤ 0.13 years/ lifetime) = 0.025
Probability (TE(angler) ≤ 0.07 years/ lifetime) = 0.01

This is a lognormal distribution with mean 7.82 and standard deviation 23.41. The ln[TE(angler)] has a normal distribution with mean 0.9064 and standard deviation of 1.5165. The mathematical development of this distribution is given in Section 4.3.3.3.

The probability distribution for TE is the same for anglers, regional general visitors, and organized sports visitors.

4.3.2.2 TE(neighborhood general visitor)

The probability distribution for the number [TE(neighborhood general visitor)] of years of general activities at the Arsenal by a neighborhood visitor is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences in the neighborhood from which that individual visits the Arsenal. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE(neighborhood general visitor) ≤ 76.60 hours/ activity day) = 0.99
Probability (TE(neighborhood general visitor) ≤ 43.41 hours/ activity day) = 0.975
Probability (TE(neighborhood general visitor) ≤ 26.64 hours/ activity day) = 0.95
Probability (TE(neighborhood general visitor) ≤ 19.37 hours/ activity day) = 0.925
Probability (TE(neighborhood general visitor) ≤ 15.17 hours/ activity day) = 0.90
Probability (TE(neighborhood general visitor) ≤ 7.67 hours/ activity day) = 0.80
Probability (TE(neighborhood general visitor) ≤ 5.92 hours/ activity day) = 0.75
Probability (TE(neighborhood general visitor) ≤ 4.69 hours/ activity day) = 0.70
Probability (TE(neighborhood general visitor) ≤ 3.08 hours/ activity day) = 0.60
Probability (TE(neighborhood general visitor) ≤ 2.08 hours/ activity day) = 0.50
Probability (TE(neighborhood general visitor) ≤ 1.40 hours/ activity day) = 0.40
Probability (TE(neighborhood general visitor) ≤ 0.92 hours/ activity day) = 0.30
Probability (TE(neighborhood general visitor) ≤ 0.73 hours/ activity day) = 0.25
Probability (TE(neighborhood general visitor) ≤ 0.56 hours/ activity day) = 0.20
Probability (TE(neighborhood general visitor) ≤ 0.29 hours/ activity day) = 0.10
Probability (TE(neighborhood general visitor) ≤ 0.22 hours/ activity day) = 0.075
Probability (TE(neighborhood general visitor) ≤ 0.16 hours/ activity day) = 0.05

Probability (TE(neighborhood general visitor) ≤ 0.10 hours/ activity day) = 0.025
Probability (TE(neighborhood general visitor) ≤ 0.06 hours/ activity day) = 0.01

This is a lognormal distribution with mean 6.92 and standard deviation 21.93. The ln[TE(neighborhood general visitor)] has a normal distribution with mean 0.7324 and standard deviation of 1.5502. The mathematical development of this distribution is given in Section 4.1.3.2.

4.3.2.3 TE(regional general visitor)

The probability distribution for the number [TE(regional general visitor)] of years of general visitor activities at the Arsenal by a regional visitor is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal. It is approximated by a lognormal distribution with mean 7.82 and standard deviation 23.41. The ln[TE(regional general visitor)] has a normal distribution with mean 0.9064 and standard deviation of 1.5165. The percentiles of this distribution are given in Section 4.3.2.1, and the mathematical development of this distribution is given in Section 4.3.3.3.

The probability distribution for TE is the same for anglers, regional general visitors, and organized sports visitors.

4.3.2.4 TE(organized sports visitor)

The probability distribution for the number [TE(organized sports visitor)] of years of organized sports activities at the Arsenal is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal. It is approximated by a lognormal distribution with mean 7.82 and standard deviation 23.41. The ln[TE(organized sports visitor)] has a normal distribution with mean 0.9064 and standard deviation of 1.5165. The percentiles of this distribution are given in Section 4.3.2.1, and the mathematical development of this distribution is given in Section 4.3.3.3.

The probability distribution for TE is the same for anglers, regional general visitors, and organized sports visitors.

4.3.3 TE - Mathematical Development

The distribution of total residence durations (TE) was derived from the data on years of current residence reported in the 1991 *PSCo Residential Energy Use Survey*, using the methodology described in Israeli and Nelson (Section 3.3.3). The possibility of an individual being an Arsenal visitor from more than one residence was incorporated by explicitly evaluating all of the residences in the entire 70 year life span of an individual.

The PSCo survey was used in Section 3.3.3 to develop the probability distribution of a residence duration. In this section (Section 4.3.3), that residence duration distribution is combined with the probability distribution on the number of residences with Arsenal visitation in an individual's 70 year life span to estimate the probability distribution for the total duration of all residences from which that individual visits the Arsenal.

4.3.3.1 TE(angler)

The probability distribution for TE is the same for anglers, regional general visitors, and organized sports visitors. For convenience, the mathematical development is discussed in Section 4.3.3.3.

4.3.3.2 TE(neighborhood general visitor)

The probability distribution for TE (years/lifetime) of general recreational visitation to the Arsenal for the neighborhood visitor subpopulation is approximated by the probability distribution of the total residence duration in years of the neighborhood visitor subpopulation.

In Section 3.3.3.1, the probability of a 70 life span containing two residence durations in the neighborhood was estimated to be less than 1.69%. The probability of more than two neighborhood residence durations is even smaller, less than 0.1%. Although the neighborhood subpopulation is the same for both the regulated/casual and recreational scenarios, the neighborhood visitor subpopulations are not the same because of the differences in the visitor activities for the different scenarios. Hence, the probabilities distribution for TE for neighborhood regulated/casual and recreational visitors are different.

The total residence duration distribution for neighborhood general recreational visitors was determined by a Monte Carlo simulation. In that simulation, 1.69% of the TE(neighborhood subpopulation) values corresponded to the 1.69% of the neighborhood visitor subpopulation who were estimated to have two residence durations in the neighborhood. These 1.69% of the TE values were equal to the sum of two independently sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. The other 98.31% (100%-1.69%) of the TE(neighborhood subpopulation) values were equal to randomly sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. Ten thousand simulated values were generated. The observed distribution of simulated values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Years/Lifetime)	Fitted Lognormal Distribution (Years/Lifetime)
99	76.77	76.60
97.5	43.09	43.41

95	26.76	26.64
92.5	19.49	19.37
90	15.17	15.17
80	7.67	7.67
75	5.91	5.92
70	4.71	4.69
60	3.09	3.08
50	2.07	2.08
40	1.40	1.40
30	0.92	0.92
25	0.73	0.73
20	0.56	0.56
10	0.28	0.29
7.5	0.22	0.22
5	0.16	0.16
2.5	0.10	0.10
1	0.06	0.06

The fitted lognormal distribution for TE(neighborhood general visitor) has mean 6.92 and standard deviation 21.93, and the ln(TE) has mean 0.7324 and standard deviation 1.5502. This is the TE (years/lifetime) distribution for the subpopulation of neighborhood recreational visitors to the Arsenal.

A graphical indication of the fit is given in Figure 4.3.3.2.

4.3.3.3 TE(regional general visitor)

The probability distribution for the number [TE(regional general visitor)] of years of general visitor activities at the Arsenal by a regional visitor was approximated by the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal.

In Section 4.1.1.3, a probability distribution on the number of residence durations for which an individual would be an Arsenal visitor was developed. The probability of a 70 life span containing zero residence durations with Arsenal visitation was estimated to be 0.8335. Among the 70 year life spans with at least one residence duration with Arsenal visitation, 78.4% had one residence duration with Arsenal visitation, 16.8% had two, 4.0% had three, 0.2% had four, and none were observed with more than four.

The total residence duration distribution for regional general recreational visitors was determined by a Monte Carlo simulation. In that simulation, 78.4% of the TE(regional general visitor) values corresponded to the 78.4% of the regional general visitor subpopulation who were estimated to have one residence durations in which Arsenal visitation occurred. In addition, 16.8%, 4.0%, and 0.2% of the TE values corresponded to the 16.8%, 4.0%, and 0.2% of the

regional general visitor subpopulation who were estimated to have 2, 3, and 4 residence durations, respectively, in which Arsenal visitation occurred. These latter TE values were equal to the sum of 2, 3, and 4, respectively, independently sampled values from the 1991 PSCo data based distribution of total residence duration at a single residence. A slight conservative bias is included in these TE values in that the sum of multiple independent individual residence durations could exceed the 70 year life span. In fact, although the 97.5th percentile of the simulated TE values did not exceed 50, the 99th percentile of the simulated TE values exceeded 80 years.

Ten thousand simulated TE values were generated. The observed distribution of simulated TE values was fit to both the normal and lognormal distributions. The best fitting distribution was a lognormal distribution. The simulated and fitted lognormal percentiles are as follows:

Percentage	Simulated Distribution (Years/Lifetime)	Fitted Lognormal Distribution (Years/Lifetime)
99	83.87	84.28
97.5	48.83	48.35
95	30.05	29.99
92.5	21.78	21.96
90	17.37	17.28
80	8.82	8.87
75	6.84	6.88
70	5.42	5.48
60	3.55	3.63
50	2.39	2.48
40	1.59	1.69
30	1.03	1.12
25	0.81	0.89
20	0.63	0.69
10	0.31	0.35
7.5	0.24	0.28
5	0.17	0.20
2.5	0.11	0.13
1	0.06	0.07

The fitted lognormal distribution for TE(regional general visitor) has mean 7.82 and standard deviation 23.41, and the ln(TE) has mean 0.9064 and standard deviation 1.5165. This is the TE (years/lifetime) distribution for the regional general recreational visitors to the Arsenal.

A graphical indication of the fit is given in Figure 4.3.3.3.

4.3.3.4 TE(organized sports visitor)

The probability distribution for TE is the same for anglers, regional general visitors, and organized sports visitors. The mathematical development is discussed in Section 4.3.3.3.

4.4 RECREATIONAL VISITOR POPULATION

Recreational activities at the Arsenal might include fishing and other recreational activities such as bicycling, jogging, walking, and outdoor sports. These activity groups are referred to as the anglers and general visitors, respectively. General visitors are subdivided into the neighborhood general visitors who live in close proximity to the Arsenal and regional general visitors who live further away. The three visitors groups are referred to as the angler, neighborhood general visitor, and regional general visitor subpopulations. The whole or total visitor population is referred to as the recreational visitor population.

Probability distributions for TM (duration of a visit in hours/day), DW (frequency of visits in days/year), and TE (years of visitation/lifetime) have been developed for each of the three subpopulations (angler, neighborhood general visitor, and regional general visitor subpopulations) in the recreational visitor population in Sections 4.1, 4.2, and 4.3, respectively.

Section 4.4 develops the TM, DW, and TE distributions for the recreational visitor population comprised of the angler, neighborhood general visitor, and regional general visitor subpopulations.

The probability distributions for TM, DW, and TE in Section 4.4 for the recreational visitor population are derived in such a way that the frequency distribution for DW*TE (days/lifetime) in the combined population is the same as the combined frequency distributions for

days/lifetime for anglers:
DW(angler)*TE(angler)

days/lifetime for neighborhood general visitors:
DW(neighborhood general visitor)*TE(neighborhood general visitor)

days/lifetime for regional general visitors:
DW(regional general visitor)*TE(regional general visitor)

and the frequency distribution TM*DW*TE (hours/lifetime) in the combined population is the same as the combined frequency distributions for

hours/lifetime for anglers:
TM(angler)*DW(angler)*TE(angler)

hours/lifetime for neighborhood general visitors:
TM(neighborhood general visitor)*DW(neighborhood general visitor)*TE(neighborhood general visitor)

hours/lifetime for regional general visitors:
TM(regional general visitor)*DW(regional general visitor)*TE(regional general visitor).

The derivations in Sections 4.4 avoid inappropriate calculations such as

TM(angler)*DW(neighborhood general visitor)*TE(regional visitor)

which do not correspond to any visitor.

The sequential development in Section 4.4 consists of the following three steps:

Step 1. The TE distributions for the component subpopulations are combined to provide a distribution of TE for the whole population.

Step 2. The DW*TE distributions for the component subpopulations are combined to provide a distribution for DW*TE for the whole population. A population DW distribution is identified such that the population DW distribution times the population TE distribution derived in Step 1 equals the distribution for DW*TE for the whole population.

Step 3. The TM*DW*TE distributions for the component subpopulations are combined to provide a distribution for TM*DW*TE for the whole population. A population TM distribution is identified such that the population TM distribution times the population DW distribution derived in Step 2 times the population TE distribution derived in Step 1 equals the distribution for TM*DW*TE for the whole population.

The development in Section 4.4 for the recreational visitor population appropriately reflects the circumstance that the data and corresponding probability distributions for TM, DW, and TE for a particular subpopulation are generally distinct from the data and probability distributions for TM, DW, and TE for a different subpopulation.

By developing separate distributions for TM, DW, and TE, Section 4.4 reflects the current structure of the PPLV computations. Currently, TM does not appear in some parts of the PPLV computation (e.g., the calculations for dermal absorption). Thus, TM and DW do not always appear together in the PPLV equations, and separate distributions for TM and DW are required, rather than a single TM*DW distribution.

Steps (1)-(3) are ordered as they are in order to have only one distribution to solve for at each step. For example, in step (1) the objective is to solve for TE. In step (2), with the distribution of TE already estimated, the DW*TE distribution can be solved for the DW distribution. In step (3), with the distributions of TE and TE already estimated, the TM*DW*TE can be solved for the TM distribution.

Because the sequential development in steps (1)-(3) logically proceeds from TE to DW to TM, the ordering of the subsections considers TE first, then DW, and TM last. Hence, the ordering in Sections 4.4 and 4.5 is the reverse of the order of topics in the balance of the document. Further, there is no section regarding the rationale for the data selected because the rationale has already been presented in Sections 4.1, 4.2, and 4.3.

4.4.1 TE - YEARS PER LIFETIME: Recreational Visitor Population

4.4.1.1 TE - Recreational Visitor Population: Probability Distribution

The probability distribution for the number [TE(recreational visitor population)] of years of recreational activity at the Arsenal by a member of the recreational visitor population is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE(recreational visitor population) ≤ 81.83 years/lifetime) = 0.99
Probability (TE(recreational visitor population) ≤ 47.18 years/lifetime) = 0.975
Probability (TE(recreational visitor population) ≤ 29.38 years/lifetime) = 0.95
Probability (TE(recreational visitor population) ≤ 21.58 years/lifetime) = 0.925
Probability (TE(recreational visitor population) ≤ 17.02 years/lifetime) = 0.90
Probability (TE(recreational visitor population) ≤ 8.78 years/lifetime) = 0.80
Probability (TE(recreational visitor population) ≤ 6.83 years/lifetime) = 0.75
Probability (TE(recreational visitor population) ≤ 5.45 years/lifetime) = 0.70
Probability (TE(recreational visitor population) ≤ 3.63 years/lifetime) = 0.60
Probability (TE(recreational visitor population) ≤ 2.48 years/lifetime) = 0.50
Probability (TE(recreational visitor population) ≤ 1.69 years/lifetime) = 0.40
Probability (TE(recreational visitor population) ≤ 1.13 years/lifetime) = 0.30
Probability (TE(recreational visitor population) ≤ 0.90 years/lifetime) = 0.25
Probability (TE(recreational visitor population) ≤ 0.70 years/lifetime) = 0.20
Probability (TE(recreational visitor population) ≤ 0.36 years/lifetime) = 0.10
Probability (TE(recreational visitor population) ≤ 0.28 years/lifetime) = 0.075
Probability (TE(recreational visitor population) ≤ 0.21 years/lifetime) = 0.05
Probability (TE(recreational visitor population) ≤ 0.13 years/lifetime) = 0.025
Probability (TE(recreational visitor population) ≤ 0.08 years/lifetime) = 0.01

This is a lognormal distribution with mean 7.67 and standard deviation 22.47. The ln[TE(recreational visitor population)] has a normal distribution with mean 0.9078 and standard

deviation of 1.5031. The mathematical development of this distribution is given in Section 4.4.1.2.

4.4.1.2 TE - Recreational Visitor Population: Mathematical Development

The distribution of TE for the recreational visitor population was estimated from simulated values combining the component subpopulation probability distributions for TE(angler), TE(neighborhood general visitor), and TE(regional general visitor) derived in Section 4.3. The simulated values for the recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, or regional general visitor are equal to the relative proportions of anglers, neighborhood general visitors, and regional general visitors within the recreational visitor population.

Step 2.

Determine a value for TE (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

In step (1), the probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, or regional general visitor are equal to the relative proportions of anglers, neighborhood general visitors, and regional general visitors within the recreational visitor population. These proportions are as follows:

Subpopulation	Number in Subpopulation	Probability (Proportion)
Angler	602	0.001965*
Neighborhood General Visitor	9,649	0.031496
Regional General Visitor	296,101	0.966539
Total	306,352	1.000000

* 0.001965 = 602/306,352

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of TE(recreational visitor population). The best fitting distribution for TE(recreational visitor population) is a lognormal distribution with mean 7.67 and standard deviation 22.47. Equivalently, the ln[TE(recreational visitor population)] has a normal distribution with mean 0.9078 and standard deviation of 1.5031. The fit is described as follows:

Percentage	Simulated Distribution (Years/Lifetime)	Fitted Lognormal Distribution (Years/Lifetime)
99	81.27	81.83
97.5	47.75	47.18
95	29.39	29.38
92.5	21.81	21.58
90	17.10	17.02
80	8.66	8.78
75	6.72	6.83
70	5.33	5.45
60	3.50	3.63
50	2.38	2.48
40	1.60	1.69
30	1.04	1.13
25	0.82	0.90
20	0.63	0.70
10	0.31	0.36
7.5	0.24	0.28
5	0.17	0.21
2.5	0.11	0.13
1	0.06	0.08

A graphical indication of the fit is given in Figure 4.4.1.2.

4.4.2 DW - DAYS PER YEAR: Recreational Visitor Population

4.4.2.1 DW - Recreational Visitor Population: Probability Distribution

The probability distribution for the number [DW(recreational visitor population)] of days per year of recreational activity at the Arsenal by a member of the recreational visitor population is estimated to be a lognormal distribution with the following percentiles:

Probability (DW(recreational visitor population) $\leq$ 21.30 days/year) = 0.99
Probability (DW(recreational visitor population) $\leq$ 14.73 days/year) = 0.975
Probability (DW(recreational visitor population) $\leq$ 10.73 days/year) = 0.95
Probability (DW(recreational visitor population) $\leq$ 8.73 days/year) = 0.925

Probability (DW(recreational visitor population) ≤ 7.44 days/year) = 0.90
Probability (DW(recreational visitor population) ≤ 4.78 days/year) = 0.80
Probability (DW(recreational visitor population) ≤ 4.04 days/year) = 0.75
Probability (DW(recreational visitor population) ≤ 3.48 days/year) = 0.70
Probability (DW(recreational visitor population) ≤ 2.65 days/year) = 0.60
Probability (DW(recreational visitor population) ≤ 2.05 days/year) = 0.50
Probability (DW(recreational visitor population) ≤ 1.59 days/year) = 0.40
Probability (DW(recreational visitor population) ≤ 1.21 days/year) = 0.30
Probability (DW(recreational visitor population) ≤ 1.04 days/year) = 0.25
Probability (DW(recreational visitor population) ≤ 0.88 days/year) = 0.20
Probability (DW(recreational visitor population) ≤ 0.56 days/year) = 0.10
Probability (DW(recreational visitor population) ≤ 0.48 days/year) = 0.075
Probability (DW(recreational visitor population) ≤ 0.39 days/year) = 0.05
Probability (DW(recreational visitor population) ≤ 0.29 days/year) = 0.025
Probability (DW(recreational visitor population) ≤ 0.20 days/year) = 0.01

This is a lognormal distribution with mean 3.402 and standard deviation 4.5018. The ln[DW(recreational visitor population)] has a normal distribution with mean 0.7183 and standard deviation of 1.0060. The mathematical development of this distribution is given in Section 4.4.2.2.

4.4.2.2 DW - Recreational Visitor Population: Mathematical Development

Procedure

As indicated in Sections 4.0.2 and 4.4, the distribution of DW(recreational visitor population) was derived by estimating the population's data based distributions for TE and [DW*TE], and then back-calculating to solve for DW. The back-calculation involves the following procedures:

Procedure 1. Estimate the lognormal distribution for days per lifetime for visitors in the recreational visitor population by combining the component DW and TE distributions developed in Sections 4.2 and 4.3 (i.e., DW(angler), DW(neighborhood general visitor), DW(regional general visitor), TE(angler), TE(neighborhood general visitor), and TE(regional general visitor)). This distribution is referred to as the [DW*TE](recreational visitor population) distribution.

Procedure 2. Using the distribution for TE(recreational visitor population) derived in Section 4.4.1, estimate the distribution for DW(recreational visitor population) by solving the mathematical formulas necessary to ensure that DW(recreational visitor population) * TE(recreational visitor population) equals [DW*TE](recreational visitor population).

The back-calculation of DW(recreational visitor population) ensures that in the PPLV equations, the product of DW(recreational visitor population) and TE(recreational visitor population) equals [DW*TE](recreational visitor population), which is the most accurate characterization of days per lifetime for the recreational visitor population based on the available data. Where DW occurs in the PPLV equations, the DW parameter is always multiplied by TE; so that, as long as the [DW*TE] distribution is accurate, the distribution of DW itself is arbitrary.

Simulation

The distribution of DW for the recreational visitor population is estimated from simulated values combining the component DW and TE distributions developed in Sections 4.2 and 4.3. The simulated values of DW*TE for the recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, or regional general visitor are equal to the relative proportions of anglers, neighborhood general visitors, and regional general visitors within the recreational visitor population.

Step 2.

Determine a value for TE (years/lifetime) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

Step 3.

Determine a value for DW (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a DW value from DW(angler).

b. If the subpopulation is neighborhood general visitors, then select a DW according to the three step procedure described in Section 4.2.3.2; namely,

i. Select the individual's general recreational activity from among bicycling, playing outdoor sports, attending outdoor sports, walking, and running/jogging.

ii. Determine a value for the individual's total number of days of participation in this activity summed over all possible locations (i.e., at the Arsenal as well as other sites).

iii. Calculate the individual's number (DW) of days of activity participation at the Arsenal by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

c. If the subpopulation is regional general visitors, then select a DW according to the two step procedure described in Section 4.2.3.3; namely,

i. Select the individual's mode of entry to the Arsenal. The probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf are assumed to be 0.81, 0.13, and 0.06, respectively, which are the relative frequencies of the Barr Lake visitors who use these three modes of entry.

ii. Determine a value for DW(regional general visitor) corresponding to the individual's selected mode of entry.

1. If the mode of entry is daily fee, then select DW from a modified Poisson distribution with mean 2.3 days/year.

2. If the mode of entry is annual pass, then select DW from a modified Poisson distribution with mean 4.6 days/year.

3. If the mode of entry is Aspen Leaf, then select DW from a modified Poisson distribution with mean 6.4 days/year.

Step 4.

Multiply these randomly generated values of DW and TE.

Steps (1) and (2) are the same as steps (1) and (2) in the simulation in Section 4.4.1.2.

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of DW*TE(recreational visitor population). The best fitting distribution for DW*TE(recreational visitor population) is a lognormal distribution with mean 26.09 and standard deviation 131.37. Equivalently, the ln[DW*TE(recreational visitor population)] has a normal distribution with mean 1.6261 and standard deviation of 1.8087. The fit is described as follows:

Percentage	Simulated Distribution (Days/Lifetime)	Fitted Lognormal Distribution (Days/Lifetime)
99	344.41	341.61
97.5	173.96	176.09
95	95.66	99.59
92.5	67.72	68.70
90	51.63	51.62
80	24.81	23.30
75	18.82	17.22
70	14.53	13.13
60	9.09	8.04
50	5.83	5.08
40	3.75	3.22
30	2.32	1.97
25	1.80	1.50
20	1.33	1.11
10	0.63	0.50
7.5	0.46	0.38
5	0.32	0.26
2.5	0.19	0.15
1	0.09	0.08

A graphical indication of the fit is given in Figure 4.4.2.2.

Result

It can be shown mathematically, that the product of two lognormal random variables is itself lognormally distributed. Furthermore, if DW, TE, and [DW*TE] are lognormally distributed and

(1) ln(DW) is normally distributed with mean A and standard deviation B,

(2) ln(TE) is normally distributed with mean C and standard deviation D, and

(3) ln([DW*TE]) is normally distributed with mean E and standard deviation F,

then

$$E = A + C \text{ and } F^2 = B^2 + D^2$$

and

$$A = E - C \text{ and } B^2 = F^2 - D^2.$$

Hence, the lognormal distribution for DW(recreational visitor population) was derived by solving the above two equations for A and B as follows. TE(recreation visitor population) is lognormally distributed with mean 7.67 and standard deviation 22.47; so that, ln(TE) has a mean of 0.9078 (C=0.9078) and standard deviation 1.5031 (D=1.5031). [DW*TE](recreation visitor population) is lognormally distributed with mean 26.09 and standard deviation 131.37; so that, ln([DW*TE]) has a mean of 1.6261 (E=1.6261) and standard deviation 1.8087 (F=1.8087). These distributions imply that

$$A = 1.6261 - 0.9078 = 0.7183 \text{ and}$$
$$B^2 = (1.8087)^2 - (1.5031)^2 = (1.0060)^2;$$

so that, DW(recreational visitor population) is lognormally distributed with mean 3.402 and standard deviation 4.5018, and ln(DW) has mean 0.7183 and standard deviation 1.0060.

4.4.3 TM - HOURS PER DAY: Recreational Visitor Population

4.4.3.1 TM - Recreational Visitor Population: Probability Distribution

The probability distribution for the number [TM(recreational visitor population)] of hours per day of recreational activity at the Arsenal by a member of the recreational visitor population is estimated to be a lognormal distribution with the following percentiles:

Probability (TM(recreational visitor population) ≤ 4.90 hours/day) = 0.99
Probability (TM(recreational visitor population) ≤ 4.17 hours/day) = 0.975
Probability (TM(recreational visitor population) ≤ 3.62 hours/day) = 0.95
Probability (TM(recreational visitor population) ≤ 3.31 hours/day) = 0.925
Probability (TM(recreational visitor population) ≤ 3.08 hours/day) = 0.90
Probability (TM(recreational visitor population) ≤ 2.54 hours/day) = 0.80
Probability (TM(recreational visitor population) ≤ 2.36 hours/day) = 0.75
Probability (TM(recreational visitor population) ≤ 2.21 hours/day) = 0.70
Probability (TM(recreational visitor population) ≤ 1.96 hours/day) = 0.60
Probability (TM(recreational visitor population) ≤ 1.75 hours/day) = 0.50
Probability (TM(recreational visitor population) ≤ 1.56 hours/day) = 0.40
Probability (TM(recreational visitor population) ≤ 1.39 hours/day) = 0.30
Probability (TM(recreational visitor population) ≤ 1.30 hours/day) = 0.25
Probability (TM(recreational visitor population) ≤ 1.20 hours/day) = 0.20
Probability (TM(recreational visitor population) ≤ 0.99 hours/day) = 0.10
Probability (TM(recreational visitor population) ≤ 0.92 hours/day) = 0.075
Probability (TM(recreational visitor population) ≤ 0.84 hours/day) = 0.05
Probability (TM(recreational visitor population) ≤ 0.73 hours/day) = 0.025
Probability (TM(recreational visitor population) ≤ 0.62 hours/day) = 0.01

This is a lognormal distribution with mean 1.928 and standard deviation 0.8984. The ln[TM(recreational visitor population)] has a normal distribution with mean 0.5585 and standard

deviation of 0.4432. The mathematical development of this distribution is given in Section 4.4.3.2.

4.4.3.2 TM - Recreational Visitor Population: Mathematical Development

Procedure

As indicated in Sections 4.0.2 and 4.4, the distribution of TM(recreational visitor population) was derived by estimating the population's data based distributions for TE, DW, and [TM*DW*TE], and then back-calculating to solve for TM. The back-calculation involves the following procedures:

Procedure 1. Estimate the lognormal distribution for hours per lifetime for visitors in the recreational visitor population by combining the component TM, DW and TE distributions developed in Sections 4.1, 4.2 and 4.3 (i.e., TM(angler), TM(neighborhood general visitor), TM(regional general visitor), DW(angler), DW(neighborhood general visitor), DW(regional general visitor), TE(angler), TE(neighborhood general visitor), and TE(regional general visitor)). This distribution is referred to as the [TM*DW*TE](recreational visitor population) distribution.

Procedure 2. Using the distributions for TE(recreational visitor population) and DW(recreational visitor population) derived in Sections 4.4.1 and 4.4.2, respectively, estimate the distribution for TM(recreational visitor population) by solving the mathematical formulas necessary to ensure that TM(recreational visitor population) * DW(recreational visitor population) * TE(recreational visitor population) equals [TM*DW*TE](recreational visitor population).

The back-calculation of TM(recreational visitor population) ensures that in the PPLV equations, the product of TM(recreational visitor population) and DW(recreational visitor population) and TE(recreational visitor population) equals [TM*DW*TE](recreational visitor population), which is the most accurate characterization of hours per lifetime for the recreational visitor population based on the available data. Where TM occurs in the PPLV equations, the TM parameter is always multiplied by DW*TE; so that, as long as the [TM*DW*TE] distribution is accurate, the distribution of TM itself is arbitrary.

Simulation

The distribution of TM for the recreational visitor population is estimated from simulated values combining the component TM, DW and TE distributions developed in Sections 4.1, 4.2 and 4.3. The simulated values of TM*DW*TE for the recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, or regional general visitor are equal to the relative proportions of anglers, neighborhood general visitors, and regional general visitors within the recreational visitor population.

Step 2.

Determine a value for TE (years/lifetime) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

Step 3.

Determine a value for DW (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a DW value from DW(angler).

b. If the subpopulation is neighborhood general visitors, then select a DW according to the three step procedure described in Section 4.2.3.2; namely,

i. Select the individual's general recreational activity from among bicycling, playing outdoor sports, attending outdoor sports, walking, and running/jogging.

ii. Determine a value for the individual's total number of days of participation in this activity summed over all possible locations.

iii. Calculate the individual's number (DW) of days of activity participation at the Arsenal by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

c. If the subpopulation is regional general visitors, then select a DW according to the two step procedure described in Section 4.2.3.3; namely,

i. . Select the individual's mode of entry to the Arsenal. The probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf are assumed to be 0.81, 0.13, and 0.06, respectively, which are the relative frequencies of the Barr Lake visitors who use these three modes of entry.

ii. Determine a value for DW(regional general visitor) corresponding to the individual's selected mode of entry.

1. If the mode of entry is daily fee, then select DW from a modified Poisson distribution with mean 2.3 days/year.

2. If the mode of entry is annual pass, then select DW from a modified Poisson distribution with mean 4.6 days/year.

3. If the mode of entry is Aspen Leaf, then select DW from a modified Poisson distribution with mean 6.4 days/year.

Step 4.

Determine a value for TM (hours/day) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a TM value from TM(angler).

b. If the subpopulation is neighborhood general visitors or regional general visitors, then select a TM according to the three step procedure described in Section 4.1.3.2; namely,

i. Select one of the five representative recreational activities. The probabilities of selecting bicycling, playing outdoor sports, attending outdoor sports, walking for exercise, or running/jogging are 0.184, 0.132, 0.036, 0.536, and 0.112, respectively.

ii. Select an activity duration from the activity duration distribution corresponding to the activity selected in action (1). Set TM(general visitor) equal to this duration.

iii. Determine if the selected recreational activity is to be combined with a picnic. If it is, then randomly select the picnic duration from the probability distribution for picnic durations, and add the picnic duration to TM(general visitor).

Step 5.

Multiply these randomly generated values of TM, DW and TE.

Steps (1)-(3) are the same as steps (1)-(3) in the simulation in Section 4.4.2.2.

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of TM*DW*TE(recreational visitor population). The best fitting distribution for TM*DW*TE(recreational visitor population) is a lognormal distribution with mean 50.32 and standard deviation 280.48. Equivalently, the ln[TM*DW*TE(recreational visitor population)] has a normal distribution with mean 2.1846 and standard deviation of 1.8622. The fit is described as follows:

Percentage	Simulated Distribution (Hours/Lifetime)	Fitted Lognormal Distribution (Hours/Lifetime)
99	674.53	676.35
97.5	343.95	341.87
95	193.26	190.12
92.5	129.46	129.71
90	95.50	96.65
80	42.18	42.60
75	31.04	31.21
70	23.53	23.60
60	13.96	14.25
50	8.61	8.89
40	5.20	5.54
30	3.09	3.35
25	2.30	2.53
20	1.62	1.85
10	0.72	0.82
7.5	0.53	0.61
5	0.36	0.42
2.5	0.20	0.23
1	0.10	0.12

A graphical indication of the fit is given in Figure 4.4.3.2.

Result

It can be shown mathematically, that the product of three lognormal random variables is itself lognormally distributed. Furthermore, if TM, DW, TE, and [TM*DW*TE] are lognormally distributed and

(1) ln(TM) is normally distributed with mean A and standard deviation B,

(2) ln(DW) is normally distributed with mean C and standard deviation D, and

(3) ln(TE) is normally distributed with mean E and standard deviation F, and

(4) ln([TM*DW*TE]) is normally distributed with mean G and standard deviation H,

then

$$G = A + C + E \text{ and } H^2 = B^2 + D^2 + F^2$$

and

$$A = G - C - E \text{ and } B^2 = H^2 - D^2 - F^2$$

Hence, the lognormal distribution for TM(recreational visitor population) was derived by solving the above two equations for A and B as follows. DW(recreation visitor population) is lognormally distributed with mean 3.40 and standard deviation 4.502; so that, ln(DW) has a mean of 0.7183 (C=0.7183) and standard deviation 1.0060 (D=1.0060). TE(recreation visitor population) is lognormally distributed with mean 7.67 and standard deviation 22.47; so that, ln(TE) has a mean of 0.9078 (E=0.9078) and standard deviation 1.5031 (F=1.5031). [TM*DW*TE](recreation visitor population) is lognormally distributed with mean 50.32 and standard deviation 280.48; so that, ln([TM*DW*TE]) has a mean of 2.1846 (G=2.1846) and standard deviation 1.8622 (F=1.8622). These distributions imply that

$$A = 2.1846 - 0.7183 - 0.9078 = 0.5585 \text{ and}$$
$$B^2 = (1.8622)^2 - (1.0060)^2 - (1.5031)^2 = (0.4432)^2;$$

so that, TM(recreational visitor population) is lognormally distributed with mean 1.928 and standard deviation 0.8984, and ln(TM) has mean 0.5585 and standard deviation 0.4432.

4.5 EXPANDED RECREATIONAL VISITOR POPULATION

If the recreational scenario were to include construction of facilities for organized team sports at the Arsenal, then the recreational visitor population would be expanded to include an organized sports visitor subpopulation in addition to the angler and general visitor subpopulations. The combined population of all four subpopulations (angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations) is referred to as the expanded recreational visitor population. The analysis of and probability distribution for the expanded recreational scenario assumes that the Arsenal will have an athletic complex for organized sports, e.g., baseball diamonds, football fields, etc. The organized sports visitor subpopulation includes both players of organized sports and attenders (spectators).

Probability distributions for TM (duration of a visit in hours/day), DW (frequency of visits in days/year), and TE (years of visitation/lifetime) have been developed in Sections 4.1, 4.2, and 4.3, respectively, for each of the four subpopulations (angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations).

Section 4.5 develops the TM, DW, and TE distributions for the expanded recreational visitor population comprised of the angler, neighborhood general visitor, regional general visitor, and organized sports visitor subpopulations.

The derivations in Sections 4.4 and 4.5 of the probability distributions for TM, DW, and TE for recreational and expanded recreational visitor populations are parallel. For example, for the expanded recreational visitor population, the population distributions of TM, DW, and TE are derived in such a way that the frequency distribution for DW*TE (days/lifetime) in the combined population is the same as the combined frequency distributions for

days/lifetime for anglers:
DW(angler)*TE(angler)

days/lifetime for neighborhood general visitors:
DW(neighborhood general visitor)*TE(neighborhood general visitor)

days/lifetime for regional general visitors:
DW(regional general visitor)*TE(regional general visitor)

days/lifetime for organized sports visitors:
DW(organized sports visitor)*TE(organized sports visitor)

and the frequency distribution TM*DW*TE (hours/lifetime) in the combined population is the same as the combined frequency distributions for

hours/lifetime for anglers:
TM(angler)*DW(angler)*TE(angler)

hours/lifetime for neighborhood general visitors:
TM(neighborhood general visitor)*DW(neighborhood general visitor)*TE(neighborhood general visitor)

hours/lifetime for regional general visitors:
TM(regional general visitor)*DW(regional general visitor)*TE(regional general visitor).

hours/lifetime for organized sports visitors:
TM(organized sports visitor)*DW(organized sports visitor)*TE(organized sports visitor).

The derivations in Sections 4.4 and 4.5 avoid inappropriate calculations such as

TM(angler)*DW(organized sports visitor)*TE(regional visitor)

which do not correspond to any visitor.

The sequential development in both Sections 4.4 and 4.5 consists of the following three steps:

Step 1. The TE distributions for the component subpopulations are combined to provide a distribution of TE for the whole population.

Step 2. The DW*TE distributions for the component subpopulations are combined to provide a distribution for DW*TE for the whole population. A population DW distribution is identified such that the population DW distribution times the population TE distribution derived in Step 1 equals the distribution for DW*TE for the whole population.

Step 3. The TM*DW*TE distributions for the component subpopulations are combined to provide a distribution for TM*DW*TE for the whole population. A population TM distribution is identified such that the population TM distribution times the population DW distribution derived in Step 2 times the population TE distribution derived in Step 1 equals the distribution for TM*DW*TE for the whole population.

The developments in Sections 4.4 and 4.5 for the recreational and expanded recreational visitor populations appropriately reflect that the data and corresponding probability distributions for TM, DW, and TE for a particular subpopulation are generally distinct from the data and probability distributions for TM, DW, and TE for a different subpopulation.

By developing separate distributions for TM, DW, and TE, Sections 4.4 and 4.5 both reflect the current structure of the PPLV computations. Currently, TM does not appear in some parts of the PPLV computation (e.g., the calculations for dermal absorption). Thus, TM and DW do not always appear together in the PPLV equations, and separate distributions for TM and DW are required, rather than a single TM*DW distribution.

Steps (1)-(3) are ordered as they are in order to have only one distribution to solve for at each step. For example, in step (1) the objective is to solve for TE. In step (2), with the distribution of TE already estimated, the DW*TE distribution can be solved for the DW distribution. In step (3), with the distributions of DW and TE already estimated, the TM*DW*TE can be solved for the TM distribution.

Because the sequential development in steps (1)-(3) logically proceeds from TE to DW to TM, the ordering of the subsections considers TE first, then DW, and TM last. Hence the ordering in Sections 4.4 and 4.5 is the reverse of the order of topics in the balance of the document. Further, there is no section regarding the rationale for the data selected because the rationale has already been presented in Sections 4.1, 4.2, and 4.3.

4.5.1 TE - YEARS PER LIFETIME: Expanded Recreational Visitor Population

4.5.1.1 TE - Expanded Recreational Visitor Population: Probability Distribution

The probability distribution for the number [TE(expanded recreational visitor population)] of years of recreational activity at the Arsenal by a member of the expanded recreational visitor population is set equal to the probability distribution for the total duration, in an individual's 70 year life span, of all residences from which that individual visits the Arsenal. It is approximated by a lognormal distribution with the following percentiles:

Probability (TE(expanded recreational visitor pop.) ≤ 81.83 years/lifetime) = 0.99
Probability (TE(expanded recreational visitor pop.) ≤ 47.18 years/lifetime) = 0.975
Probability (TE(expanded recreational visitor pop.) ≤ 29.38 years/lifetime) = 0.95
Probability (TE(expanded recreational visitor pop.) ≤ 21.58 years/lifetime) = 0.925
Probability (TE(expanded recreational visitor pop.) ≤ 17.02 years/lifetime) = 0.90
Probability (TE(expanded recreational visitor pop.) ≤ 8.78 years/lifetime) = 0.80
Probability (TE(expanded recreational visitor pop.) ≤ 6.83 years/lifetime) = 0.75
Probability (TE(expanded recreational visitor pop.) ≤ 5.45 years/lifetime) = 0.70
Probability (TE(expanded recreational visitor pop.) ≤ 3.63 years/lifetime) = 0.60
Probability (TE(expanded recreational visitor pop.) ≤ 2.48 years/lifetime) = 0.50
Probability (TE(expanded recreational visitor pop.) ≤ 1.69 years/lifetime) = 0.40
Probability (TE(expanded recreational visitor pop.) ≤ 1.13 years/lifetime) = 0.30
Probability (TE(expanded recreational visitor pop.) ≤ 0.90 years/lifetime) = 0.25
Probability (TE(expanded recreational visitor pop.) ≤ 0.70 years/lifetime) = 0.20
Probability (TE(expanded recreational visitor pop.) ≤ 0.36 years/lifetime) = 0.10
Probability (TE(expanded recreational visitor pop.) ≤ 0.28 years/lifetime) = 0.075
Probability (TE(expanded recreational visitor pop.) ≤ 0.21 years/lifetime) = 0.05
Probability (TE(expanded recreational visitor pop.) ≤ 0.13 years/lifetime) = 0.025
Probability (TE(expanded recreational visitor pop.) ≤ 0.08 years/lifetime) = 0.01

This is a lognormal distribution with mean 7.67 and standard deviation 22.47. The ln[TE(expanded recreational visitor population)] has a normal distribution with mean 0.9078 and standard deviation of 1.5032. The mathematical development of this distribution is given in Section 4.5.1.2.

4.5.1.2 TE - Expanded Recreational Visitor Population: Mathematical Development

The distribution of TE for the expanded recreational visitor population was estimated from simulated values combining the component subpopulation probability distributions for TE(angler), TE(neighborhood general visitor), TE(regional general visitor), and TE(organized sports visitor) derived in Section 4.3. The simulated values for the expanded recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, regional general visitor, or organized sports visitor are equal to the relative proportions of anglers, neighborhood general visitors, regional general visitors, and organized sports visitor within the expanded recreational visitor population.

Step 2.

Determine a value for TE (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

d. If the subpopulation is organized sports visitors, then TE is selected from TE(organized sports visitor).

In step (1), the probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, regional general visitor, or organized sports visitor are equal to the relative proportions of anglers, neighborhood general visitors, regional general visitors, and organized sports visitor within the expanded recreational visitor population. These proportions are as follows:

Subpopulation	Number in Subpopulation	Probability (Proportion)
Angler	602	0.001944*
Neighborhood General Visitor	9,649	0.031153
Regional General Visitor	296,101	0.956003
Organized Sports Visitor	3,376	0.010900
Total	309,728	1.000000

* 0.001944 = 602/309,728

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of TE(expanded recreational visitor population). The best fitting distribution for TE(expanded

recreational visitor population) is a lognormal distribution with mean 7.67 and standard deviation 22.47. Equivalently, the ln[TE(expanded recreational visitor population)] has a normal distribution with mean 0.9078 and standard deviation of 1.5032. The fit is described as follows:

Percentage	Simulated Distribution (Years/Lifetime)	Fitted Lognormal Distribution (Years/Lifetime)
99	81.27	81.83
97.5	47.75	47.18
95	29.39	29.38
92.5	21.81	21.58
90	17.10	17.02
80	8.66	8.78
75	6.71	6.83
70	5.33	5.45
60	3.50	3.63
50	2.38	2.48
40	1.60	1.69
30	1.04	1.13
25	0.82	0.90
20	0.63	0.70
10	0.31	0.36
7.5	0.24	0.28
5	0.17	0.21
2.5	0.11	0.13
1	0.06	0.08

A graphical indication of the fit is given in Figure 4.5.1.2.

4.5.2 DW - DAYS PER YEAR: Expanded Recreational Visitor Population

4.5.2.1 DW - Expanded Recreational Visitor Population: Probability Distribution

The probability distribution for the number [DW(expanded recreational visitor population)] of days per year of recreational activity at the Arsenal by a member of the recreational visitor population is estimated to be a lognormal distribution with the following percentiles:

Probability (DW(expanded recreational visitor pop.) $\leq$ 21.64 days/year) = 0.99
Probability (DW(expanded recreational visitor pop.) $\leq$ 14.98 days/year) = 0.975
Probability (DW(expanded recreational visitor pop.) $\leq$ 10.92 days/year) = 0.95
Probability (DW(expanded recreational visitor pop.) $\leq$ 8.89 days/year) = 0.925
Probability (DW(expanded recreational visitor pop.) $\leq$ 7.59 days/year) = 0.90
Probability (DW(expanded recreational visitor pop.) $\leq$ 4.88 days/year) = 0.80

Probability (DW(expanded recreational visitor pop.) ≤ 4.13 days/year) = 0.75
Probability (DW(expanded recreational visitor pop.) ≤ 3.55 days/year) = 0.70
Probability (DW(expanded recreational visitor pop.) ≤ 2.71 days/year) = 0.60
Probability (DW(expanded recreational visitor pop.) ≤ 2.10 days/year) = 0.50
Probability (DW(expanded recreational visitor pop.) ≤ 1.63 days/year) = 0.40
Probability (DW(expanded recreational visitor pop.) ≤ 1.24 days/year) = 0.30
Probability (DW(expanded recreational visitor pop.) ≤ 1.07 days/year) = 0.25
Probability (DW(expanded recreational visitor pop.) ≤ 0.90 days/year) = 0.20
Probability (DW(expanded recreational visitor pop.) ≤ 0.58 days/year) = 0.10
Probability (DW(expanded recreational visitor pop.) ≤ 0.50 days/year) = 0.075
Probability (DW(expanded recreational visitor pop.) ≤ 0.40 days/year) = 0.05
Probability (DW(expanded recreational visitor pop.) ≤ 0.29 days/year) = 0.025
Probability (DW(expanded recreational visitor pop.) ≤ 0.20 days/year) = 0.01

This is a lognormal distribution with mean 3.470 and standard deviation 4.5700. The ln[DW(expanded recreational visitor population)] has a normal distribution with mean 0.7411 and standard deviation of 1.0030. The mathematical development of this distribution is given in Section 4.5.2.2.

4.5.2.2 DW - Expanded Recreational Visitor Population: Mathematical Development

Procedure

As indicated in Sections 4.0.2 and 4.5, the distribution of DW(expanded recreational visitor population) was derived by estimating the population's data based distributions for TE and [DW*TE], and then back-calculating to solve for DW. The back-calculation involves the following procedures:

Procedure 1. Estimate the lognormal distribution for days per lifetime for visitors in the recreational visitor population by combining the component DW and TE distributions developed in Sections 4.2 and 4.3 (i.e., DW(angler), DW(neighborhood general visitor), DW(regional general visitor), DW(organized sports visitor), TE(angler), TE(neighborhood general visitor), TE(regional general visitor), and TE(organized sports visitor)). This distribution is referred to as the [DW*TE](expanded recreational visitor population) distribution.

Procedure 2. Using the distribution for TE(expanded recreational visitor population) derived in Section 4.5.1, estimate the distribution for DW(expanded recreational visitor population) by solving the mathematical formulas necessary to ensure that DW(expanded recreational visitor population) * TE(expanded recreational visitor population) equals [DW*TE](expanded recreational visitor population).

The back-calculation of DW(expanded recreational visitor population) ensures that in the PPLV equations, the product of DW(expanded recreational visitor population) and TE(expanded recreational visitor population) equals [DW*TE](expanded recreational visitor population), which is the most accurate characterization of hours per lifetime for the expanded recreational visitor population based on the available data. Where DW occurs in the PPLV equations, the DW parameter is always multiplied by TE; so that, as long as the [DW*TE] distribution is accurate, the distribution of DW itself is arbitrary.

Simulation

The distribution of DW for the expanded recreational visitor population is estimated from simulated values combining the component DW and TE distributions developed in Section 4.2 and 4.3. The simulated values of DW*TE for the expanded recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, regional general visitor, or organized sports visitor are equal to the relative proportions of anglers, neighborhood general visitors, regional general visitors, and organized sports visitors within the expanded recreational visitor population.

Step 2.

Determine a value for TE (years/lifetime) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

d. If the subpopulation is organized sports visitors, then TE is selected from TE(organized sports visitor).

Step 3.

Determine a value for DW (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a DW value from DW(angler).

b. If the subpopulation is neighborhood general visitors, then select a DW according to the three step procedure described in Section 4.2.3.2; namely,

   i. Select the individual's general recreational activity from among bicycling, playing outdoor sports, attending outdoor sports, walking, and running/jogging.

   ii. Determine a value for the individual's total number of days of participation in this activity summed over all possible locations (i.e., at the Arsenal as well as other sites).

   iii. Calculate the individual's number (DW) of days of activity participation at the Arsenal by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

c. If the subpopulation is regional general visitors, then select a DW according to the two step procedure described in Section 4.2.3.3; namely,

   i. Select the individual's mode of entry to the Arsenal. The probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf are assumed to be 0.81, 0.13, and 0.06, respectively, which are the relative frequencies of the Barr Lake visitors who use these three modes of entry.

   ii. Determine a value for DW(regional general visitor) corresponding to the individual's selected mode of entry.

      1. If the mode of entry is daily fee, then select DW from a modified Poisson distribution with mean 2.3 days/year.

      2. If the mode of entry is annual pass, then select DW from a modified Poisson distribution with mean 4.6 days/year.

      3. If the mode of entry is Aspen Leaf, then select DW from a modified Poisson distribution with mean 6.4 days/year.

d. If the subpopulation is organized sports visitors, then select a DW according to the five step procedure described in Section 4.2.3.4; namely,

   i. Determine whether the organized sports visitor is a player or a spectator.

ii. Determine the number of organized sports leagues in which the individual will participate.

iii. For each organized sports league, randomly determine whether that league will play its games at the Arsenal.

iv. For each league that plays at the Arsenal, randomly determine the total number of games (including practices) in which the individual will participate.

v. DW is the sum, over the leagues that play at the Arsenal, of the number of games per league in which an individual is assumed to participate.

Step 4.

Multiply these randomly generated values of DW and TE.

Steps (1) and (2) are the same as steps (1) and (2) in the simulation in Section 4.5.1.2.

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of DW*TE(expanded recreational visitor population). The best fitting distribution for DW*TE(expanded recreational visitor population) is a lognormal distribution with mean 26.62 and standard deviation 133.62. Equivalently, the ln[DW*TE(expanded recreational visitor population)] has a normal distribution with mean 1.6489 and standard deviation of 1.8071. The fit is described as follows:

Percentage	Simulated Distribution (Days/Lifetime)	Fitted Lognormal Distribution (Days/Lifetime)
99	350.53	348.21
97.5	178.00	179.60
95	98.22	101.62
92.5	68.66	70.12
90	52.82	52.71
80	25.03	23.80
75	19.01	17.60
70	14.66	13.42
60	9.14	8.22
50	5.84	5.20
40	3.75	3.29
30	2.32	2.02
25	1.79	1.54

20	1.32	1.14
10	0.61	0.51
7.5	0.45	0.39
5	0.31	0.27
2.5	0.18	0.15
1	0.08	0.08

A graphical indication of the fit is given in Figure 4.5.2.2.

Result

It can be shown mathematically, that the product of two lognormal random variables is itself lognormally distributed. Furthermore, if DW, TE, and [DW*TE] are lognormally distributed and

(1) ln(DW) is normally distributed with mean A and standard deviation B,

(2) ln(TE) is normally distributed with mean C and standard deviation D, and

(3) ln([DW*TE]) is normally distributed with mean E and standard deviation F,

then

$$E = A + C \text{ and } F^2 = B^2 + D^2$$

and

$$A = E - C \text{ and } B^2 = F^2 - D^2.$$

Hence, the lognormal distribution for DW(expanded recreational visitor population) was derived by solving the above two equations for A and B as follows. TE(expanded recreation visitor population) is lognormally distributed with mean 7.67 and standard deviation 22.47; so that, ln(TE) has a mean of 0.9078 (C=0.9078) and standard deviation 1.5032 (D=1.5032). [DW*TE](expanded recreation visitor population) is lognormally distributed with mean 26.62 and standard deviation 133.62; so that, ln([DW*TE]) has a mean of 1.6489 (E=1.6489) and standard deviation 1.8071 (F=1.8071). These distributions imply that

$$A = 1.6489 - 0.9078 = 0.7411 \text{ and}$$
$$B^2 = (1.8071)^2 - (1.5032)^2 = (1.0030)^2;$$

so that, DW(expanded recreational visitor population) is lognormally distributed with mean 3.470 and standard deviation 4.5700, and ln(DW) has mean 0.7411 and standard deviation 1.0030.

4.5.3 TM - HOURS PER DAY: Expanded Recreational Visitor Population

4.5.3.1 TM - Expanded Recreational Visitor Population: Probability Distribution

The probability distribution for the number [TM(expanded recreational visitor population)] of hours per day of recreational activity at the Arsenal by a member of the expanded recreational visitor population is estimated to be a lognormal distribution with the following percentiles:

Probability (TM(expanded recreational visitor pop.) ≤ 5.10 hours/day) = 0.99
Probability (TM(expanded recreational visitor pop.) ≤ 4.30 hours/day) = 0.975
Probability (TM(expanded recreational visitor pop.) ≤ 3.71 hours/day) = 0.95
Probability (TM(expanded recreational visitor pop.) ≤ 3.37 hours/day) = 0.925
Probability (TM(expanded recreational visitor pop.) ≤ 3.13 hours/day) = 0.90
Probability (TM(expanded recreational visitor pop.) ≤ 2.55 hours/day) = 0.80
Probability (TM(expanded recreational visitor pop.) ≤ 2.36 hours/day) = 0.75
Probability (TM(expanded recreational visitor pop.) ≤ 2.20 hours/day) = 0.70
Probability (TM(expanded recreational visitor pop.) ≤ 1.94 hours/day) = 0.60
Probability (TM(expanded recreational visitor pop.) ≤ 1.72 hours/day) = 0.50
Probability (TM(expanded recreational visitor pop.) ≤ 1.53 hours/day) = 0.40
Probability (TM(expanded recreational visitor pop.) ≤ 1.35 hours/day) = 0.30
Probability (TM(expanded recreational visitor pop.) ≤ 1.26 hours/day) = 0.25
Probability (TM(expanded recreational visitor pop.) ≤ 1.16 hours/day) = 0.20
Probability (TM(expanded recreational visitor pop.) ≤ 0.95 hours/day) = 0.10
Probability (TM(expanded recreational visitor pop.) ≤ 0.88 hours/day) = 0.075
Probability (TM(expanded recreational visitor pop.) ≤ 0.80 hours/day) = 0.05
Probability (TM(expanded recreational visitor pop.) ≤ 0.69 hours/day) = 0.025
Probability (TM(expanded recreational visitor pop.) ≤ 0.58 hours/day) = 0.01

This is a lognormal distribution with mean 1.919 and standard deviation 0.9474. The ln[TM(expanded recreational visitor population)] has a normal distribution with mean 0.5425 and standard deviation of 0.4671. The mathematical development of this distribution is given in Section 4.5.3.2.

4.5.3.2 TM - Expanded Recreational Visitor Population: Mathematical Development

Procedure

As indicated in Sections 4.0.2 and 4.5, the distribution of TM(expanded recreational visitor population) was derived by estimating the population's data based distributions for TE, DW, and [TM*DW*TE], and then back-calculating to solve for TM. The back-calculation involves the following procedures:

Procedure 1. Estimate the lognormal distribution for hours per lifetime for visitors in the expanded recreational visitor population by combining the component TM, DW and TE distributions developed in Sections 4.1, 4.2 and 4.3 (i.e., TM(angler), TM(neighborhood general visitor), TM(regional general visitor), TM(organized sports visitor), DW(angler), DW(neighborhood general visitor), DW(regional general visitor), TM(organized sports visitor), TE(angler), TE(neighborhood general visitor), TE(regional general visitor), and TE(organized sports visitor)). This distribution is referred to as the [TM*DW*TE](expanded recreational visitor population) distribution.

Procedure 2. Using the distributions for TE(expanded recreational visitor population) and DW(expanded recreational visitor population) derived in Sections 4.5.1 and 4.5.2, respectively, estimate the distribution for TM(expanded recreational visitor population) by solving the mathematical formulas necessary to ensure that TM(expanded recreational visitor population) * DW(expanded recreational visitor population) * TE(expanded recreational visitor population) equals [TM*DW*TE](expanded recreational visitor population).

The back-calculation of TM(expanded recreational visitor population) ensures that in the PPLV equations, the product of TM(expanded recreational visitor population), DW(expanded recreational visitor population), and TE(expanded recreational visitor population) equals [TM*DW*TE](expanded recreational visitor population), which is the most accurate characterization of hours per lifetime for the expanded recreational visitor population based on the available data. Where TM occurs in the PPLV equations, the TM parameter is always multiplied by DW*TE; so that, as long as the [TM*DW*TE] distribution is accurate, the distribution of TM itself is arbitrary.

Simulation

The distribution of TM for the expanded recreational visitor population is estimated from simulated values combining the component TM, DW and TE distributions developed in Sections 4.1, 4.2 and 4.3. The simulated values of TM*DW*TE for the expanded recreational visitor population are obtained by repeating the following steps 10,000 times:

Step 1.

Select an individual's subpopulation. The probabilities of the individual's selected subpopulation being angler, neighborhood general visitor, regional general visitor, or organized sports visitor are equal to the relative proportions of anglers, neighborhood general visitors, regional general visitors, and organized sports visitors within the expanded recreational visitor population.

Step 2.

Determine a value for TE (years/lifetime) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then TE is selected from TE(angler).

b. If the subpopulation is neighborhood general visitors, then TE is selected from TE(neighborhood general visitor).

c. If the subpopulation is regional general visitors, then TE is selected from TE(regional general visitor).

d. If the subpopulation is organized sports visitors, then TE is selected from TE(organized sports visitor).

Step 3.

Determine a value for DW (days/year) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a DW value from DW(angler).

b. If the subpopulation is neighborhood general visitors, then select a DW according to the three step procedure described in Section 4.2.3.2; namely,

   i. Select the individual's general recreational activity from among bicycling, playing outdoor sports, attending outdoor sports, walking, and running/jogging.

   ii. Determine a value for the individual's total number of days of participation in this activity summed over all possible locations.

   iii. Calculate the individual's number (DW) of days of activity participation at the Arsenal by multiplying the individual's total number of days of participation in this activity summed over all possible locations by a selected fraction corresponding to the Arsenal's capture rate for that individual.

c. If the subpopulation is regional general visitors, then select a DW according to the two step procedure described in Section 4.2.3.3; namely,

   i. Select the individual's mode of entry to the Arsenal. The probabilities of the individual's selected mode of entry being analogous to daily fee, annual pass, and Aspen Leaf are assumed to be 0.81, 0.13, and 0.06,

respectively, which are the relative frequencies of the Barr Lake visitors who use these three modes of entry.

ii. Determine a value for DW(regional general visitor) corresponding to the individual's selected mode of entry.

1. If the mode of entry is daily fee, then select DW from a modified Poisson distribution with mean 2.3 days/year.

2. If the mode of entry is annual pass, then select DW from a modified Poisson distribution with mean 4.6 days/year.

3. If the mode of entry is Aspen Leaf, then select DW from a modified Poisson distribution with mean 6.4 days/year.

d. If the subpopulation is organized sports visitors, then select a DW according to the five step procedure described in Section 4.2.3.4; namely,

i. Determine whether the organized sports visitor is a player or a spectator.

ii. Determine the number of organized sports leagues in which the individual will participate.

iii. For each organized sports league, randomly determine whether that league will play its games at the Arsenal.

iv. For each league that plays at the Arsenal, randomly determine the total number of games (including practices) in which the individual will participate.

v. DW is the sum, over the leagues that play at the Arsenal, of the number of games per league in which an individual is assumed to participate.

Step 4.

Determine a value for TM (hours/day) corresponding to the individual's selected subpopulation.

a. If the subpopulation is anglers, then select a TM value from TM(angler).

b. If the subpopulation is neighborhood general visitors or regional general visitors, then select a TM according to the three step procedure described in Section 4.1.3.2; namely,

i. Select one of the five representative recreational activities. The probabilities of selecting bicycling, playing outdoor sports, attending outdoor sports, walking for exercise, or running/jogging are 0.184, 0.132, 0.036, 0.536, and 0.112, respectively.

ii. Select an activity duration from the activity duration distribution corresponding to the activity selected in action (1). Set TM(general visitor) equal to this duration.

iii. Determine if the selected recreational activity is to be combined with a picnic. If it is, then randomly select the picnic duration from the probability distribution for picnic durations, and add the picnic duration to TM(general visitor).

c. If the subpopulation is organized sports visitors, then select a TM value from TM(organized sports visitor).

Step 5.

Multiply these randomly generated values of TM, DW and TE.

Steps (1)-(3) are the same as steps (1)-(3) in the simulation in Section 4.5.2.2.

The normal and lognormal distributions were fit to the percentiles of the 10,000 simulated values of TM*DW*TE(expanded recreational visitor population). The best fitting distribution for TM*DW*TE(expanded recreational visitor population) is a lognormal distribution with mean 51.07 and standard deviation 286.99. Equivalently, the ln[TM*DW*TE(expanded recreational visitor population)] has a normal distribution with mean 2.1914 and standard deviation of 1.8665. The fit is described as follows:

Percentage	Simulated Distribution (Hours/Lifetime)	Fitted Lognormal Distribution (Hours/Lifetime)
99	684.97	687.74
97.5	350.98	347.09
95	195.21	192.76
92.5	131.46	131.40
90	96.43	97.84
80	42.41	43.05
75	31.12	31.51
70	23.70	23.81
60	13.99	14.36

50	8.63	8.95
40	5.20	5.58
30	3.07	3.36
25	2.28	2.54
20	1.61	1.86
10	0.71	0.82
7.5	0.52	0.61
5	0.35	0.42
2.5	0.18	0.23
1	0.09	0.12

A graphical indication of the fit is given in Figure 4.5.3.2.

Result

It can be shown mathematically, that the product of three lognormal random variables is itself lognormally distributed. Furthermore, if TM, DW, TE, and [TM*DW*TE] are lognormally distributed and

(1) ln(TM) is normally distributed with mean A and standard deviation B,

(2) ln(DW) is normally distributed with mean C and standard deviation D, and

(3) ln(TE) is normally distributed with mean E and standard deviation F, and

(4) ln([TM*DW*TE]) is normally distributed with mean G and standard deviation H,

then

$$G = A + C + E \text{ and } H^2 = B^2 + D^2 + F^2$$

and

$$A = G - C - E \text{ and } B^2 = H^2 - D^2 - F^2$$

Hence, the lognormal distribution for TM(expanded recreational visitor population) was derived by solving the above two equations for A and B as follows. DW(expanded recreation visitor population) is lognormally distributed with mean 3.47 and standard deviation 4.570; so that, ln(DW) has a mean of 0.7411 (C=0.7411) and standard deviation 1.0030 (D=1.0030). TE(expanded recreation visitor population) is lognormally distributed with mean 7.67 and standard deviation 22.47; so that, ln(TE) has a mean of 0.9078 (E=0.9078) and standard deviation 1.5032 (F=1.5032). [TM*DW*TE](expanded recreation visitor population) is lognormally distributed with mean 51.07 and standard deviation 286.99; so that, ln([TM*DW*TE]) has a mean of 2.1914 (G=2.1914) and standard deviation 1.8665

(F=1.8665). These distributions imply that

$$A = 2.1914 - 0.7411 - 0.9078 = 0.5425 \text{ and}$$
$$B^2 = (1.8665)^2 - (1.0030)^2 - (1.5032)^2 = (0.4671)^2;$$

so that, TM(expanded recreational visitor population) is lognormally distributed with mean 1.919 and standard deviation 0.9474, and ln(TM) has mean 0.5425 and standard deviation 0.4671.