2.0 3MRA Methodology : A Summary Description

This section provides a description of the essential elements of the 3MRA methodology as they relate to developing a design for the facilitating software system. Detailed descriptions of the 3MRA methodology are presented in "A Framework for Finite-Source Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (3MRA)" [1] .

The 3MRA national assessment methodology is a screening-level risk-based assessment of potential human and ecological health risks resulting from long-term (chronic) exposure to chemicals released from land-based waste management units (WMUs). The assessment is national in scale and site-based, that is, risks are assessed at individual sites across the U.S. and rolled-up to represent a national distribution of risks. The resulting national distribution of risks forms the basis for determining wastestream constituent concentrations that satisfy regulatory criteria that are based on the percentage of nationwide receptors and sites that are "protective". Protective, in this context, means that receptors (human and ecological) do not experience health risks or hazards greater than those established by Agency policy (e.g., excess cancer risk of 10^{-6})

The following sections describe the 3MRA assessment methodology in a manner that leads directly to a statement of requirements for a technology design. First, a brief description of the site-based risk assessment, including the conceptual modeling approach, data requirements, and risk outputs, is presented in Section 2.1. Section 2.2 describes the manner in which expressions of risk at the site level are accumulated and stored in a database that can be queried to provide expressions of national protection. Finally, Section 2.3 describes the essential features of the Monte Carlo-based approach, including the general algorithm, that facilitates the probabilistic applications of the 3MRA modeling tools and provides a means for quantifying and separating variability and uncertainty. With this background information the 3MRA national assessment technology is presented in Section 3.

2.1 Site-based Modeling Approach

At the core of the 3MRA methodology is the assessment of human and ecological risks at a statistically derived sample of sites across the U.S. These risks are estimated using an integrated multimedia modeling approach. Described in Sections 2.1.1, 2.1.2, and 2.1.3 are, respectively, the conceptual modeling approach for conducting site-based human and ecological risk assessments, the modeling input data, and the modeling outputs.

2.1.1 Conceptual Modeling Approach

Figure 2.1 illustrates the conceptual layout of a typical 3MRA site where exposures and related health risks are to be modeled. Figure 2.1a illustrates that the geographic center of a site, for modeling purposes, is the waste management unit (WMU). The geographic extent of the modeling "area of interest" (AOI) is bounded by a circle whose radius extends from the edge of the source outward 2 kilometers. This extent is a function of a modeling assumption that states that the peak, and in a cumulative sense, the most significant portion of the risk resulting from chemical releases from the WMU, occur within 2 kilometers of the source. This geographic

extent is not a limitation of the 3MRA modeling system. Also shown in Figure 2.1a is the conceptual view of how the human population distribution in the AOI is assigned. U.S. Census data is used to locate "Census Block" centroids within the AOI. Block group populations, characterized by age cohorts, are assigned a resident location at the centroid of the block group. Thus, for purposes of exposure and risk all receptors within the block group experience the same exposure concentrations. Further, the 3MRA assumes the population will be present throughout the duration of a site simulation (which may be on the order of hundreds or thousands of years). 3MRA employs the concept of generational cohorts which assumes that a each receptor lifetime is followed by a series of identical receptors until the end of the simulation. Finally, Figure 2.1a includes two additional concentric rings at 0.5 kilometers and 1.0 kilometers, respectively. These rings define distances for aggregating exposure and risks across receptors, thus providing decision analysts a risk vs distance from source perspective.

Figure 2.1b illustrates the conceptualization of watersheds and surface waters for 3MRA. Within the AOI watersheds are delineated using GIS software. There is no limit to the number of watershed sub-basins that can be modeled in 3MRA. Each watershed sub-basin is assigned to specific surface waters for purpose of routing runoff and erosive fluxes. The surface waters within the AOI may include streams, ponds, lakes, and wetlands. Inter-connected surface waters form a "waterbody network" and there may be multiple water networks within the AOI. Finally, Figure 2.1b includes "local watershed sub-basins" that represent the land area between the WMU and the surface water segment receiving the source runoff. This area is specifically modeled in 3MRA.

Figure 2.1.c illustrates the conceptualization of ecological habitats within the AOI. Habitats are delineated using GIS-based maps displaying landuse and ecological regions. Individual specie home ranges are randomly assigned in a manner that is consistent with predator prey relationships among the habitat species. Related to habitats are foodwebs that involve both plants and animals and associated diets. 3MRA habitat types include several terrestrial and aquatic environments. Also shown in Figure 2.1c are farms where crops may be exposed and result in exposure to humans via the food chain.

Figure 2.1d illustrates an integrated view of the site layout features described above. This is shown to make the point that in reality these features seamlessly overlap and connect. That is, for example, habitats overalp watersheds that drain into both the sub-surface and surface waters. In 3MRA, all such connections are explicitly assigned with appropriate modeling of intermedia fluxes.

Not shown in Figure 2.1 are the atmospheric and groundwater media included in 3MRA. Atmospheric fate and transport of chemicals released from the WMU is based on meteorological data associated with a regional weather station. Subsurface components of the site layout include a vadose zone directly beneath the WMU and a regional aquifer at a uniform depth and flow direction.

Table 2.1 lists the "dimensions" of modeling associated with the simulation of the movement of chemical through each of the media of the 3MRA site layout. The dimensions reflect the collection of physical/chemical/biological processes that are modeled in an attempt to characterize the release, fate, transport, exposure, and risk associated with waste disposal. The general steps in the site-based modeling assessment are as follows:

1) Simulate the loading of wastestreams to land-based waste management unit (WMU) over the lifetime of the WMU (including surface impoundments, landfills, land application units, waste piles, and aerated tanks).
2) Simulate the release of chemical from the WMU to air (volatilization, particle re-entrainment), vadose zone (leaching), groundwater(leaching), watersheds and surface waters (overland runoff/erosion).
3) Simulate the fate and transport of chemical in and between major environmental media (air, watershed soils, vadose zone, groundwater, surface water, and sediments).
4) Simulate movement of chemical through the farm foodchain and aquatic and terrestrial foodwebs.
5) Simulate human and ecological exposure via selected pathways (for human receptors the pathways include air inhalation, shower air inhalation, groundwater ingestion, soil ingestion, produce ingestion, beef ingestion, milk ingestion, fish ingestion, and breast milk ingestion for infants).
6) Estimate human and ecological risk per receptor per pathway.
7) Repeat this sequence for each of a series of waste concentrations (Cw) to establish a quantitative relationship between Cw and risk/hazard.

To execute this series of steps 3MRA utilizes a collection of seventeen science modules, each simulating a self bounding component of the integrated system. Figure 2.2 identifies the modules and illustrates their relative position in the 3MRA-based sequential execution of the steps listed above.

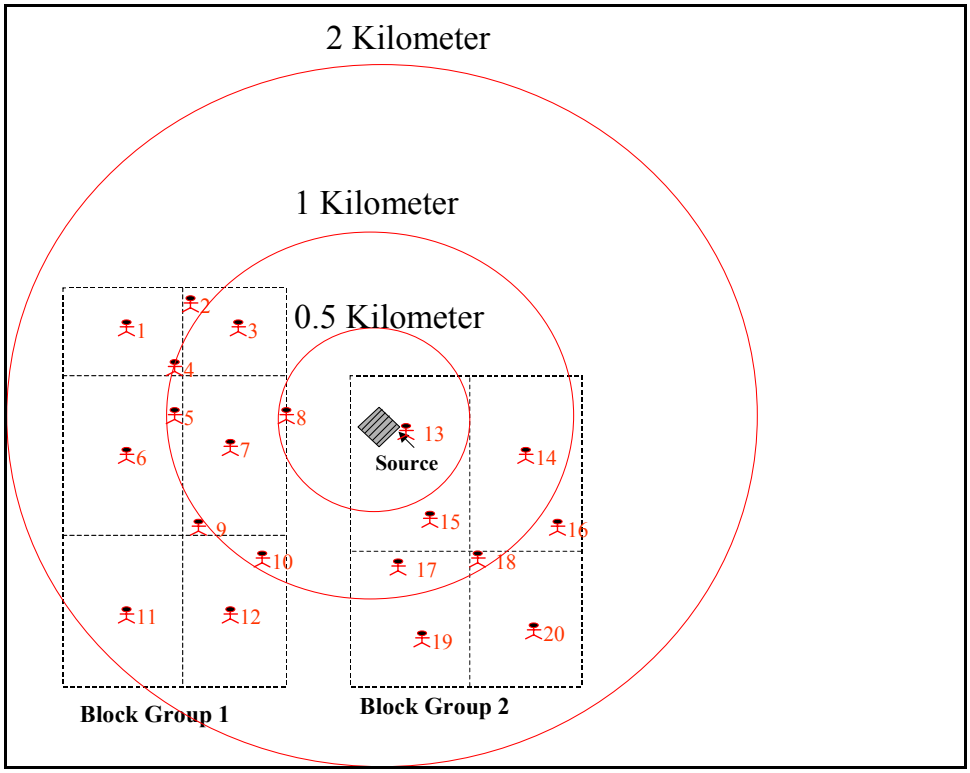

Figure 2.1.a 3MRA Site Layout Example of Human Population Distribution and Extent of Modeling Area of Interest

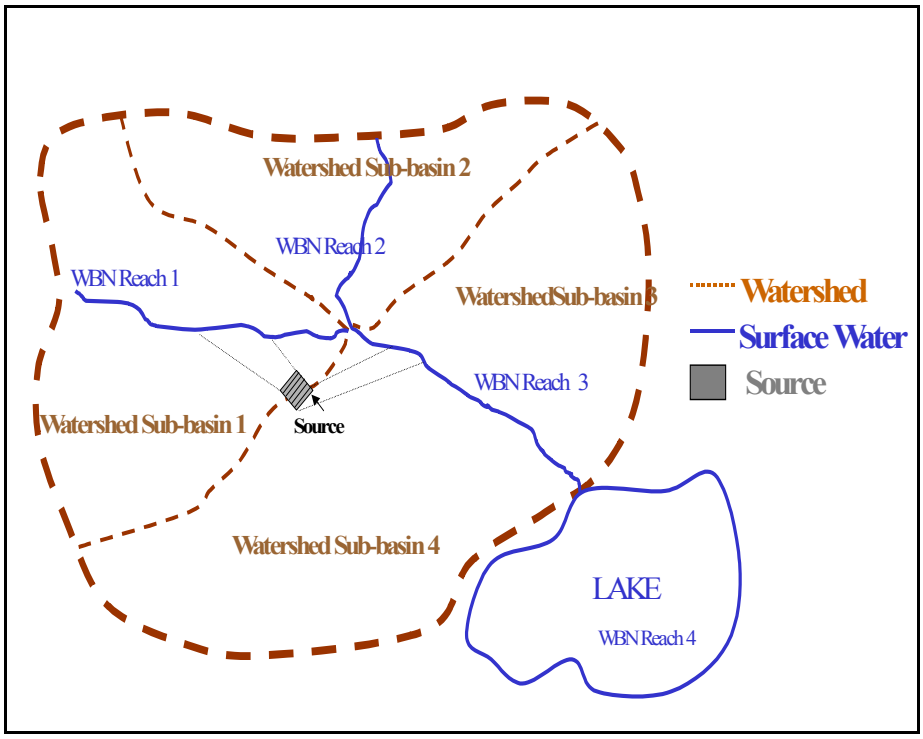

Figure 2.1.b 3MRA Site Layout Example of Watersheds and Surface Waters

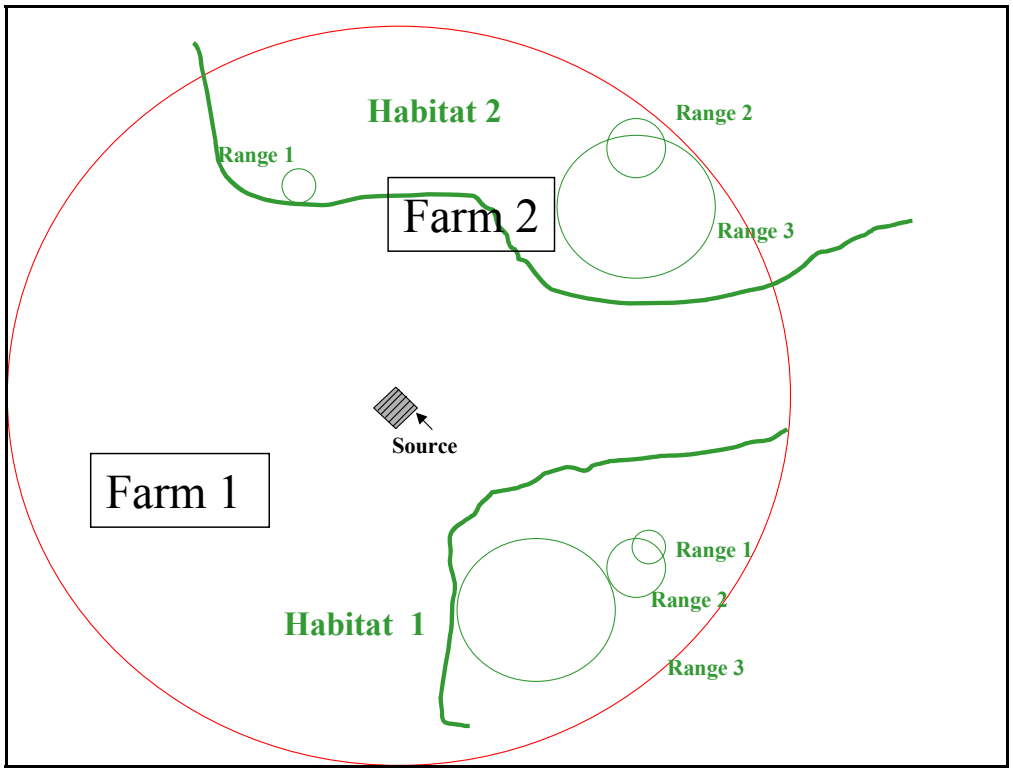

Figure 2.1.c 3MRA Site Layout Example of Ecological Habitats and Farms

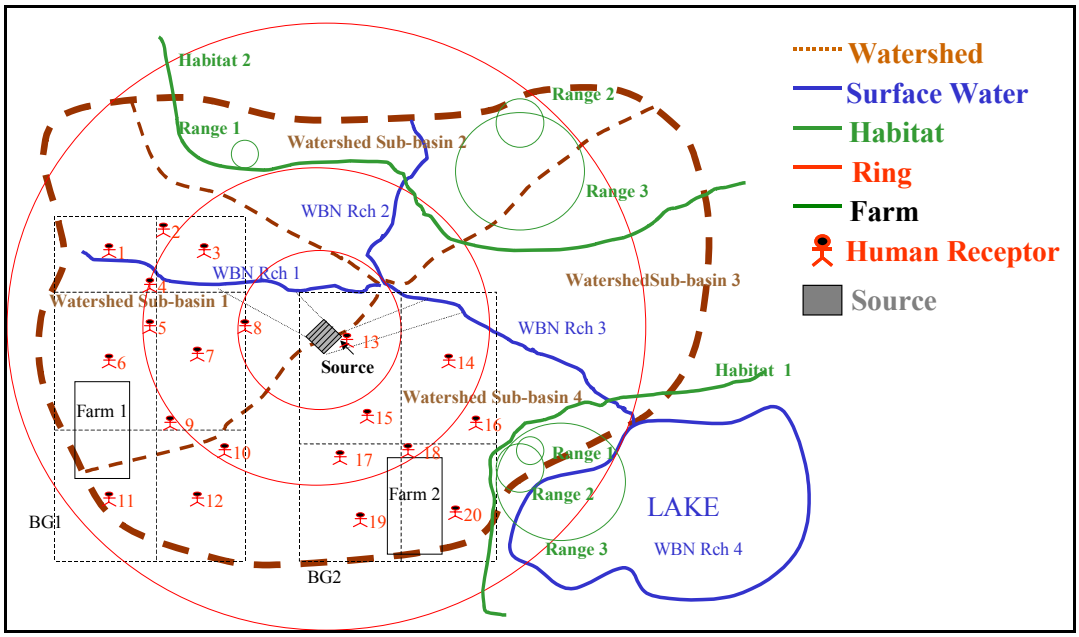

Figure 2.1.d Integrated 3MRA Site Layout

Table 2.1 Dimensions of 3MRA Site-based Risk Assessment

CONTAMINANTS Organics (approx. 200) Metals (20) **SOURCE TYPES** Landfill Land Application Unit Surface Impoundment Aerated Tank Waste Pile **SOURCE TERM CHARACTERISTICS** Mass Balance Multimedia Partitioning Chemical Decay **SOURCE RELEASE MECHANISMS** Erosion Volatilization Runoff Leaching Particle Resuspension **TRANSPORT MEDIA** Atmosphere Soil Vadose zone Saturated zone Surface water **FATE PROCESSES** Chemical/Biological Transformation (and associated products of transformation) Linear partitioning (water/air, water/soil, air/plant, water/biota) Nonlinear partitioning (metals in vadose zone) Chemical Reaction/Speciation **AGE GROUPS FOR HUMAN RECEPTORS** Infant < 1 year Child-a 1- 5 years Child-b 6 - 11 years Child-c 12- 19 years Adult 20+ years	**INTERMEDIA CONTAMINANT FLUXES** Source -> Air (vol, resuspension) Source -> Vadose zone (leaching) Source Surface soil -> Local Watershed Soil (erosion, runoff) Air -> Watershed/Farm /Habitat Soil (wet/dry dep) Air -> Surface water (wet/dry dep) Air -> Vegetation (dep/uptake) Farm/Habitat Soil -> Vegetation (root uptake) Watershed Soil -> Surface water (erosion, runoff) Surface water -> Aquatic organisms (uptake) Surface water -> Sediment (sedimentation) Vadose zone -> Groundwater (percolation) Groundwater -> Surface water Soil -> Vegetation (uptake, dep) Vegetation, Soil, Water -> Beef and dairy (uptake) **FOODCHAIN** Human (Farm) Human (Aquatic) Ecological (Aquatic Habitat) Ecological (Terrestrial Habitat) **RECEPTORS** Human Resident (Adult & Child) Beef Farmer (Adult & Child) Dairy Farmer (Adult & Child) Home Gardener (Adult & Child) Recreational Fisher (Adult & Child) Ecological Mammals, Birds, Soil Communities, Terrestrial Plants, Aquatic Communities, Benthic Communities, Aquatic Plants, Amphibians, and Reptiles. **EXPOSURE ROUTES/PATHWAYS** Ingestion (plant, meat, milk, aquatic food, water, soil) Inhalation (gases, particulates) Direct Contact (soil, water) **HUMAN AND ECOLOGICAL RISK ENDPOINTS** Human Cancer Risk Human Noncancer Hazard Quotient Ecological Population and Community Hazard Quotients

2.1.2 3MRA Data

The data requirements for 3MRA modeling are substantial. The primary categories of input data are listed in Table 2.2 and include site data (layout and environmental), human and ecological exposure data, chemical data, and meteorological data. The 3MRA methodology calls for the use of "site-based" data, meaning that, to the extent practicable, data used in the modeling is to be directly reflective of the 3MRA sampled-sites from across the U.S. Because of several factors, including the lack of availability of various data at specific sites, resource limitations associated with collecting the data, and the screening level nature of the modeling approach, not all data is site-specific. Lacking site-specific data, statistical distributions of data values within the geographic region containing the site is accessed and sampled. The resulting value is assigned to the site. Further, when a regional source of data is unavailable, a national scale statistical distribution of the variable sampled and assigned to the site. In all, several hundred variables are required to model any given site. Table 2.2 lists the categories of data required for 3MRA and the source of the data, i.e., site-specific, regional, national databases, or a combination of sources.

Included in the 3MRA database containing site data are 201 individual site locations involving a total of 419 site/WMU combinations. Each site contains one or more of the WMUs but no site contains all five unit types.

Table 2.2 3MRA Data Requirements and Sources

Data Type	Data Representation		
	Site-based	Regional	National
Site Layout Data			
Waste Management Unit	●		●
Watershed and waterbody layout	●		
Human receptor characteristics and location	●		●
Ecological habitat type, receptors, and location	●	●	
Site Environmental Data			
Waste properties			●
Atmosphere		●	
Surface water		●	●
Soil/vadose zone	●		●
Aquifer	●	●	●
Farm food chain/terrestrial food web			●

Aquatic food web		●	●
Human and Ecological Exposure/Risk Data			
Human exposure factors			●
Ecological exposure factors		●	●
Risk and control variables			●
Meteorological Data		●	
Chemical Data *			
Physical properties			●
Biouptake/bioaccumulation factors			●
Chemical/Biological Transformation Rates			●
Human health benchmarks			●
Ecological benchmarks			●

*** The chemical data is labeled under National to imply that the same data is applied to all sites.**

2.1.3 3MRA Site Modeling Outputs

As stated previously the objective of the 3MRA site-based modeling is to estimate the annual average risk (and/or hazard quotient) for human and ecological receptors residing within the area of interest surrounding a waste management unit at a site. To arrive at this endpoint the 3MRA site modeling generates the following outputs for each year of simulation :

1) Source Release Chemical Fluxes
   - air (volatilization, particle re-entreinment)
   - watershed (erosion, runoff)
   - sub-surface (leaching)
2) Inter-media Chemical Fluxes
   - air to surface soil
   - surface soil to vadose zone
   - vadose zone to aquifer
   - aquifer to surface water
   - surface soil to surface water
3) Media Chemical Concentrations at Exposure Locations
   - air
   - water
   - soil
   - biota (crop, plant, prey)
4) Receptor Exposures per Pathway

- Human (Inhalation Route)
  - ambient air
  - shower air
- Human (Ingestion Route)
  - soil
  - water
  - crop
  - beef
  - milk
  - fish
  - breast milk (infants)
- Ecological
  - Ingestion
    - media (soil)
    - plant
    - prey

5) Receptor Health Effects
- Carcinogenic (Human)
- Hazard Quotient (Human)
- Hazard Quotient (Ecological)

Each of the above outputs are reported on an annual basis for the duration of a simulation, which can be up to 10,000 years. Figure 2.2 illustrates how the primary 3MRA outputs , i.e., risks/hazard quotients (HQs), are computed based on exposure concentrations and exposure durations. Risks/HQs are computed for each exposure period (duration of exposure associated with either carcinogenic risk or hazard quotient). A time series of risks/HQs is generated for each receptor type/cohort combination, at each location where receptors reside (e.g., U.S. Census Block centroid), for each exposure pathway (involving each combination of exposure route and contact medium). Risks and HQs time series are also identified with the combination of chemical, waste management unit type, wastestream concentration level, site, and exposure area (i.e., defined by distance from source). These indices of risk/HQ are maintained in order to allow the decision analyst to accumulate national risk according to different regulatory scenarios. A regulatory scenario includes an endpoint (e.g., chemical concentration in a wastestream), a risk-based set of criteria (e.g., that 95% of nationwide receptors experience less than 10^{-6} risk of excess cancer), and assessment factors (i.e., the indices associated with the modeled risk outputs, e.g., WMUs, receptor of concern, distance from source).

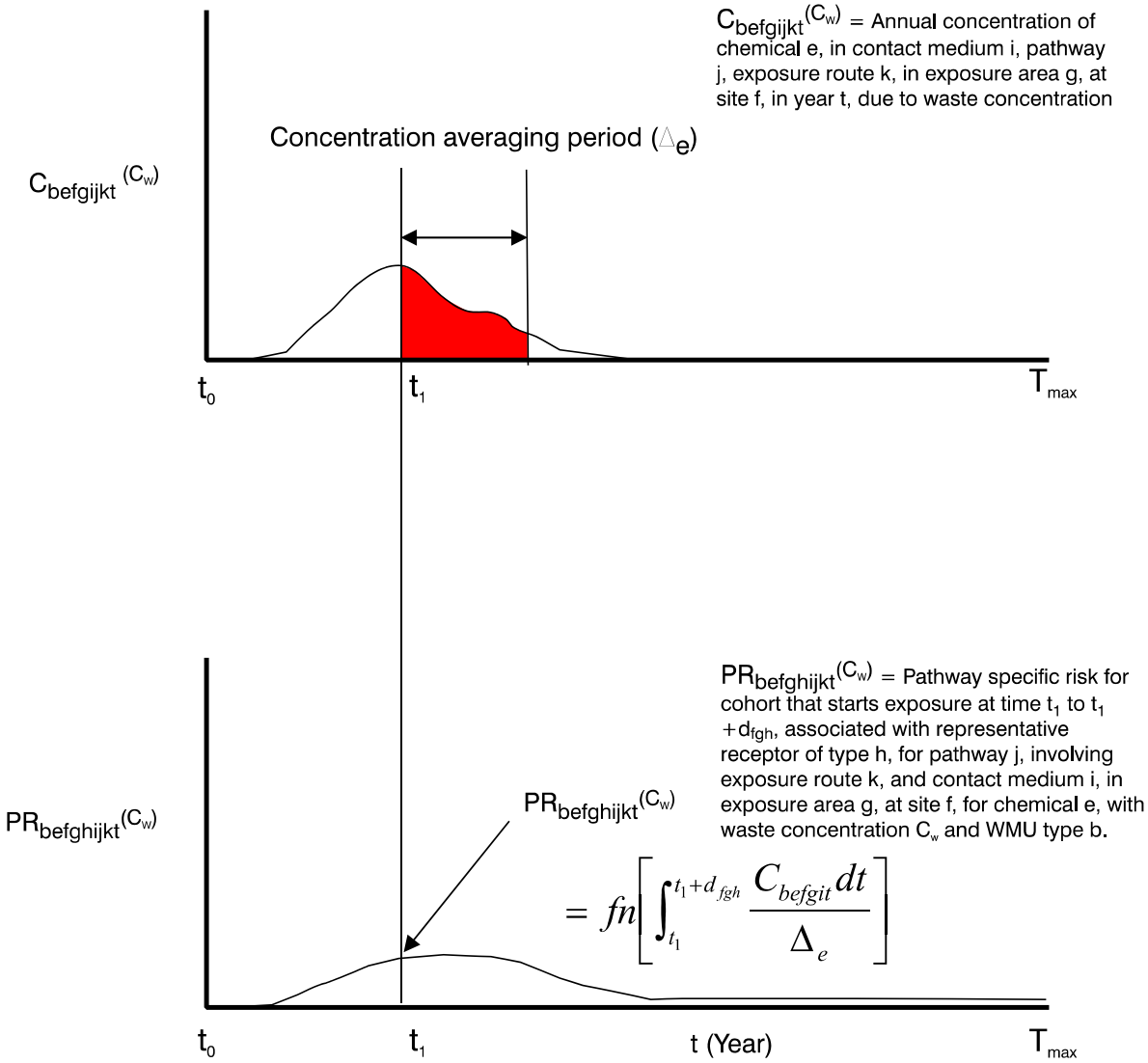

Figure 2.2 Relationship Between Exposure Concentration and Pathway Risk

Consolidation of Risk Time Series Output Data

Anticipating that the amount of computer memory required to store the full extent of the risk/HQ time series across all site simulations is prohibitively large it was necessary to condense the information contained in the time series and store only that data required for subsequent national regulatory decision analysis. To this end, 3MRA employs two specific steps in the risk module to reduce the risk/HQ time series data. First, risk/HQ time series representing individual exposure locations are collapsed into three cumulative frequency histograms, one for each of three areas defined by circular rings drawn at specific distances around the waste management unit (0.5 km, 1.0 km, 2.0 km). The histograms are constructed annually and include a series of risk/HQ intervals (referred to as risk bins) and the number of receptors of a given type that incur risks/HQs within the interval. Tables 2.3 and 2.4 list the human risk and hazard quotient intervals (bins) within which population counts are accumulated. Thus, for example, assume that 100 receptor locations are present within the AOI. Further, assume that 17 of the locations lie within 0.5 km of the source, 31 locations lie between 0.5 km and 1.0 km, and 52 locations lie between 1.0 km and 2.0 km. Following the consolidation protocol the 17 time series for receptor locations within 0.5 km are collapsed into a single time series with each year containing a histogram showing the number of receptors from across the 17 locations, that experience risks/hazards within the binned range. Similar consolidations are performed for the 1.0 km and 2.0 km distances. After this first step of consolidation only three sets of risk/HQ time series remain per risk index. This step may reduce the amount of data to be stored by one or more orders of magnitude, depending on the total number of receptor locations occurring within the exposure areas.

The second step of consolidation of risk/HQ time series information eliminates the time series. In this step, each time series of risk/HQ is scanned to determine the year in which the maximum risk/HQ occurs. This year is referred to as the critical year (Tcrit). Of the complete time series of cumulative histograms only those associated with Tcrit years are output and stored. Specifically, for each distance ring, receptor/cohort combination, and exposure pathway (for which the entire time series of histograms has been developed), the histogram associated with the Tcrit year for that pathway is output. In addition, however, the histograms associated with all other pathways at that same Tcrit year are also output. These other histograms will not necessarily be the histograms corresponding to their own Tcrit years. However, it is of interest to examine risk distributions for other pathways during the critical year for a given pathway, because this presents information about the contribution of these pathways to the total risk/HQ. Thus, for example, if there are M receptor/ring combinations for each of N pathways, then MxN sets of histograms are output. Storing histograms for only Tcrit may reduce data storage needs by more than three orders of magnitude, depending on the total number of years included in the simulation. Table 2.5 lists the full set of dimensions for which the human risk/HQ bins are produced.

Similar histograms (for HQs only) are produced and stored for ecological receptors, however, the breakdown of reporting dimensions is different than for human receptors. Rather than pathway specific HQs the ecological cumulative frequency histograms are stored for various combinations of habitat group, habitat type, receptor group, and trophic level.

Table 2.3 Summary of Human Risk Bins

Risk Bin Number	Risk Bin Range
1	$0.0 <= X < 5 \times 10^{-9}$
2	$5 \times 10^{-9} <= X < 7.5 \times 10^{-8}$
3	$7.5 \times 10^{-8} <= X < 7.5 \times 10^{-7}$
4	$7.5 \times 10^{-7} <= X < 2.5 \times 10^{-6}$
5	$2.5 \times 10^{-6} <= X < 7.5 \times 10^{-6}$
6	$7.5 \times 10^{-6} <= X < 5 \times 10^{-5}$
7	$5 \times 10^{-5} <= X$

Table 2.4 Summary of Human Hazard Quotient (HQ) Bins

Human HQ Bin	Human HQ Bin Range
1	$0.0 <= X < 0.05$
2	$0.05 <= X < 0.5$
3	$0.5 <= X < 5.0$
4	$5.0 <= X$

Table 2.5 Summary of Human Risk Module Output Dimensions Associated with Risk Bins

Parameters	Dimensions Human-Risk Module Outputs
Number of Distances[(a)]	3
Number of Exposure Pathways plus Summation of Pathways[(b)]	12
Number of Receptor Types plus Summation of Receptor Types[(c)]	16
Number of Cohorts plus Summation of Cohorts[(d)]	5
Number of Bins to Tally Individual Excess Cancers[(e)]	7
Number of Bins to Tally hazard Quotients (Non-Cancer)[(f)]	4
Number of Critical Year Percentiles[(g)]	1
Number of C_ws[(h)]	5
Number of Chemicals[(i)]	40
WMU Types[(j)]	5
Number of Sites/WMU-Type Combinations[(k)]	419

(a) The distance rings are: 0 to 0.5 km, 0 km to 1 km, and 0 to 2 km from the edge of the waste site area.
(b) Inhalation Air, Inhalation through Showering, Summation of all Inhalation Pathways, Ingestion of Groundwater, Ingestion of Soil, Ingestion of Meat, Ingestion of Milk, Ingestion of Fish, Ingestion of Breast Milk, Ingestion of Vegetables, Summation of all Ingestion Pathways, Summation of all Inhalation and Ingestion Pathways.
(c) The risk module analyzes 16 receptor types (8 each with and without drinking water): Beef Farmer, Dairy Farmer, Beef Farmer Fisher, Dairy Farmer Fisher, Gardener, Gardener Fisher, Resident, and Resident Fisher. Of these 16 receptor types, the risk module rolls-up the results and passes only 5 receptor types to the ELP-I: Beef/Dairy Farmer, Gardener, Fisher, Resident, and Summation of Receptor Types.
(d) The risk module analyzes five cohorts: Infants, 1-6 years old, 7-12 years old, 13-17 years old, and 18 years old and older (adult).
(e) Risk bins include ($0.0 - 5.0 \times 10^{-9}$, ($5.0 \times 10^{-9} - 7.5 \times 10^{-8}$), ($7.5 \times 10^{-8} - 7.5 \times 10^{-7}$), ($7.5 \times 10^{-7} - 2.5 \times 10^{-6}$), ($2.5 \times 10^{-6} - 7.5 \times 10^{-6}$), ($7.5 \times 10^{-6} - 5.0 \times 10^{-5}$), and $>5.0 \times 10^{-5}$.
(f) Hazard bins include (0.0 - 0.05), (0.05 - 0.5), (0.5 - 5.0), and >5.0.
(g) The critical year is defined as the year associated with a risk representing a percentage of the peak
(h) Five levels of C_w, before disposal are stored (mg/L for waste water [SI and AT], mg/kg dry weight for solids [WP and LF], and mg/kg wet weight [LAU]). These levels are chemical specific.
(i) Currently, 43 chemicals are included in the 3MRA chemical database
(j) WP, LAU, SI, AT, and LF.
(k) Each site may contain multiple WMU types, but each WMU type will be assessed one at a time. The maximum possible number of possible combinations is 419, as some sites may not contain a particular WMU type.

2.2 National Protection Measures

To establish national regulatory limits (e.g., concentration thresholds that define hazardous versus non-hazardous wastestreams), it is necessary to accumulate the site-based risk results into expressions of national risk. In the case of 3MRA, site-based risk/HQ that quantify the number of receptors incurring risks/HQ at various levels are transformed into percentages of receptor populations that are protective at the various levels of risk. This normalization of the population counts allows site risks to be accumulated in order to determine the percentage of nationwide receptors that are protected. It is possible to establish a regulatory limit based on the percentage of protected receptors. For example, a limit could be established based on criteria that specifies that 95% of all receptors across all sites, across all pathways, across all waste management unit types, within 2 km of the WMU, incur an excess cancer risk of 10^{-6} or less. Because the risk/HQ data at the site level is stored by indices including receptor type, exposure pathway, exposure ring distance, and waste management unit, it is possible to construct "views" of the national scale protectiveness that reflect varying combinations of the indices. For example, protection measures can be applied, without loss of generality, to individual receptor types, combinations of receptor types, individual waste management units, etc., as required by the regulatory analyst.

A second measure of protection is the nationwide distribution of sites that are protected. A site is protective if the percentage of site-based receptors incur a risk/HQ less than a specified target value.

These measures of protection are combined in 3MRA to allow a decision analyst to specify both the percentage of receptors nationwide as well as the percentage of sites that are to be protected (e.g., 95% of the sites are protective of 99% of the site-based receptors).

2.3 3MRA Monte Carlo Scheme to Quantify Uncertainty

The final element of the 3MRA national assessment methodology is associated with the need to characterize the uncertainty related to the national estimates of protectiveness. There are two general categories of uncertainty that are important to the 3MRA methodology, uncertainties that characterize a lack of knowledge or error and those that reflect the natural variability of the cause and effect relationships being modeled. In terms of error-based uncertainty there is error associated with the selection of sites sampled to represent the national population of waste management facilities/locations. There is error in the data collected to represent environmental conditions at each of the sites. There is error associated with the simulation models used to simulate the movement of chemicals from waste management units, through environmental media, to locations where contact with human and ecological receptors occur. Finally, there is simulation error, that is, the error associated with the finite number of Monte Carlo simulations conducted. Natural variability associated with the risk/HQ results from the fact that the myriad of factors that influence exposure and risk process are different both within and across sites.

The motivation for separating the various sources of uncertainty is to identify those that can be reduced as opposed to those that can not. Uncertainties due to error are reducible (e.g., sampling error may be reduced by increasing the number of samples) while those that reflect natural variability are non-reducible. To facilitate the characterization and separation of these

two types of uncertainty the 3MRA methodology includes a two-stage Monte Carlo simulation procedure. The Monte-Carlo procedure is designed to meet the following objectives:

- Provide an estimate of the uncertainty in the estimated measures of protection associated with modeling outputs (i.e., limiting waste concentration (C_w);
- Provide a mechanism for accounting separately for variability and uncertainty;
- Provide a (value of information) basis for comparing the potential benefit (reduced prediction uncertainty) versus cost of future efforts to reduce the level of error in the assessment (e.g., collect more data, develop better models, etc.);
- Provide a flexible framework that can accommodate alternate policy formulations including different definitions of protection criteria.

The first stage of the 3MRA Monte Carlo procedure is designed to account for variability while the second stage addresses error-based uncertainty. Figure 2.2 illustrates the matrix oriented organization of information that results from a two-stage Monte Carlo simulation applied to 3MRA. Within each cell of the matrix resides the risk/HQ results from a single site simulation. A single iteration of the first stage of the Monte Carlo simulation results in one column of information in the matrix, which represents the variability of risks/HQs occurring across individual sites. If no error existed in the data, sampling, or modeling a single execution of the first stage would yield a certain expression of the natural variability in risk. Because error does exist, the second stage of the procedure allows the error to be characterized and processed explicitly. For example, a modeling variable that is naturally varying, such as hydraulic conductivity, may be characterized by collecting a number of random samples and constructing a statistical distribution to represent the variability. However, there is uncertainty in the parameters of the statistical distribution due to both measurement error and sampling error. IF these errors can be
characterized, then they can be processed as part of the second stage of the Monte Carlo procedure. Executing this second stage is represented across the columns of the matrix shown in Figure 2.2.

Each iteration of the first stage results in an estimate of variability "with" uncertainty. When information in this matrix is queried the regulatory analyst can generate quantitative statements of uncertainty associated with the national measures of protectiveness. Figure 2.3(a) presents an example corresponding to a query for a target risk level of 10^{-6} from the N_i (columns) iterations of risk matrices corresponding to a waste concentration of 10^{-3} mg/kg. The figure indicates that there is a 5% chance that the level of protection (% of receptors that would be protected at the target risk level for the given waste concentration) would be less than or equal to 85%. Similarly, there is a 25% chance that less than or equal to 93% of the receptors would be protected at the target risk level for the given waste concentration.

The result of repeating the query for different target risk levels for the same waste concentration 10^{-3} mg/kg is illustrated by Figure 2.3(b), which presents the uncertainty in the percent of protected receptors for each risk level. From Figure 2.3(b), it can be inferred that there is a 95% chance that setting the waste concentration regulatory limit to 0.001 mg/kg, would result in at least 85% of the receptors protected to a 10^{-6} risk level (*or 5% chance that, at the risk level of 10^{-6}, less than 85% of the receptors will be protected*), and at least 90% of the receptors protected to a 10^{-5} risk level. Similarly, there would be a 95% chance that at least 95% of the

receptors would be protected to the 10^{-4} risk level, and at least 50% of the receptors would be protected to the 10^{-4} risk level.

Querying the output data base for different waste concentrations can produce the set of graphs such as those shown in Figures 2.3(a), (b), and (c). The figure shows how the percent protection varies as a function of the target risk, the waste concentration and the confidence limit; and can be used to select the waste concentration that meets a specified protection measure. These types of figures could also be produced for subsets of receptors to investigate the effects of selecting a waste concentration on secondary protection measures.

Note: The full two-stage Monte Carlo scheme is not yet implemented within 3MRA. This is primarily due to the fact that data characterizing the uncertainty associated with the various sources of error is not available. It is, however, the case that a limited two-stage Monte Carlo capability has been implemented. The same matrix of risk information shown in Figure 2.2 is produced except that the uncertainty iterations (i.e., columns) reflect simulation error for the first stage of the Monte Carlo only.

Figure 2.3 Nf x Ni Pathway Risk Matrix Output.

For fixed: Chemical Type (e) Waste concentration (C_w) WMU Type (b)			UNCERTAINTY ITERATION				
VARIABILITY			1	2	3		N_i
	FACILITY	1	$PR_{b,e,1}(C_w, 1)$	$PR_{b,e,1}(C_w, 2)$			$PR_{b,e,1}(C_w, N_i)$
		2	$PR_{b,e,2}(C_w, 1)$	$PR_{b,e,2}(C_w, 2)$			$PR_{b,e,1}(C_w, N_i)$
		3					
						$PR_{b,e,f}(C_w, IT)$	
		N_f	$PR_{b,e,Nf}(C_w, 1)$	$PR_{b,e,Nf}(C_w, 2)$			$PR_{b,e,Nf}(C_w, N_i)$

Note: Each element of the above matrix can be any risk matrix, e.g., $PR_{b,e,f}(C_w, IT)$, or $MR_{b,e,f}(C_w, IT)$, where $PR_{b,e,f}(C_w, IT)$ is the pathway risk matrix for WMU type b, chemical e, and site for waste concentration C_w and iteration IT, and $MR_{b,e,f}(C_w, IT)$ is the contact medium risk matrix for WMU type b, chemical e, and site for waste concentration C_w and iteration IT.

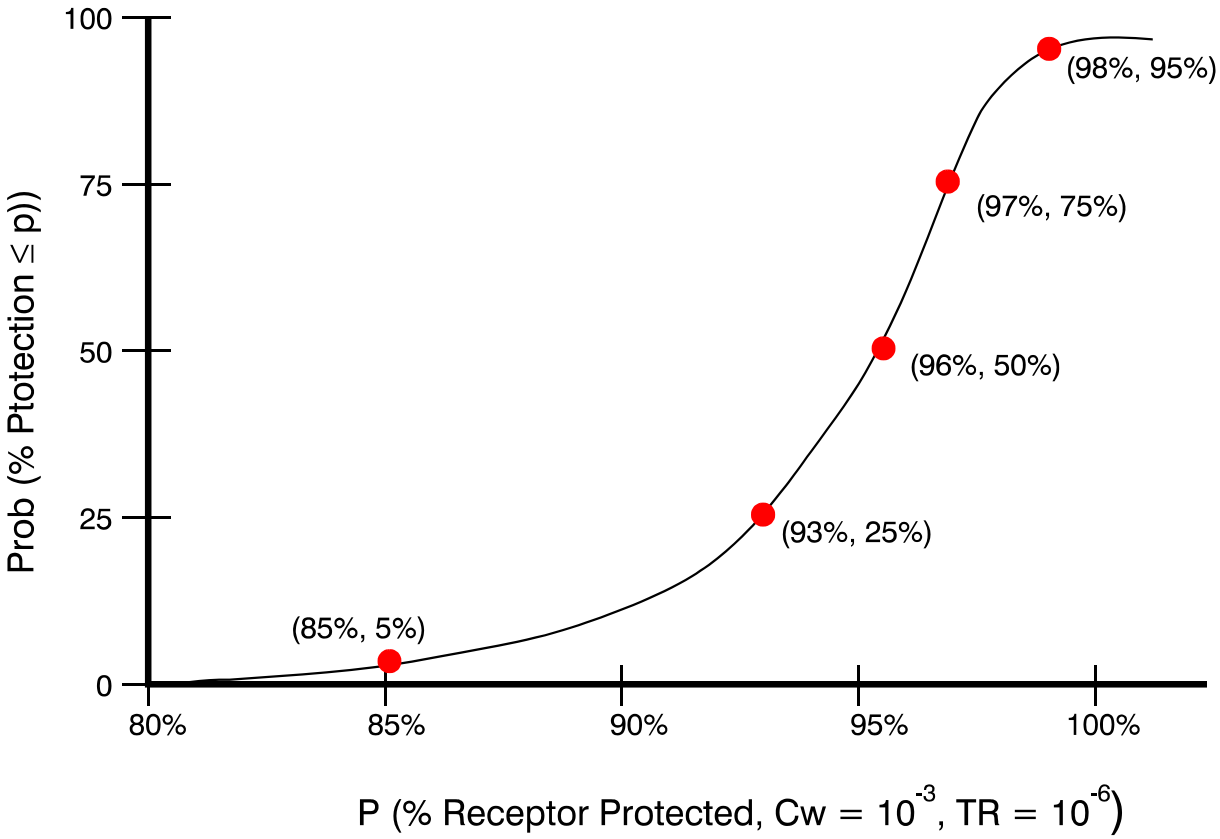

Figure 2.3.a Probability that percent protection is less than P for a given waste concentration and target risk level.

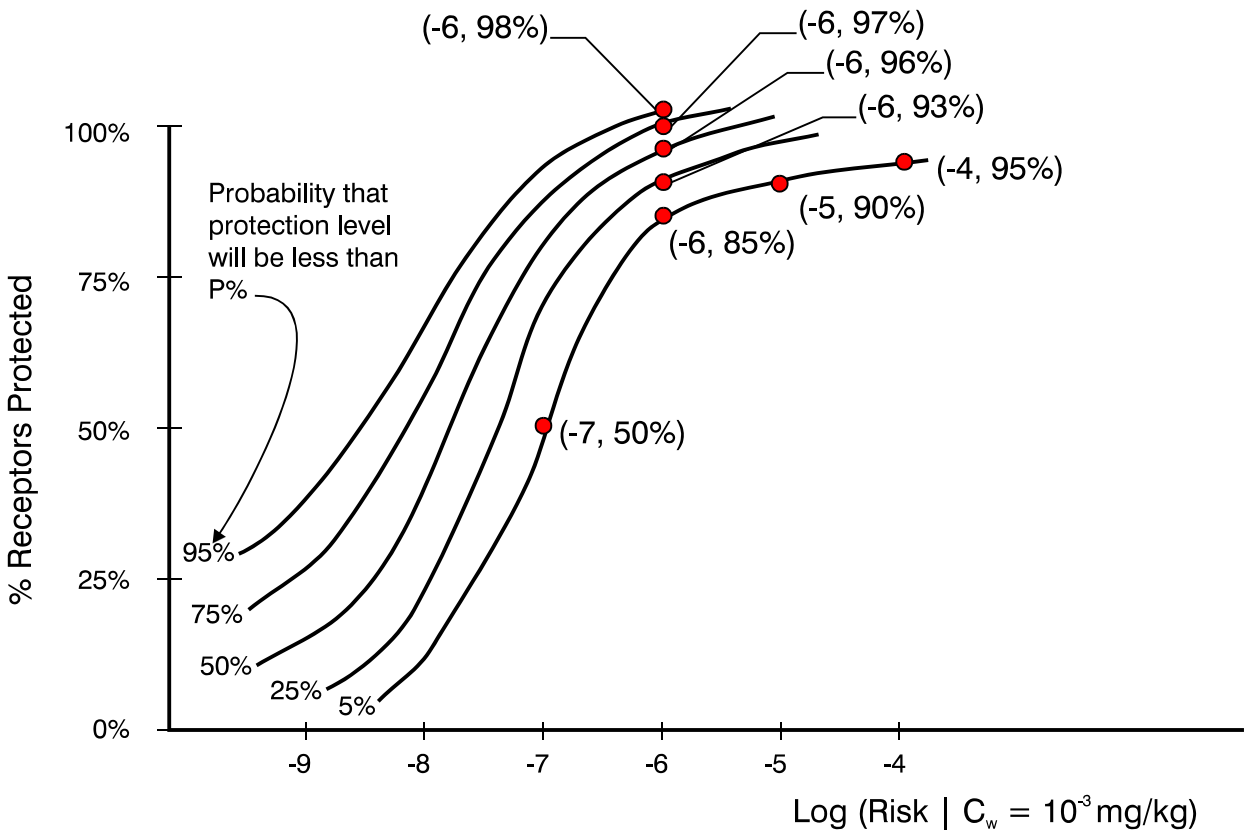

Figure 2.3.b Percent of receptors protected for different risk levels and $C_w=10^{-3}$ for N_i Monte-Carlo iterations.

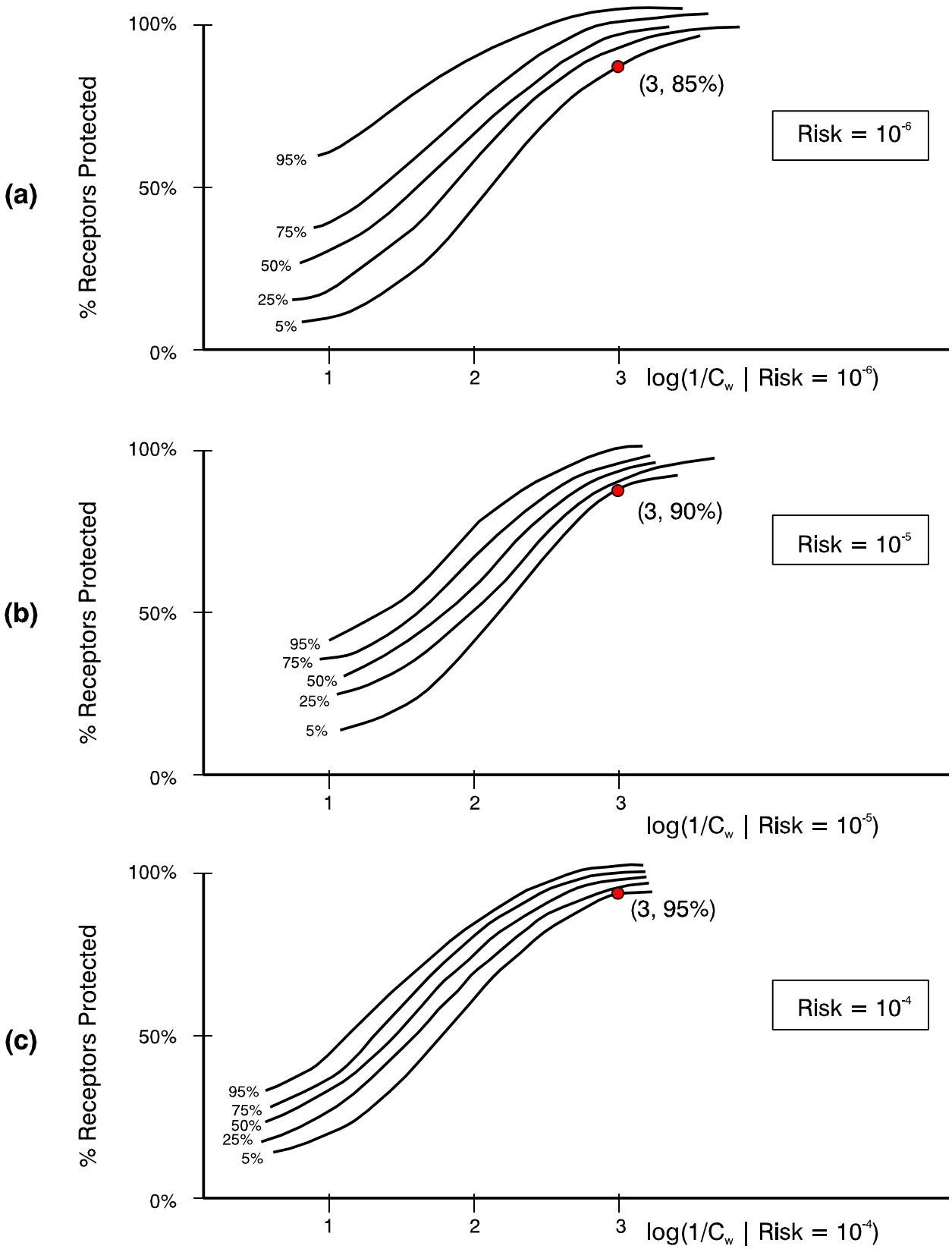

Figure 2.4 Percent of receptors protected for different waste concentrations and risk levels.