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National Exposure Research Laboratory
Ecosystems Research Division

A Risk Assessment of Landfill Disposal of WTP-Generated ABRs Using the Integrated Multimedia Modeling System 3MRA 1.x

Justin Babendreier

Office of Research and Development, NERL/ERD

Symposium on Disposal of Arsenic-Bearing Water Treatment Residuals:
Assessing the Potential for Environmental Contamination
Tucson, Arizona; February 13-14, 2006

Presentation Outline

- **FRAMES & 3MRA**
  - **Definitions & Versions 3MRA 1.0, 1.x, 2.0**
  - **Overview of 3MRA Version 1.x**
- **A Risk Assessment Approach of Landfill Disposal of WTP-Generated Arsenic Bearing Residuals**
  - **ABR specific data considerations used in the study**
  - **Descriptions of scenarios and 4 model experiments**
- **Results**
- **Conclusions**
  - **Based on 3MRA modeling and associated assumptions, at a national scale, deposition of ABRs in unlined landfills appear to present low risk to ecological and human receptors, considering hazard quotients >0.5/>1 (humans/eco) and human cancer risk levels > $5x10^{-5}$.**

Multimedia Modeling R&D at USEPA: Evolution of FRAMES-3MRA

3MRA Version 1.0: Site-based risk assessment technology with regional and national scale roll-up capabilities

3MRA Version 1.x: A tool set extension that facilitates/enhances:
- Pre/Post-processing capabilities
- Parallel processing of 3MRA model runs
- Uncertainty and sensitivity analysis studies

3MRA Version 2.0: ***(in beta testing)*** Advances the underlying design of FRAMES:
- Geared to site-specific risk assessments
- Retains existing 3MRA science and data
- Easier to add/update science models, data
- Drag-and-drop conceptual site model design

FRAMES 2.0 (i.e., the infrastructure): joint, multi-agency development

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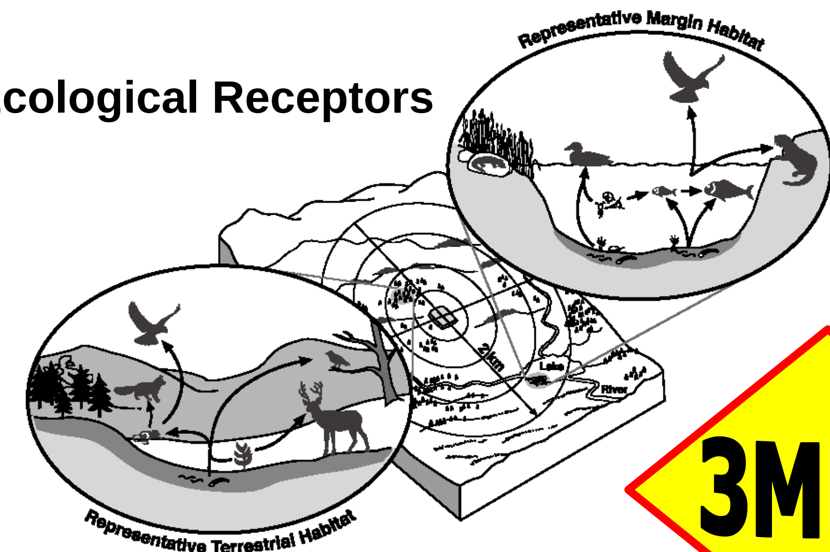
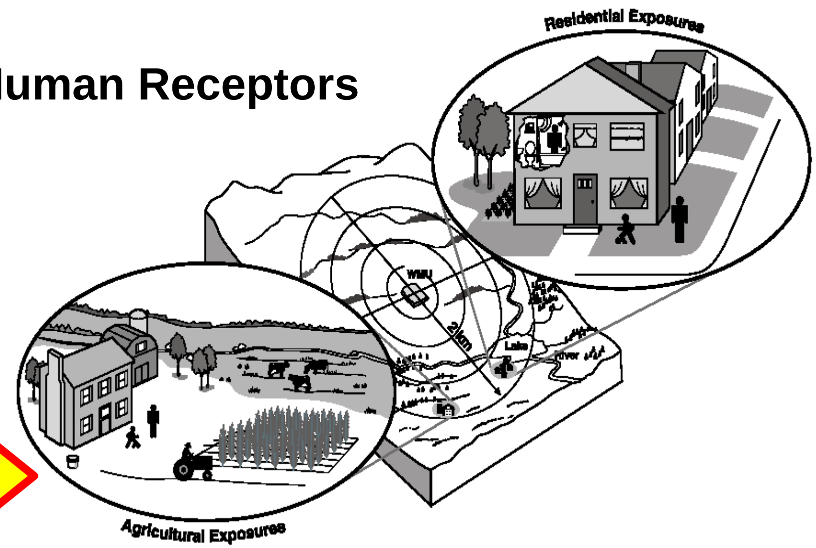
FRAMES 3MRA Version 1.0/1.x

Multimedia, Multipathway, Multireceptor Risk Assessment

Ecological Receptors

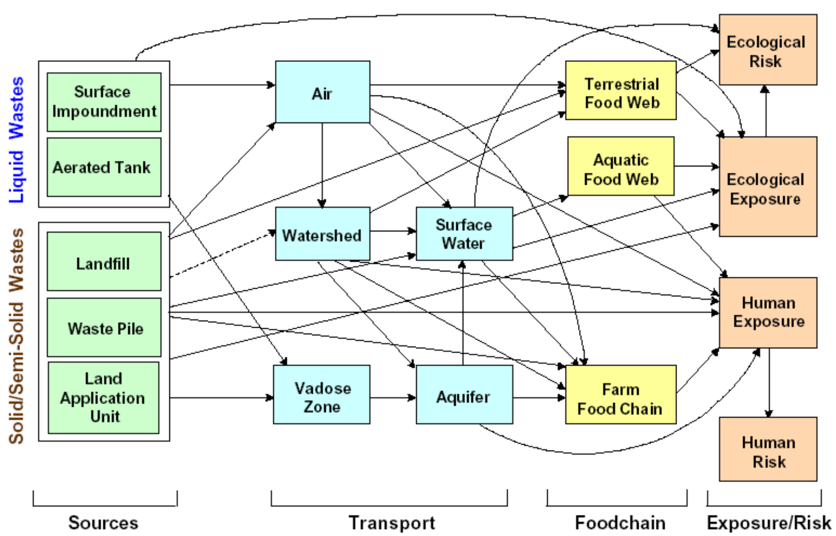


Human Receptors

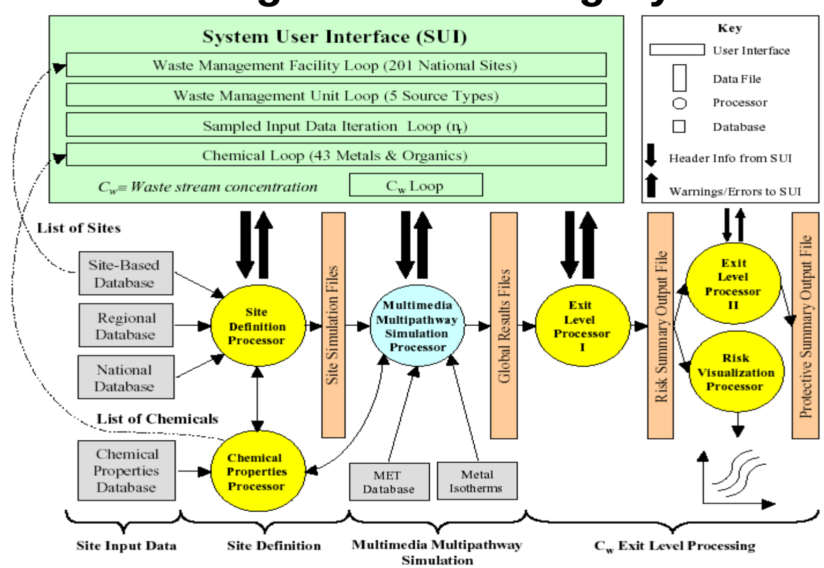


3MRA

Science Models and Connectivity



Integrated Modeling System

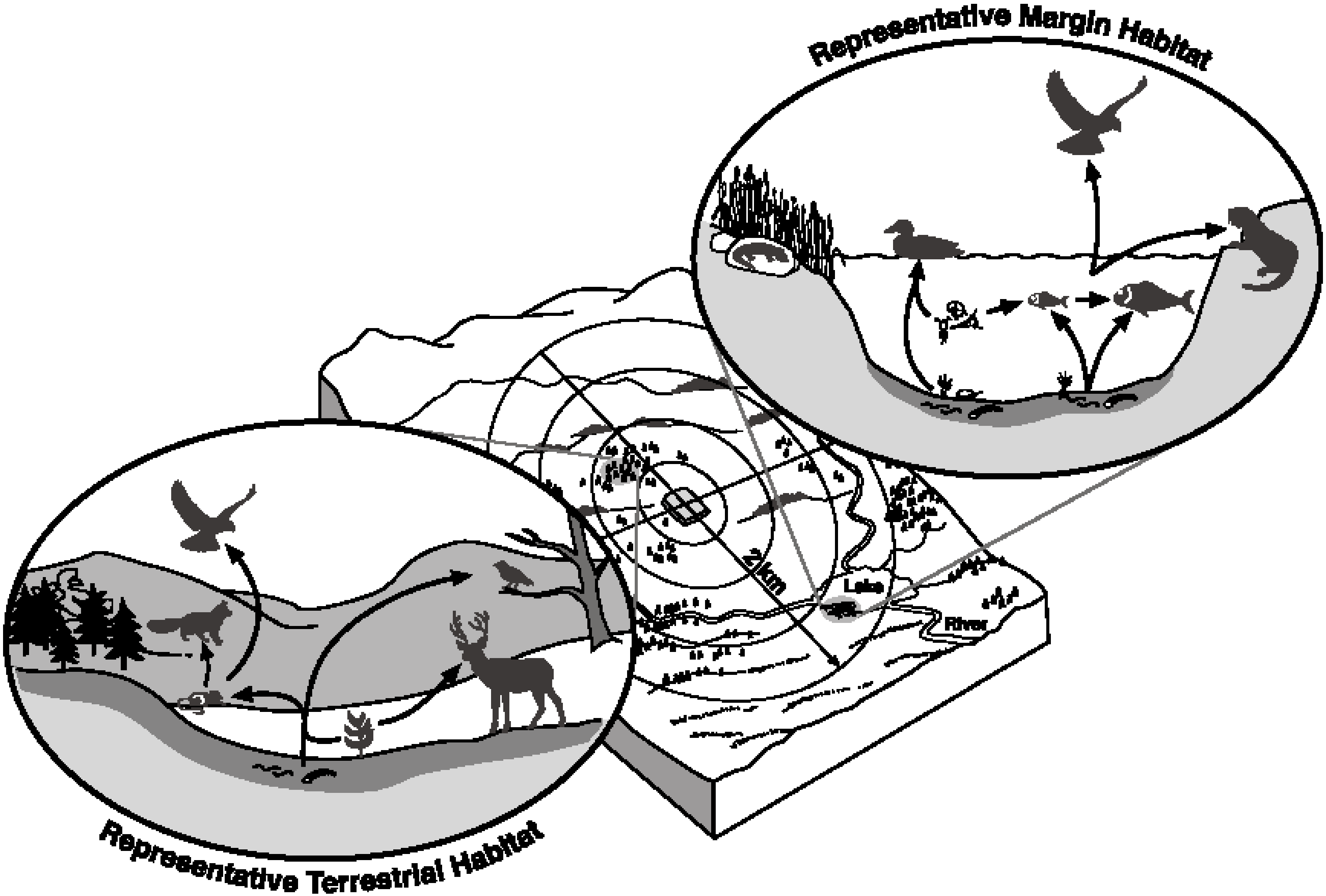


What is FRAMES-3MRA ?

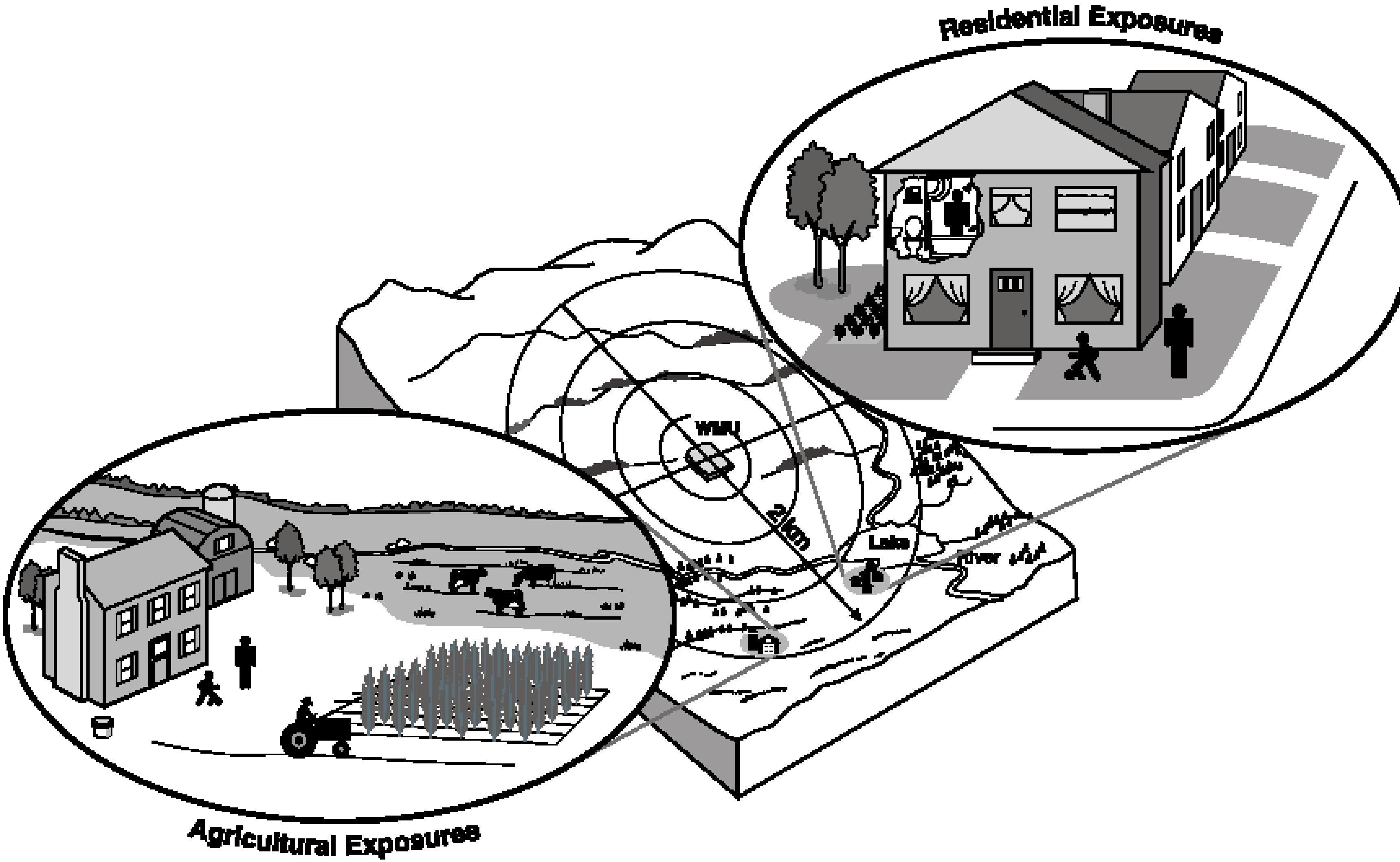
A State-of-the-Art Human/Ecological Exposure and Risk Assessment Technology Encompassing:

- **Multimedia** ***(Air, Water, Soil, Sediments, Biota)***
- **Multipathway** ***(Food Ingestion, Water Ingestion, Soil Ingestion, Air Inhalation, etc)***
- **Multireceptor** ***(Resident, Farmer, Gardener, Fisher, Ecological Populations, etc)***
- **Risk** ***(Human Cancer Risk & Non-cancer Effects, Ecological Population and Community Effects)***
- **Assessment** ***(Strategy to inform environmental decisions; integrally deals with uncertainty & variability)***

Conceptual Framework For Ecological Receptors



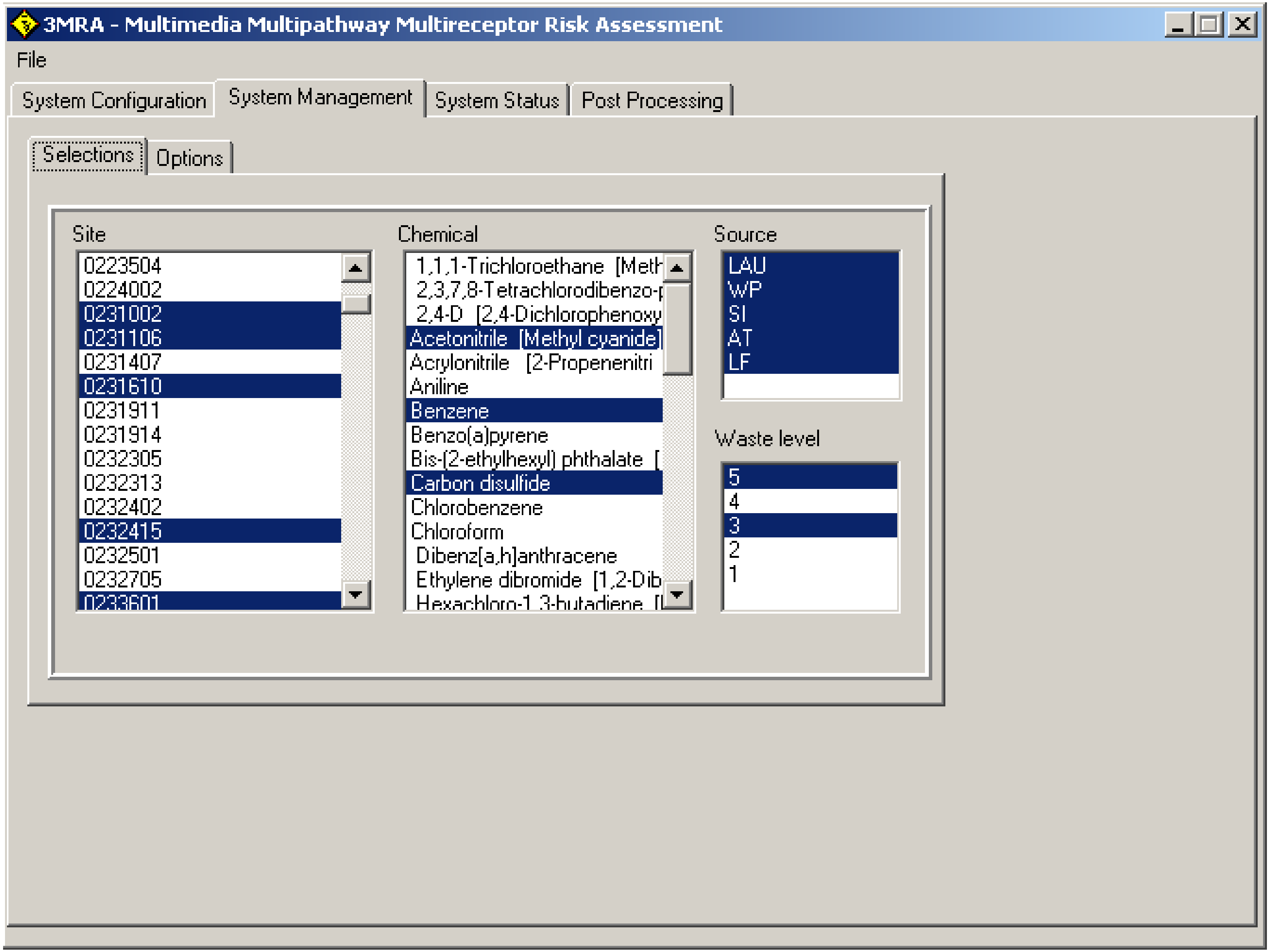
Conceptual Framework For Human Receptors



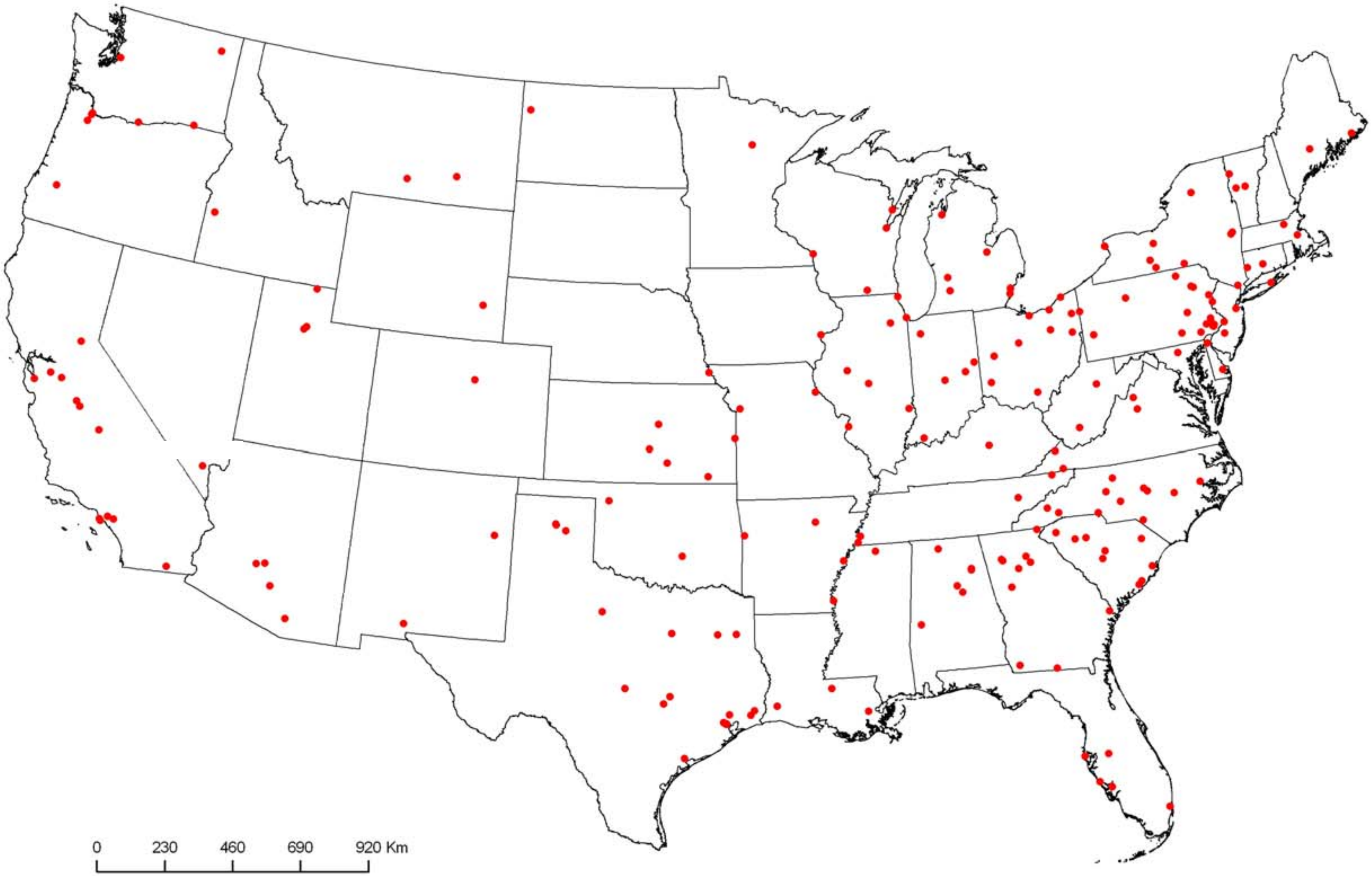
Elements of the 3MRA National Exposure and Risk Assessment Methodology

- Site-based, integrated human and ecological assessment
- Data driven (e.g., statistical sample of industrial sites)
- Multiple sources, contaminants; media, pathways, receptors
- Tiered data (hierarchical site-based, regional, national datasets)
- Probabilistic approach; addresses uncertainty & variability
- Population-based risk estimates by site, source, chemical
- Facilitates regional-scale and national-scale roll-up of risks
- Multiple measures of protection to inform decision-making:
  - Probability of protection (% of population, % of sites)
  - Protection as a function of distance from facility, risk level, etc.
  - Protection per receptor type, cohort, other subpopulation bases
  - Protection per combination of receptor and media/pathway

FRAMES 3MRA 1.0 User Interface

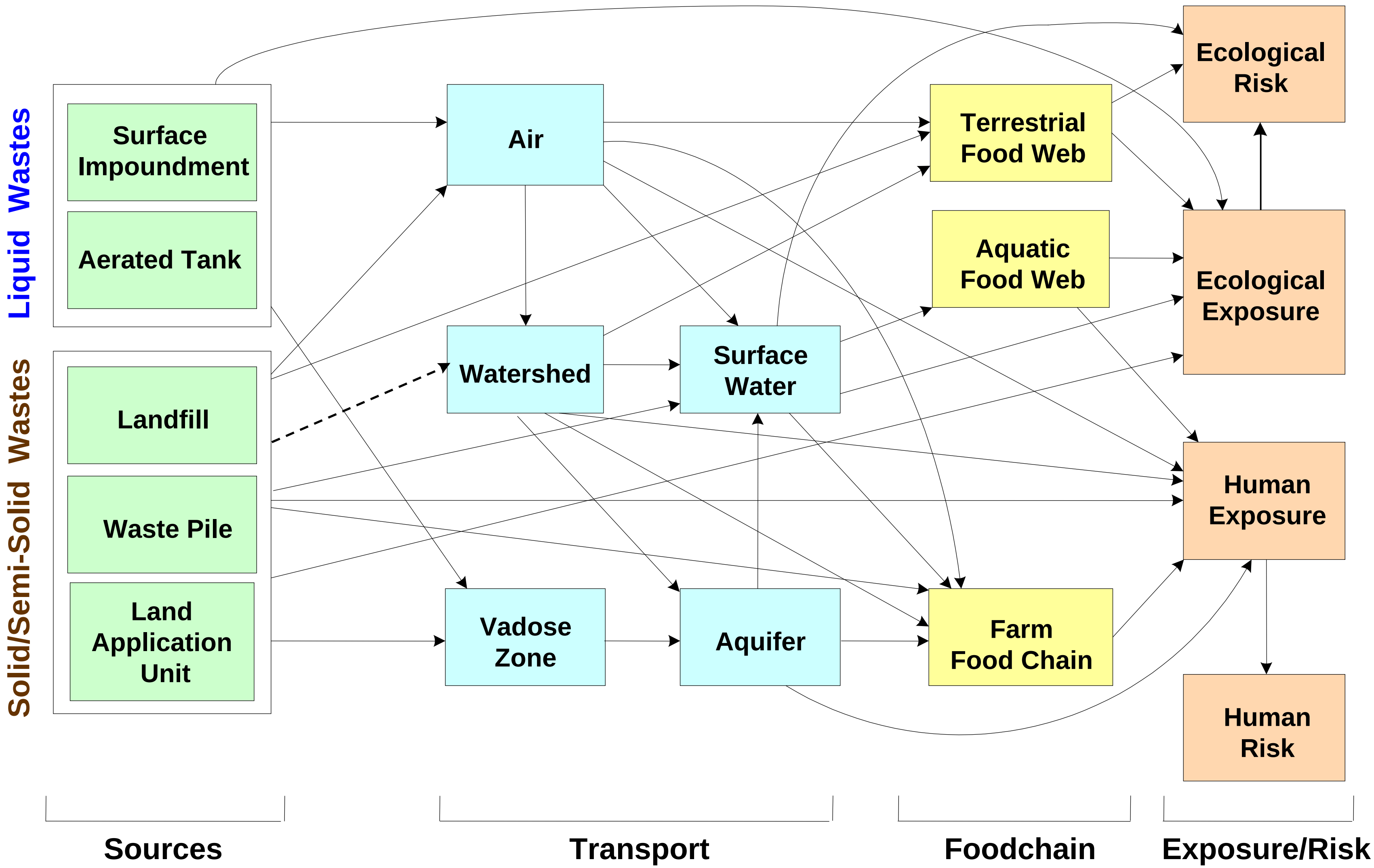


3MRA 1.x Site-Based Database: Sampled-Sites

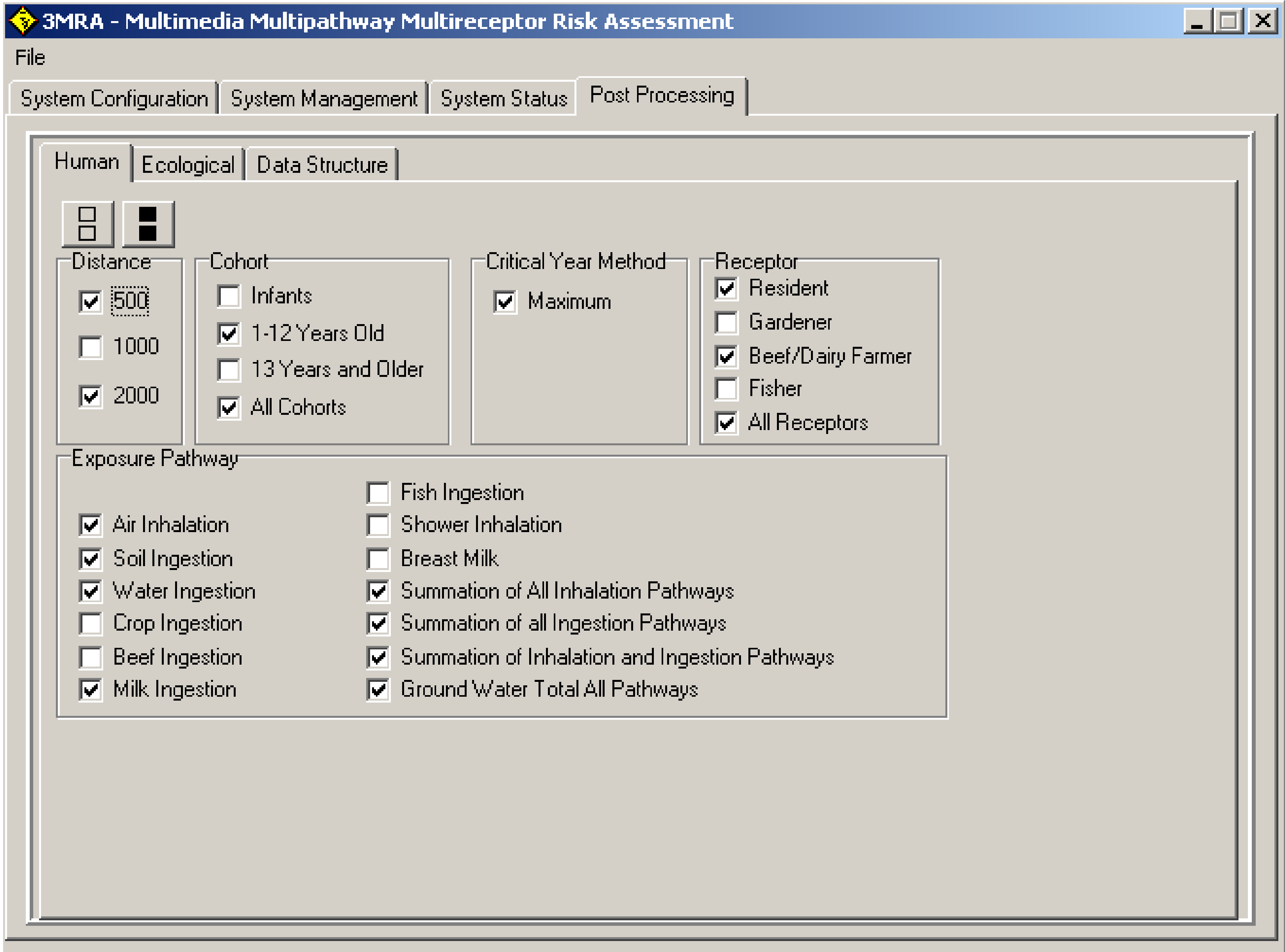


3MRA 201 site database; 419 site-source combinations; 56 landfills

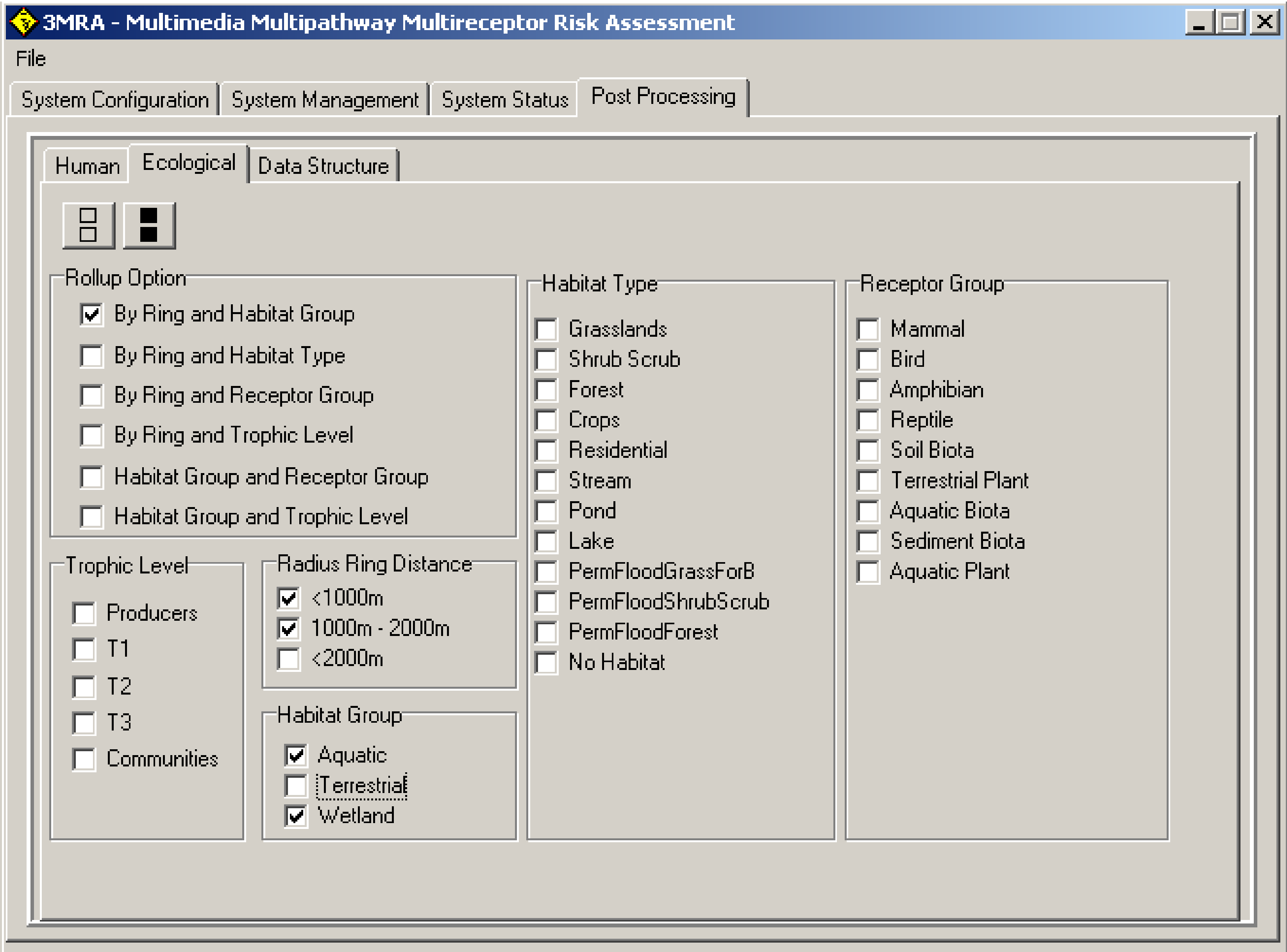
3MRA Version 1.0
Science Modules and Connectivity



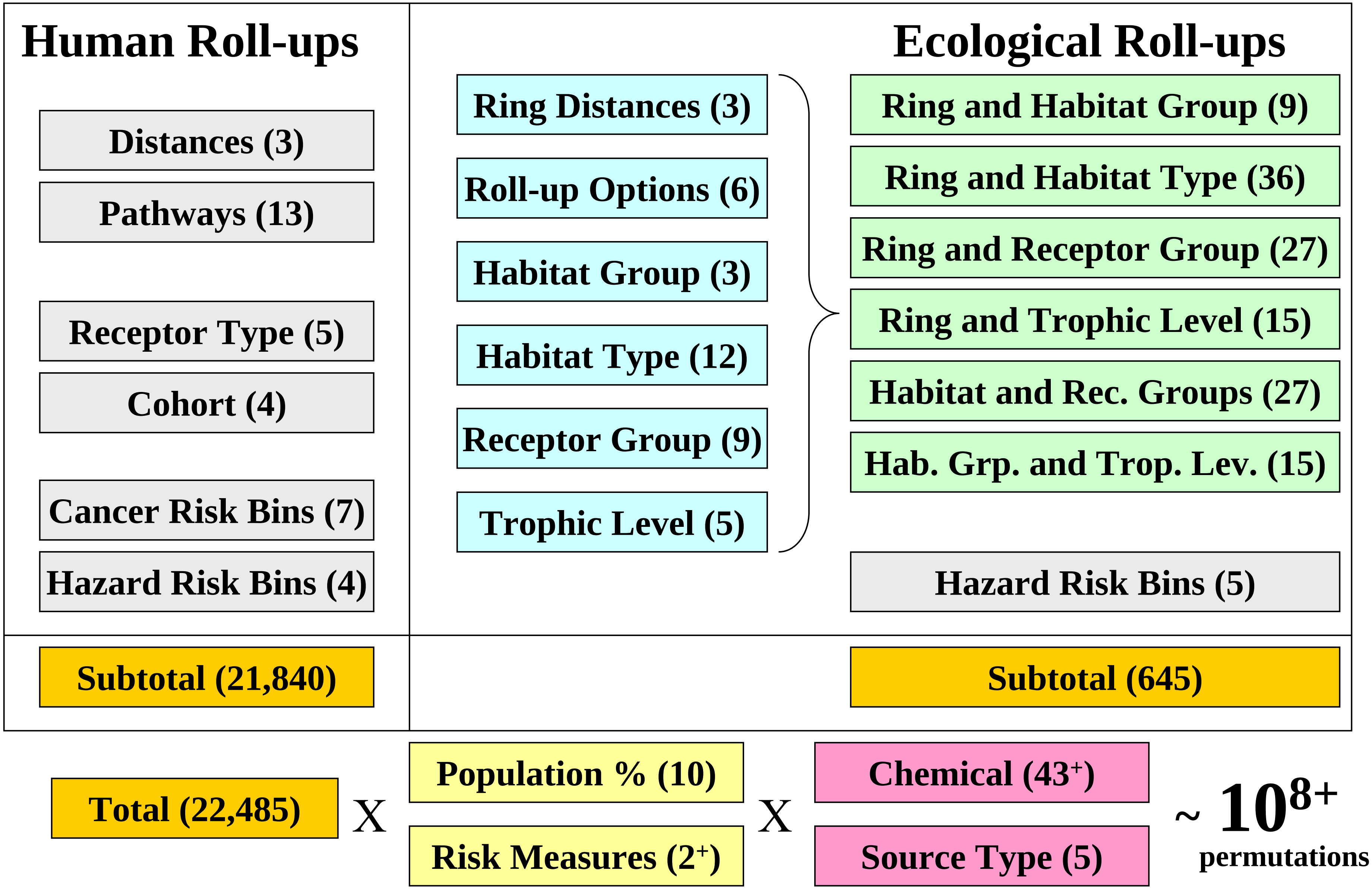
FRAMES 3MRA 1.x Post-Processing (HH)



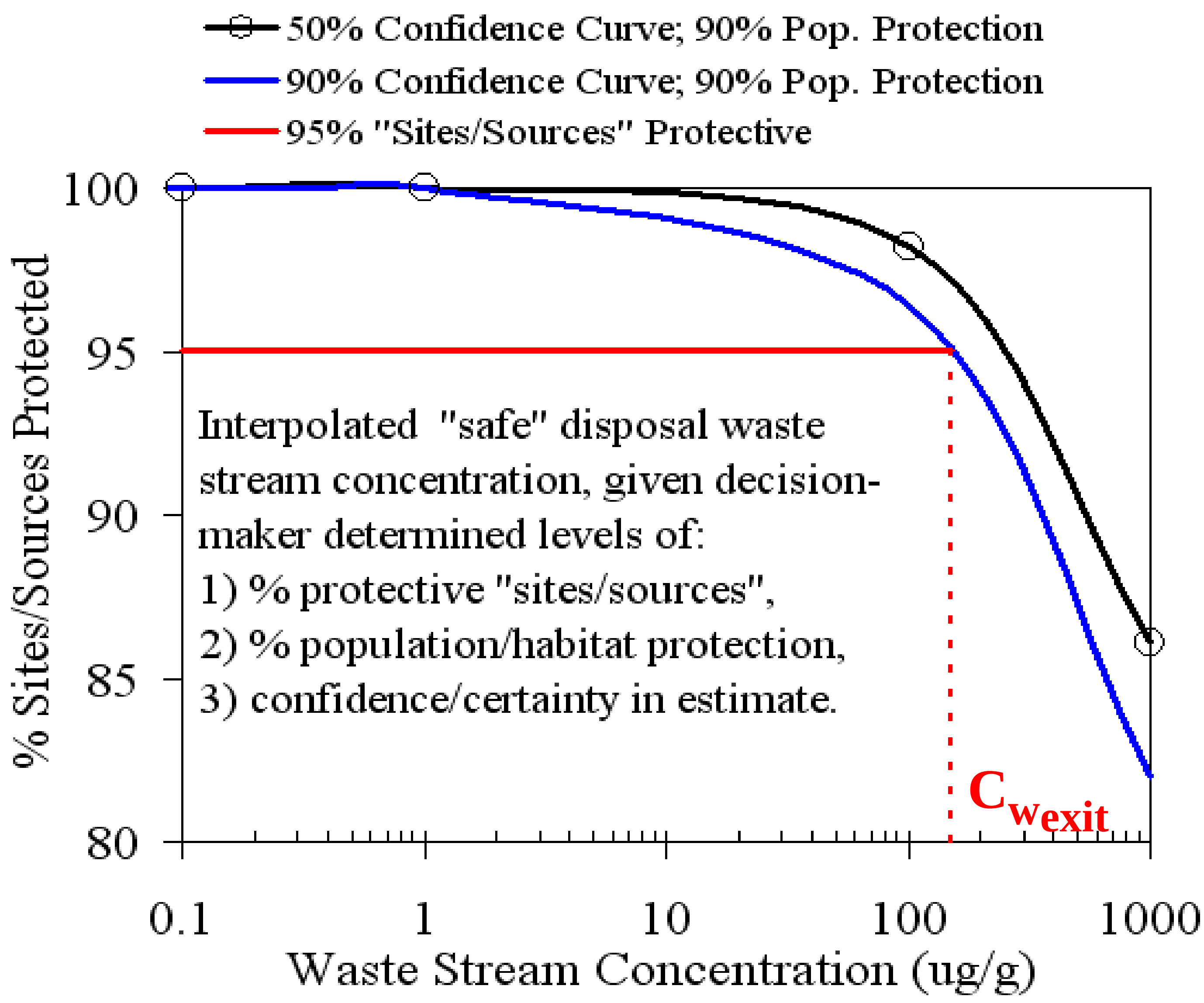
FRAMES 3MRA 1.x Post-Processing (Eco)



Population-Based Risk Profiles Possible in FRAMES 3MRA 1.0/1.x



Example 3MRA Output: Risk Curve Calculation



Similar graphic available for each exposure profile noted in previous slide…..

About "Exit" Levels

- A fundamental capability of 3MRA is **the ability to quantify "safe" waste/wastestream concentration levels** for treatment, storage, disposal, and/or reuse management practices.

- **This "safe" level can take on many forms (e.g.,** exit level, entry level, cleanup level, reuse level)

- 3MRA can also address other problem statement perspectives (e.g., evaluating risk/reduction based on new waste/material management practices).

FRAMES-3MRA: Uniquely Qualified to Support Environmental Decision-Making

- **State of the art** in how it integrates exposure and risk assessment across media/pathways/receptors
- Assesses both human and eco side of equation
- **Successfully undergone rigorous peer-reviews; specifically recommended for use by U.S. EPA's SAB for national-scale assessments.**

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A Risk Assessment of Landfill Disposal of WTP-Generated Arsenic Bearing Residuals (ABRs)

National-Scale ABR Problem Statement

At what waste stream concentration (C_{wsafe}) will ABRs, when placed in non-hazardous landfills (e.g., industrial, municipal) over the unit's life, result in:

1. **(Human)** Greater than **A%** of the people living within **B** distance of the facility with a risk/hazard of **C** or less, and
2. **(Ecological)** Greater than **D%** of the habitats within **E** distance of the facility with an ecological hazard less than **F**,
3. **(National)** At **G%** of facilities nationwide,
4. **(Uncertainty)** With confidence **H%** accounting for subjective input uncertainty (i.e., accuracy), and confidence **I%** accounting for output sampling error (i.e., precision).

Example 3MRA Decision Variables in Red

C_{wsafe} **≡ safe level**

3MRA ABR Assessment Approach

Conducted national-scale assessment using 3MRA 1.x, and associated national, regional, site-based data sets.

Constructed problem-specific input distributions based on Ghosh (2005), Ela *et al.* (2005), Jing et al. (2005), and Bayer Inc. (as provided by W. Ela) for the following:

✓ **Dry bulk density of waste (BDw: g/cm^3)**

- **Triangular distribution T(0.4, 0.7, 1)**

  3MRA default distribution = T(1, 1.83, 2.65)

✓ **Volumetric water content of waste on trucks (mcW: %vol.)**

- **Triangular distribution T(35%, 55%, 75%)**

  3MRA default distribution = T(1%, 40%, 75%)

✓ ***In-situ* ABR waste partition coefficient (Kd: L/kg)**

- **Triangular distribution T(35, 1000, 3500)**

  3MRA default distribution = T(1.6, 1268, 16000)

Also modified landfill input parameter "mass fraction in fill" →

Effective Mass Fraction of the Fill

Estimating mass fraction Fwmu is the key issue:

- Reportedly, estimated 3000 WTPs will dispose of their ABRs in 600-700 landfills nationwide, spatially clustered.
- Anticipated range of WTPs per landfill = 2 to 8, median 5.
- Total nationwide loading rate: 4000 TPY, avg. 3750 ppm.
- This analysis assumed typical receiving facilities would have waste flows ranging from 50 to 400 TPD.
- From these data, and imparting a correlation structure between landfill daily intake rates and #WTPs, an effective mass fraction of ABRs *in situ* was developed:
  - Uniform distribution U(0.00002, 0.0002)
  - 3MRA default distribution = U(0,1)

Note: Fwmu derivation is independent of actual concentration.

ABR Risk Assessment Experiments Conducted

For illustrative purposes, reference, and to assess ABRs:

369 samples
- **Exp#1 (3MRA: Fwmu=U(0,1)): Original EPA SAB review documentation, defining default 3MRA input and output and an example national assessment of Arsenic in landfills.**

300 samples
- **Exp#2 (3MRA-FwmuCon): Represents Exp#1, except Fwmu was set to a constant value = 1, defining expected risk of maximum loading <u>to all facilities</u> across the country.**

300 samples
- **Exp#3 (ABR-CP/FwmuCon): Represents Exp#2, except ABR chemical properties for Kd, BDw, and mcW were used. Similarly, defines expected risk of maximum loading of ABRs <u>to all facilities</u> across the country (e.g. 100% vol.).**

300 samples
- **Exp#4 (ABR-CP/Fwmu): Represents Exp#3, except mass fraction distribution for ABRs was used. This experiment represents predicted outcomes for planned WTP loading.**

Experimental Simulation Design
(i.e., for each of 4 experiments conducted)

Deterministic Model Runs

Source Types - WMU (1)

Site Samples (56)

Waste Levels (5)

Chemicals (1)

MC Iterations (300-500$^+$)

UA/SA

Total Simulations

84,000 to 140,0000$^+$

Avg. Runtime for Arsenic/Landfill = 320 sec.

One national realization for 1 chemical, 1 source = 280 runs
(i.e., for exit levels: 5 C_w * 56 site-WMUs = one output sample)

Actual # of runs simulated determines precision (I%) of results

SuperMUSE Parallel Computing Cluster at ORD/NERL/ERD, Athens, Georgia

SuperMUSE – Supercomputer for Model Uncertainty and Sensitivity Evaluation

Basic Description of Scenarios Evaluated

Exit Level Description	Scenario	
Scenario ID	**1**	**2**
Protection Levels		
% Population Protected	99%	99%
% Sites Protected	95%	95%
Protective?	More	Less
Human		
Distance (m)	<500	<2000
Cancer Risk — ***various discrete bins***	~ 10^{-7} to 10^{-4}	~ 10^{-7} to 10^{-4}
Hazard Risk — ***various discrete bins***	~ 0.05 to 5	~ 0.05 to 5
Exposure Pathway[1]	Sum Ing. & Sum Inh.[1]	
Receptor Group	All Receptors	
Cohort Group	All Cohorts	
[1]For Arsenic, cancer risks are non-additive, hazard only for ingestion.		
Ecological		
Ring Distance (m)	<1000	<2000
Hazard Risk — ***various discrete bins***	~ 0.1 to 10	~ 0.1 to 10
Roll-up by Habitat Group[2]	Terrestrial, Aquatic, Wetland	

Scenario Identification for Joint Human and Ecological Risk Assessment		
[2] To evaluate ecological roll-ups jointly with human concerns, scenarios are further broken down by habitat group.		
Scenario 1		
Scenario 1a	Human	Terrestrial
Scenario 1b	Human	Aquatic
Scenario 1c	Human	Wetland
Scenario 2		
Scenario 2a	Human	Terrestrial
Scenario 2b	Human	Aquatic
Scenario 2c	Human	Wetland

Note: For all experiments ,associated simulations and scenarios: the existing 3MRA landfill module simulates « unlined » conditions.

Interpreting Scenario Description Tags Used Here

Scenario Primary Tag Identifiers			
Ring Distance	**Habitat Group**	**Cancer Risk Bins**	**Hazard Quotient Bins**
(1) D1 = <500m HH	(a) ter = terrestrial	(R7) = $7.5x10^{-8}$ to $7.5x10^{-7}$	HQH0.5E1 = HH 0.05 to 0.5; Eco 0.1 to 1
= <1000m Eco	(b) aqu = aquatic	(R6) = $7.5x10^{-7}$ to $2.5x10^{-6}$	-- always grouped here with R7 & R6
(2) D2 = <2000m HH & Eco	(c) wet = wetland	(R5) = $2.5x10^{-6}$ to $7.5x10^{-6}$	HQH5E10 = HH 0.5 to 5; Eco 1 to 10
		(R4) = $7.5x10^{-6}$ to $5x10^{-5}$	-- always grouped here with R5 & R4

Example Scenario: **Primary tag:** 1aR6: Primary tag is sufficient to identify scenario

Secondary tag: D1;ter;R$2.5x10^{-6}$/HQH0.5E1

Interpretation: For Human Health Risk: <500m, Excess Cancer Risk < 2.5x10-6, Hazard Quotient < 0.5

For Ecological Risk: <1000m, Terrestrial Receptor Group, Hazard Quotient <1

Estimates given here at ◎10^{-4} use linear curve fitting based upon underlying cancer-slope relationship (i.e., Cw).

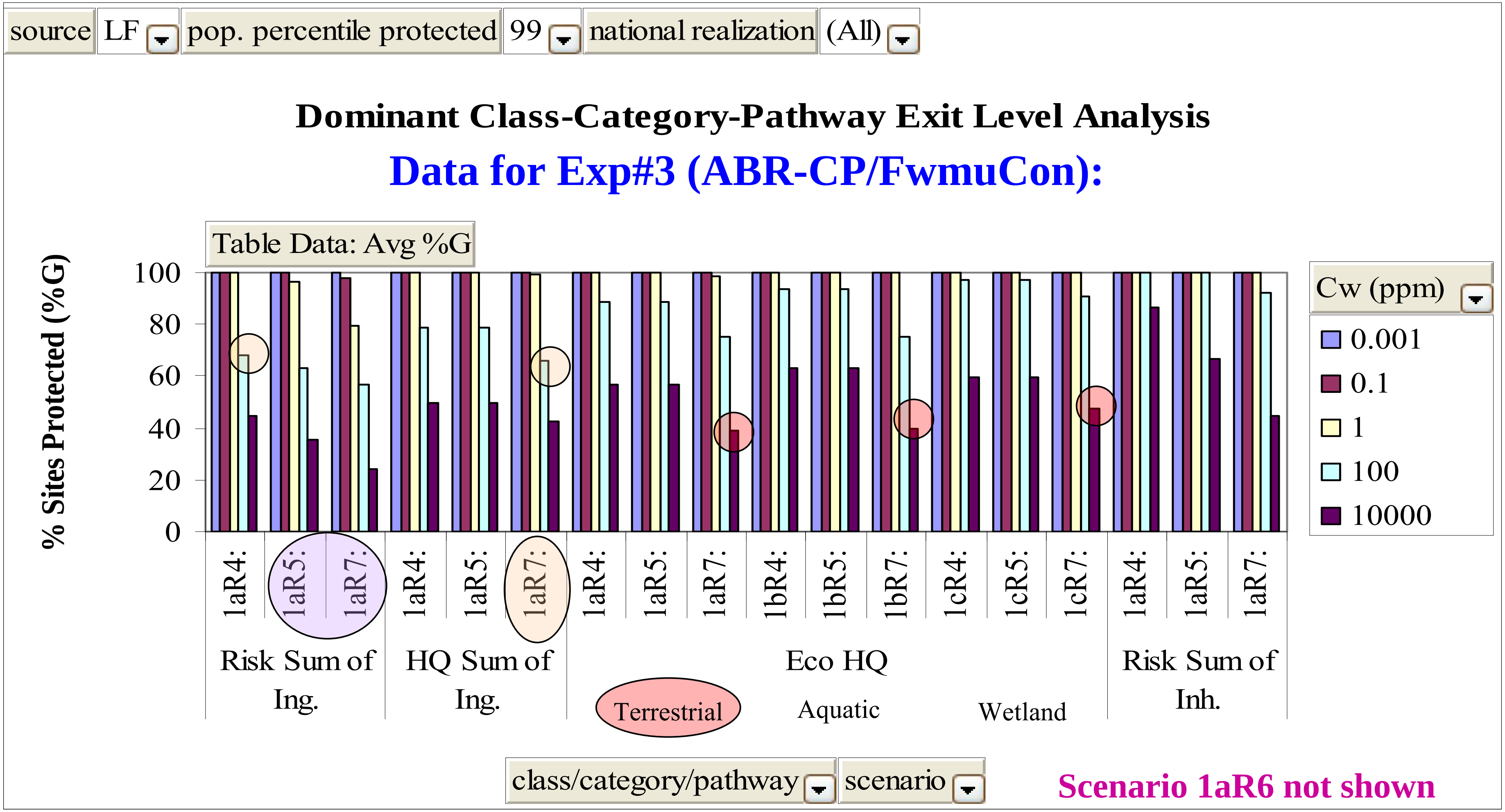
Notes on primary tags:

For HH aspects, scenarios with (b), (c) are always same as (a), need consider only (a).

For HH & Eco Health Hazard aspects, scenarios with R7 are always same as R6, and similarly, scenarios with R5 are always same as R4; need consider only 1 in each group.

Tagging differentiates various exposure profiles considered in each experiment conducted.

Dominant Class-Category-Pathway (<500m)

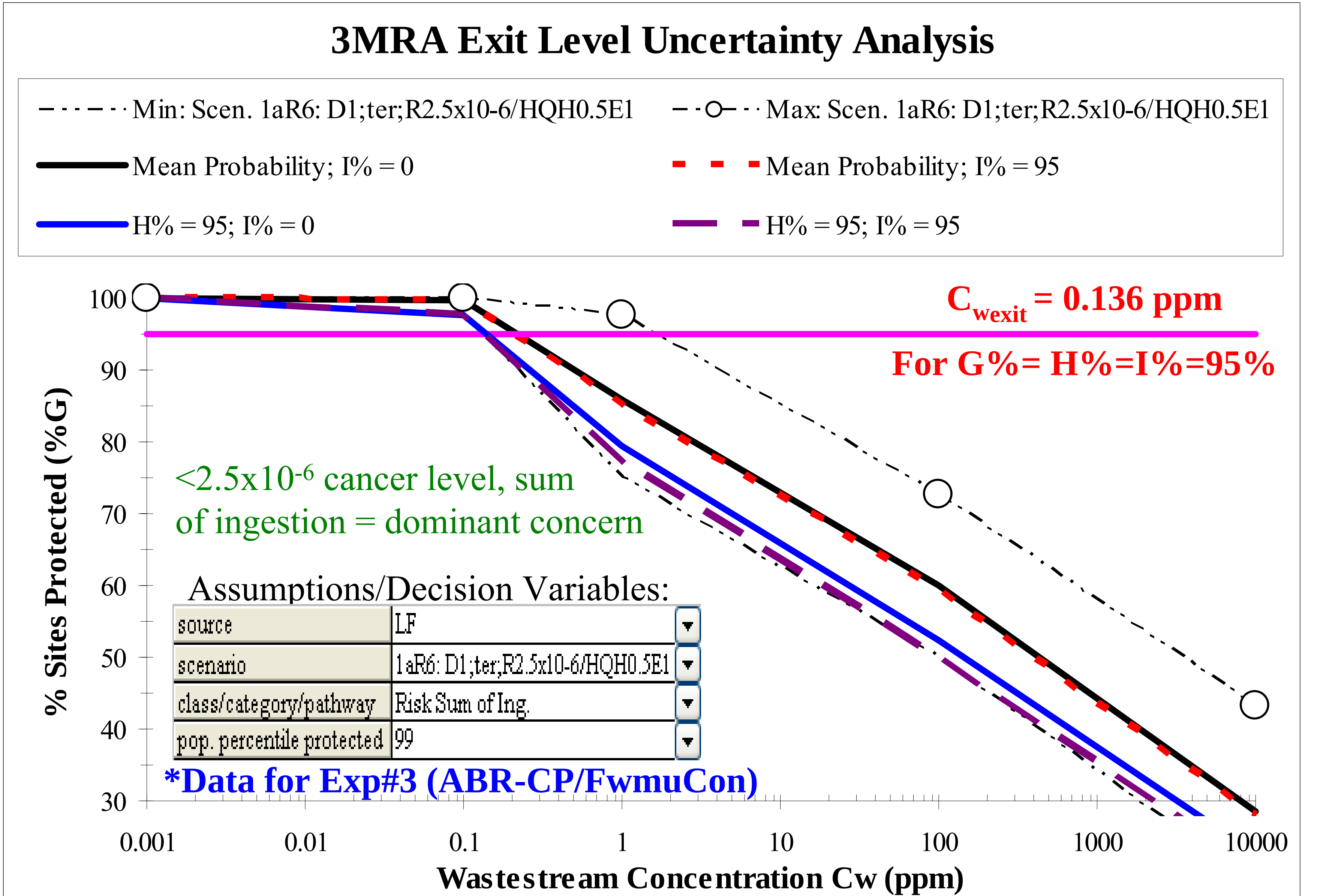


HH Cancer Risk, Sum of All Ingestion Pathways is generally dominant concern, except for cancer risk levels > $7.5x10^{-6}$ where HH Ingestion Health Hazard HQ<0.5 can dominate.

At 95% sites protection, generally holds true for both 500m and 2000m radial distances

For ecological receptors, generally the terrestrial habitat group experienced greater risk.

Determining Influent Waste "Exit Level" with UA



This slide not representative of WTP ABR deposition scenario = Exp#4 (ABR-CP/Fwmu)

Example Data Analysis Summary for C_{wexit}

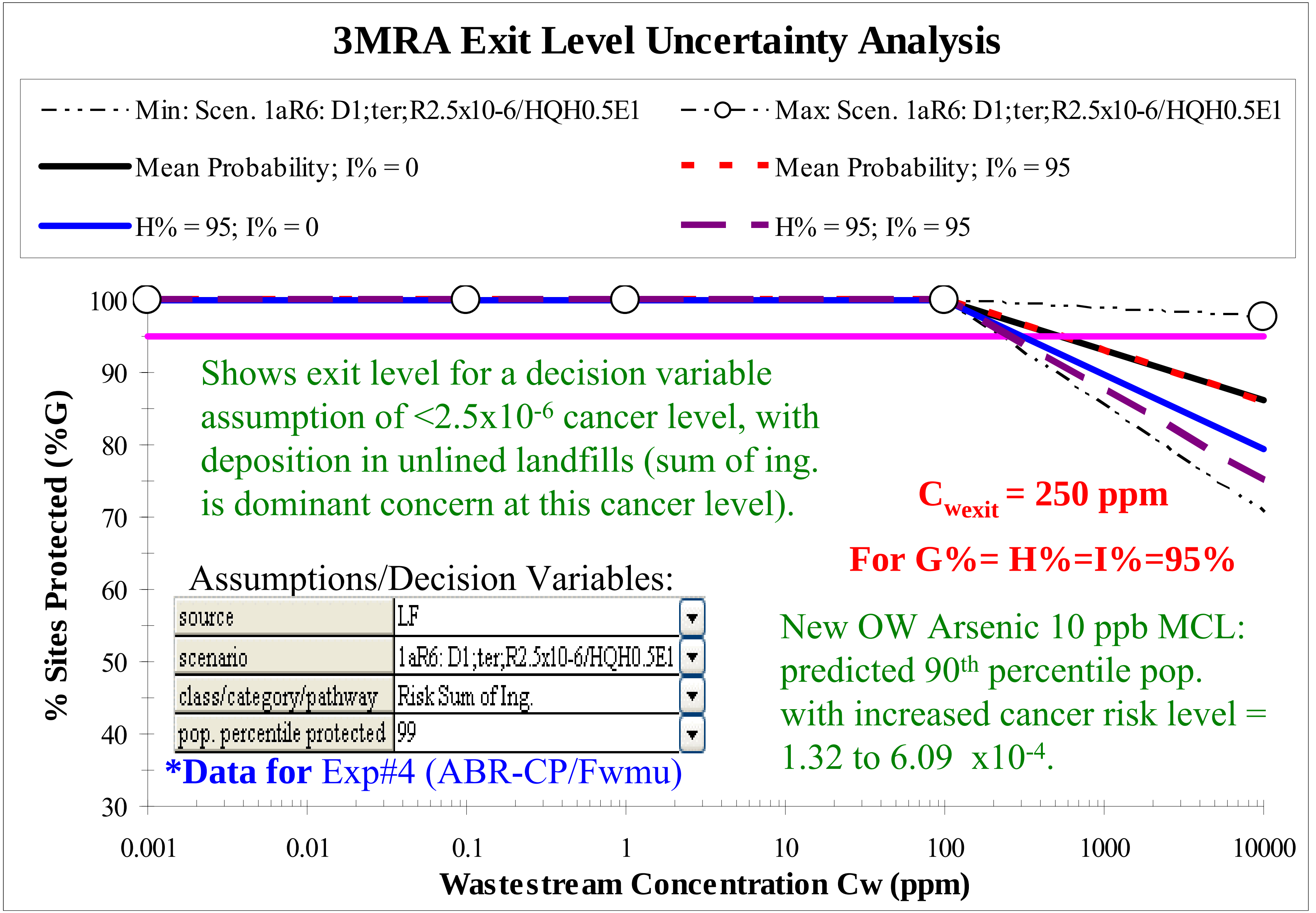
Monte Carlo Empirical Uncertainty Analysis (Accuracy*)							
Interpolation Scheme Solution >>		Log-linear				Linear	
User Selected %Ge	%Ge	95	95	95			
User Selected %He	%He	95	80	Median	Mean	Mean	
Log-linear interpolation scheme for y = m*Ln(x) + b	x_1	0.1	0.1	0.1	0.1	0.1	%H, %I = 0
	x_2	1	1	1	1	1	
	y_1	97.7	100.0	100.0	99.8	99.8	
	y_2	79.5	81.8	86.4	85.9	85.9	
	b	79.5	81.8	86.4	85.9	101.3	
	m	-7.90	-7.90	-5.92	-6.05	-15.48	
Exit Level (ppm) at H% Confidence		1.41E-01	1.88E-01	2.33E-01	2.21E-01	4.09E-01	

Monte Carlo Simulation Error Analysis (Precision*)							
User Selected %Ie	%Ie	95	95	95			
Log-linear interpolation scheme for y = m*Ln(x) + b	x_1	0.1	0.1	0.1	0.1	0.1	%H, %I
	x_2	1	1	1	1	1	
	y_1	97.72727	100	100	99.7127	99.7127	
	y_2	77.2	81.8	86.4	85.4	85.4	
	b	77.2	81.8	86.4	85.4	101.3	
	m	-8.90	-7.90	-5.92	-6.22	-15.92	
Exit Level (ppm) at H%, I% Confidence		1.36E-01	1.88E-01	2.33E-01	2.13E-01	3.96E-01	

This data associated with previous slide and assumptions: **Exp#3 (ABR-CP/FwmuCon)**

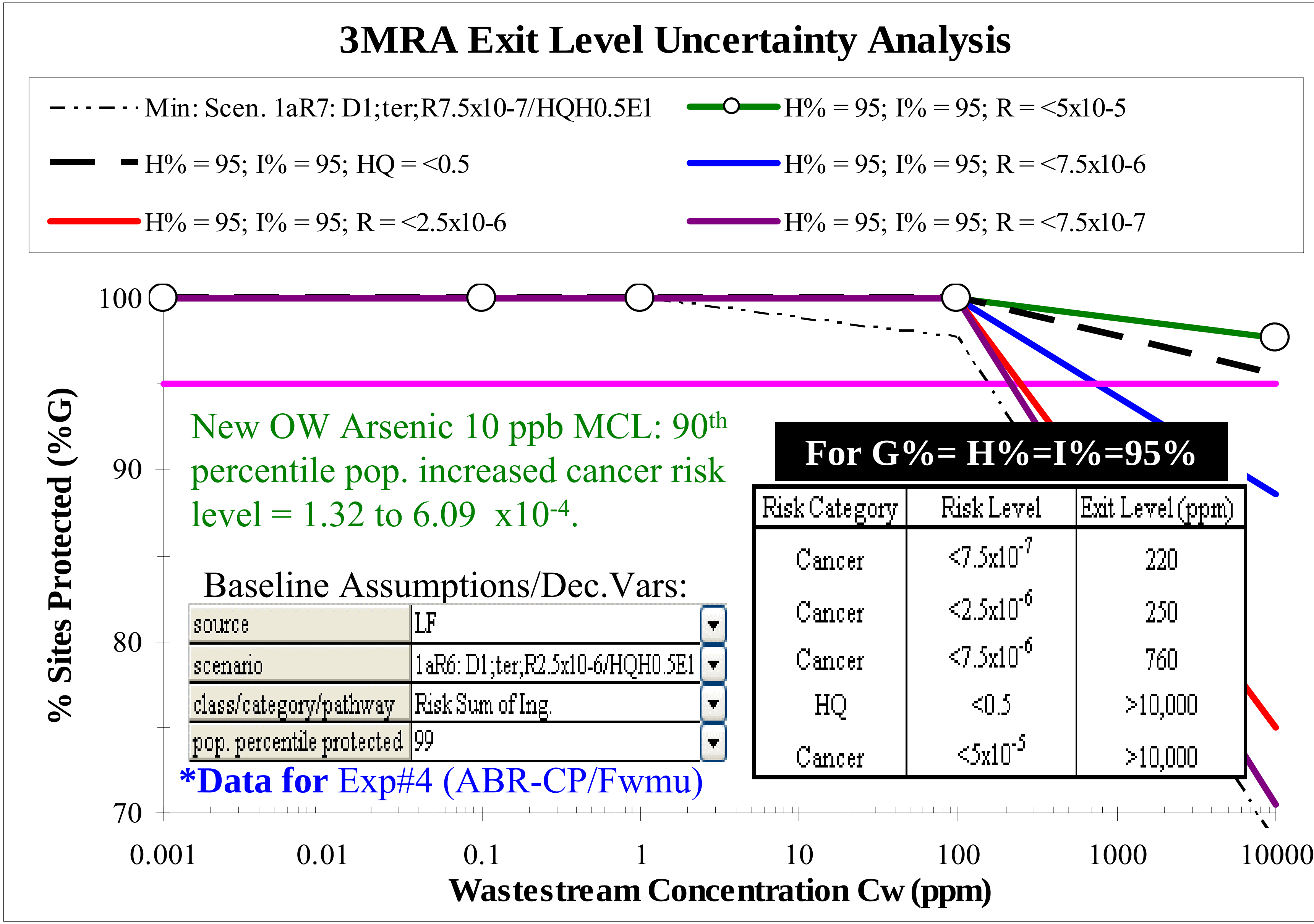
This slide not representative of WTP ABR deposition scenario = Exp#4 (ABR-CP/Fwmu)

Exit Level Analysis for ABR Deposition Scenario



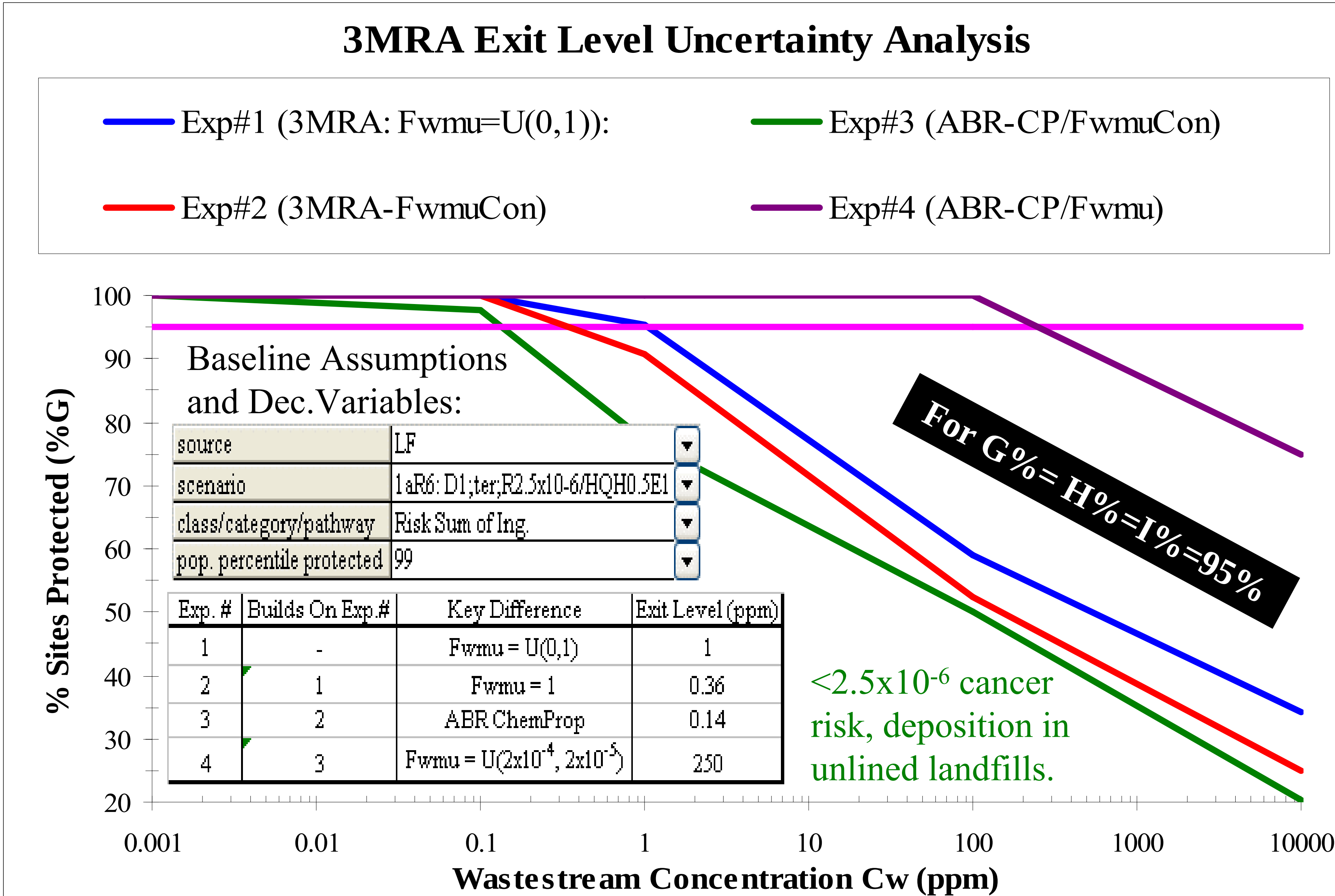
This slide based on Exp#4 (ABR-CP/Fwmu), unlined landfills, <2.5x10^{-6} cancer level.

ABR Scenario: Comparison Across Risk Levels



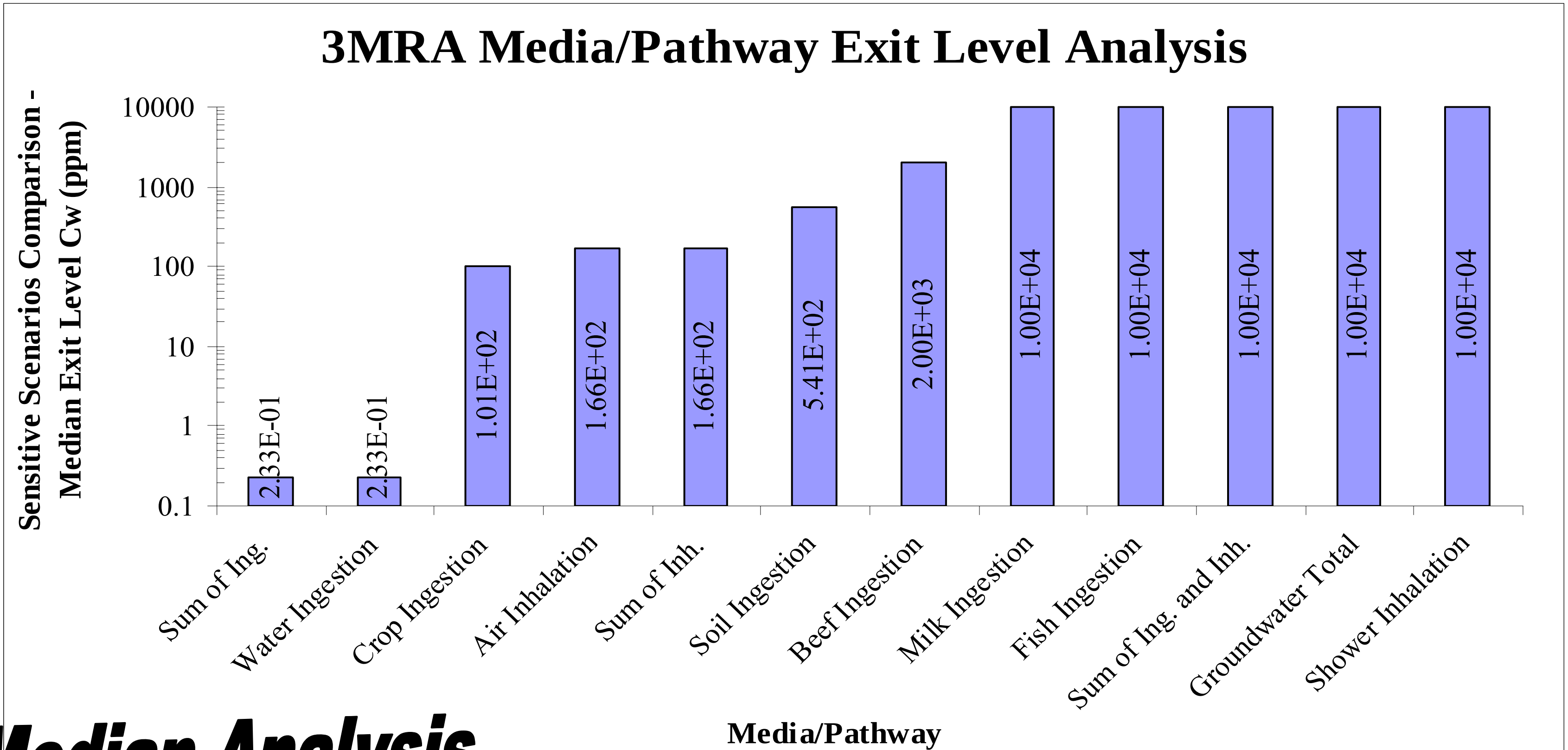
This slide based on data for Exp#4 (ABR-CP/Fwmu), unlined landfills, various risk levels.

Comparison of Exit Levels Across 4 Experiments



This slide based on data for Exp#1, #2, #3, and #4, unlined landfills, various assumptions.

3MRA Exit Level Analysis for Arsenic in Landfills: Sensitive Media/Pathway Combinations for Dominant Class-Category-Pathway



Median Analysis

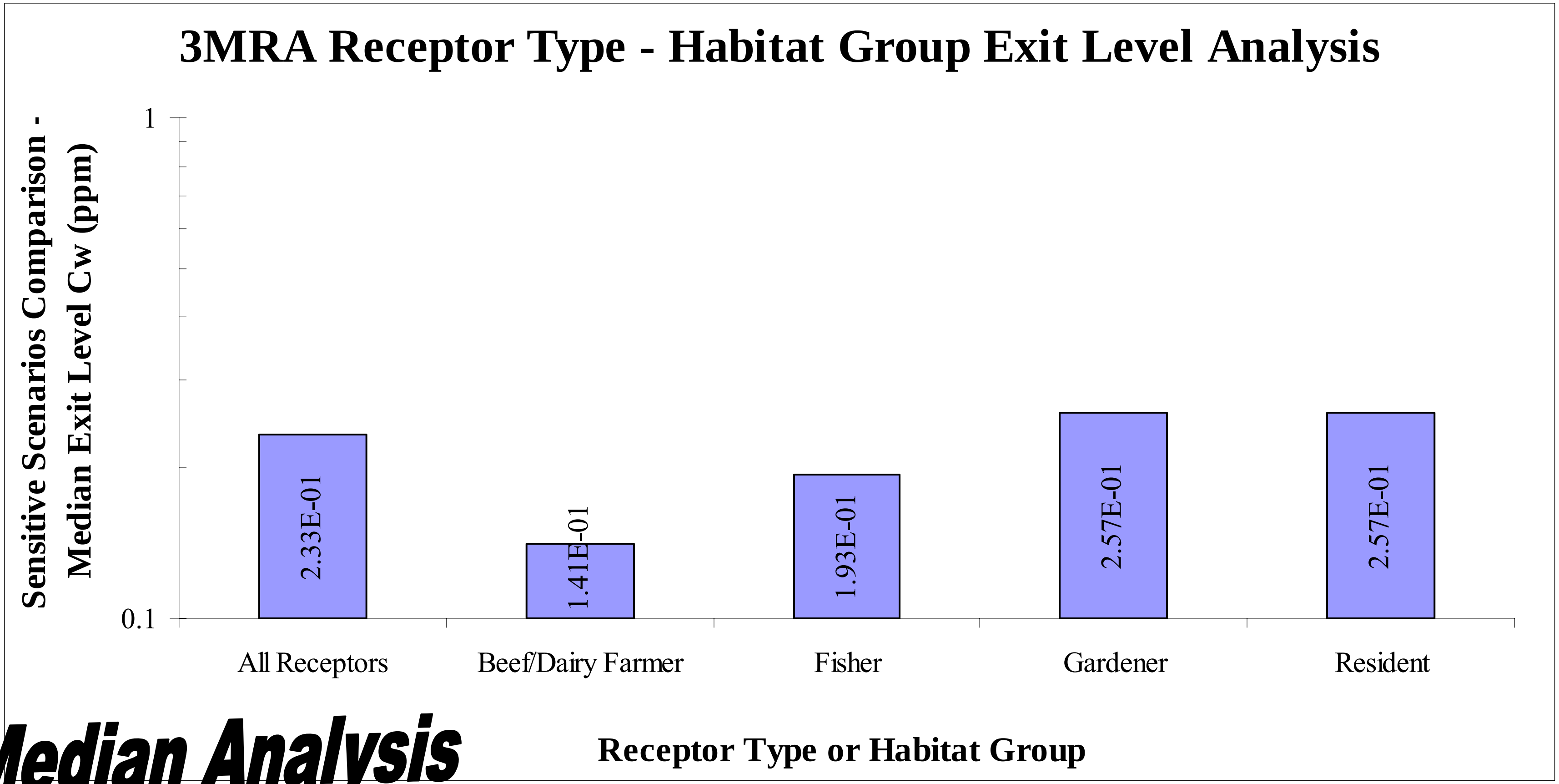
Assumptions/Decision Variables:

*** Data for Exp#3 (ABR-CP/FwmuCon)**

source	LF
scenario	1aR6: D1;ter;R2.5x10-6/HQH0.5E1
class/category/pathway	Risk Sum of Ing.
pop. percentile protected	99

This slide based on Exp#3 (ABR-CP/FwmuCon), unlined landfills, <2.5x10^{-6} cancer level.

3MRA Exit Level Analysis for Arsenic in Landfills:
Sensitive Receptor Type or Habitat Group for Dominant Class-Category-Pathway



Median Analysis

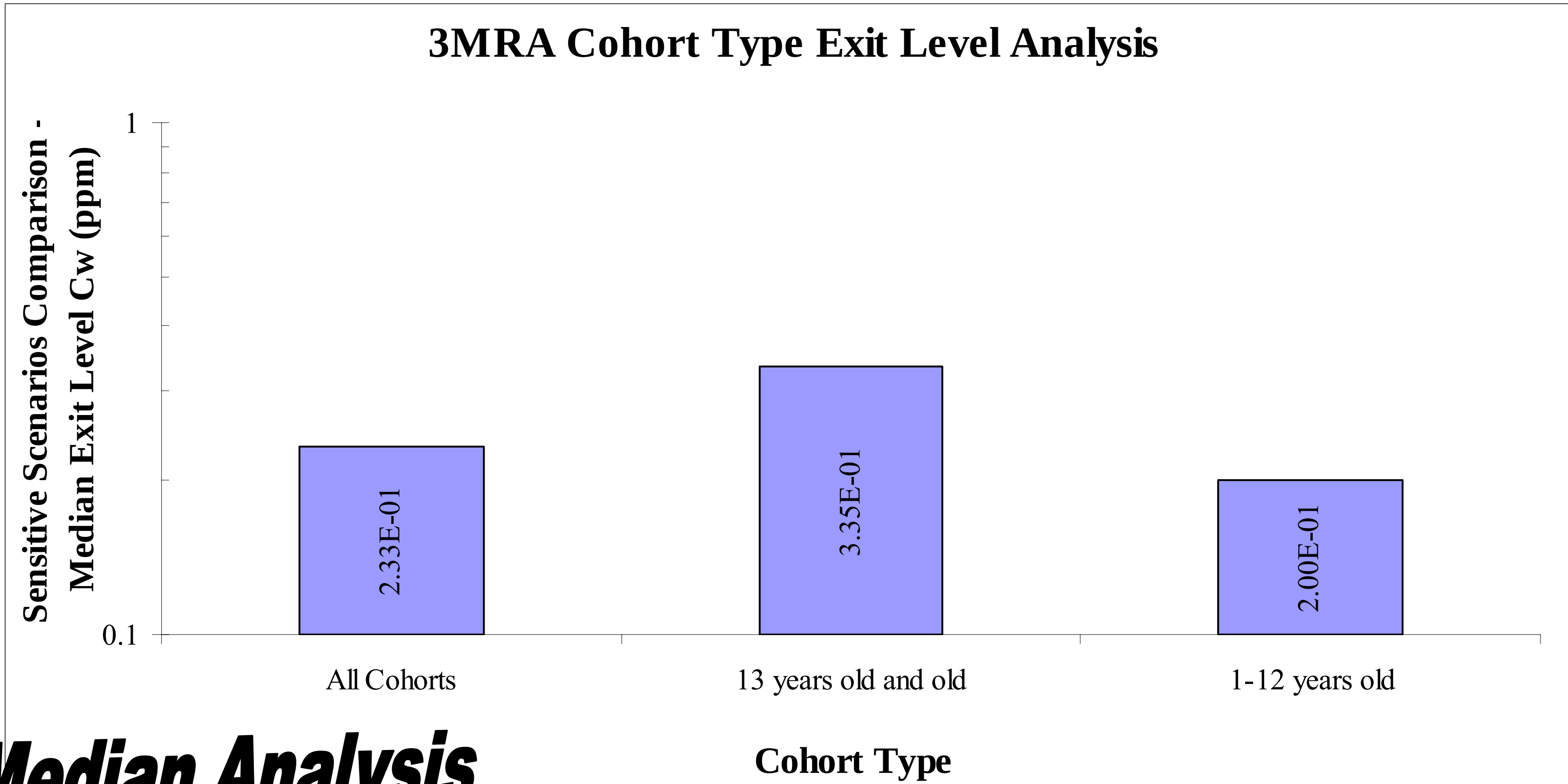
Assumptions/Decision Variables:

*** Data for Exp#3 (ABR-CP/FwmuCon)**

source	LF
scenario	1aR6: D1;ter;R2.5x10-6/HQH0.5E1
class/category/pathway	Risk Sum of Ing.
pop. percentile protected	99

This slide based on Exp#3 (ABR-CP/FwmuCon), unlined landfills, <$2.5x10^{-6}$ cancer level.

3MRA Exit Level Analysis for Arsenic in Landfills:
Sensitive Cohort Type for Dominant Class-Category-Pathway



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scenario	1aR6: D1;ter;R2.5x10-6/HQH0.5E1
class/category/pathway	Risk Sum of Ing.
pop. percentile protected	99

This slide based on Exp#3 (ABR-CP/FwmuCon), unlined landfills, <2.5x10^{-6} cancer level.

Conclusions

- Human Health (HH) Cancer Risk, Sum of All Ingestion Pathways was generally found to be the dominant concern at radial distances of 500m and 2000m, except for cancer risk levels > $7.5x10^{-6}$ where Human Health Ingestion Health Hazard HQ<0.5 can dominate.

- **Groundwater ingestion** (Sensitivity ≡ 1.0) **was the dominant pathway**, followed by far lesser, relative concerns seen from crop ingestion (S=2.3E-03) and ambient air inhalation (S=1.4E-03).

- The Beef/Dairy Farmer group, and to a lesser degree the Fisher receptor group, were on average modestly more at risk than Resident and Gardner receptor groups, the former experiencing greater risk than "All Receptors".

- Similarly, the cohort for children 1 to 12 years old were at slightly higher risk than the cohort for receptors 13 years and older.

Conclusions (Continued)

- Based on the chemical properties of ABRs utilized in this study for Kd, BDw, and mcW, modestly increased risks to receptors were generally noted at similar waste stream concentrations, compared to use of 3MRA default parameter values for industrial wastes.

- Regarding deposition of anticipated flow of ABRs, with 95% confidence, 3MRA estimated protection of 99% of humans at 95% of all sites for the following associated cancer risk levels, health hazard levels, and waste stream concentrations (i.e., Exp#4):

Risk Category	Risk Level	Exit Level (ppm)
Cancer	$<7.5\times10^{-7}$	220
Cancer	$<2.5\times10^{-6}$	250
Cancer	$<7.5\times10^{-6}$	760
HQ	<0.5	>10,000
Cancer	$<5\times10^{-5}$	>10,000

- At 5×10^{-5} cancer risk level, bounding the new MCL standard of 10 ppb, deposition of ABRs at all levels up to 10,000 ppm were observed to be protective for 95% of humans at 100% of sites studied in the analysis. The presence of liners in receiving facilities increases the likelihood of similar outcomes for lower risk levels and higher population percentiles.

- Assuming Fwmu = U(0.0015, 0.000015), equivalent to 20 to 500 TPD landfill flow rates, where 20 TPD facilities would receive ABRs from up to 8 WTP facilities, an exit level of 1600 ppm was estimated for the cancer risk level 10^{-4}, and 9100 ppm for 6.1×10^{-4}.

Limitations/Qualifications

- 3MRA uses a cancer slope factor approach, whereas OW rule utilized DWS development approach, neither are wrong, they only represent different methodologies for assigning effects.

- This analysis did not include the new Generalized Soil Column Model under development which may improve upon model estimates in dealing with certain aspects of boundary conditions.

- This analysis does not fully evaluate all potential sources of uncertainty (e.g., model error, distribution uncertainty, etc.). It also does not account for background As levels and other sources *in situ*.

- The analysis assumes the 3MRA site-based landfill database is representative of the population of landfills receiving ABRs.

- The analysis did not account for mitigation of risk by landfill liners.

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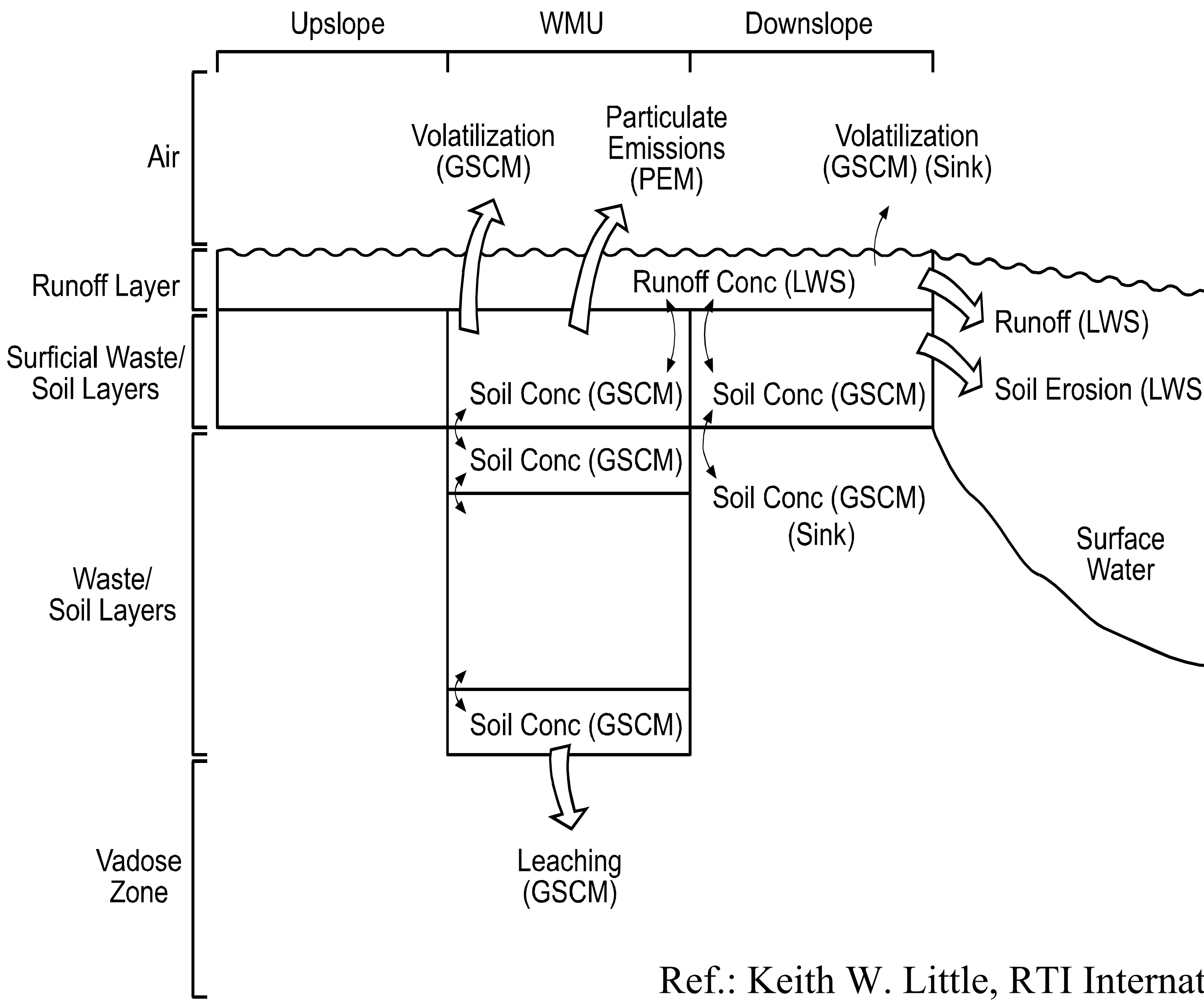
Materials for Additional Symposium Discussion Sessions:

3MRA Landfill Source Term Module and Elements of Uncertainty Analysis

Interaction of Algorithms: Land-Based WMUs

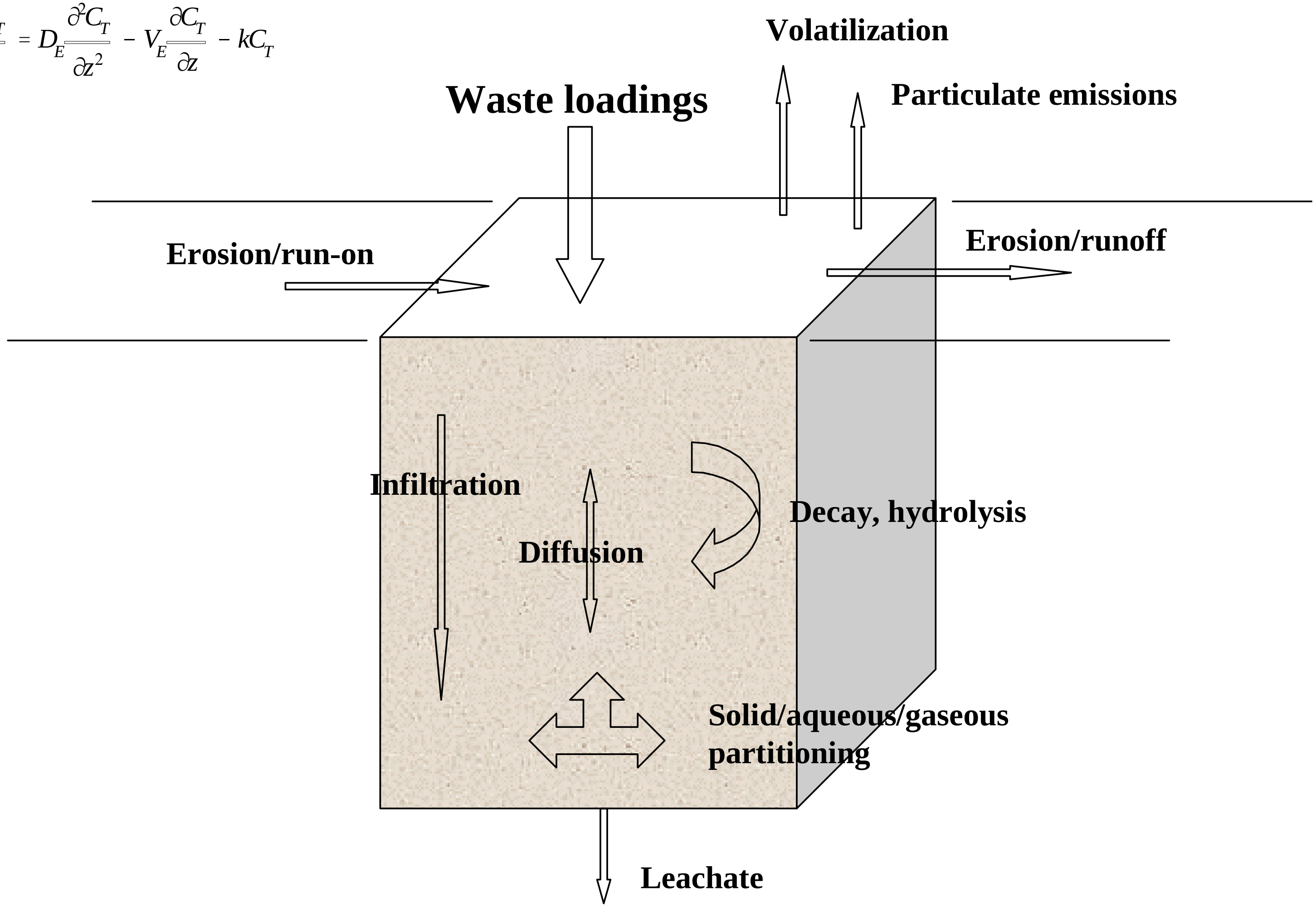


Ref.: Keith W. Little, RTI International, 2003

3MRA Generalized Soil Column Model

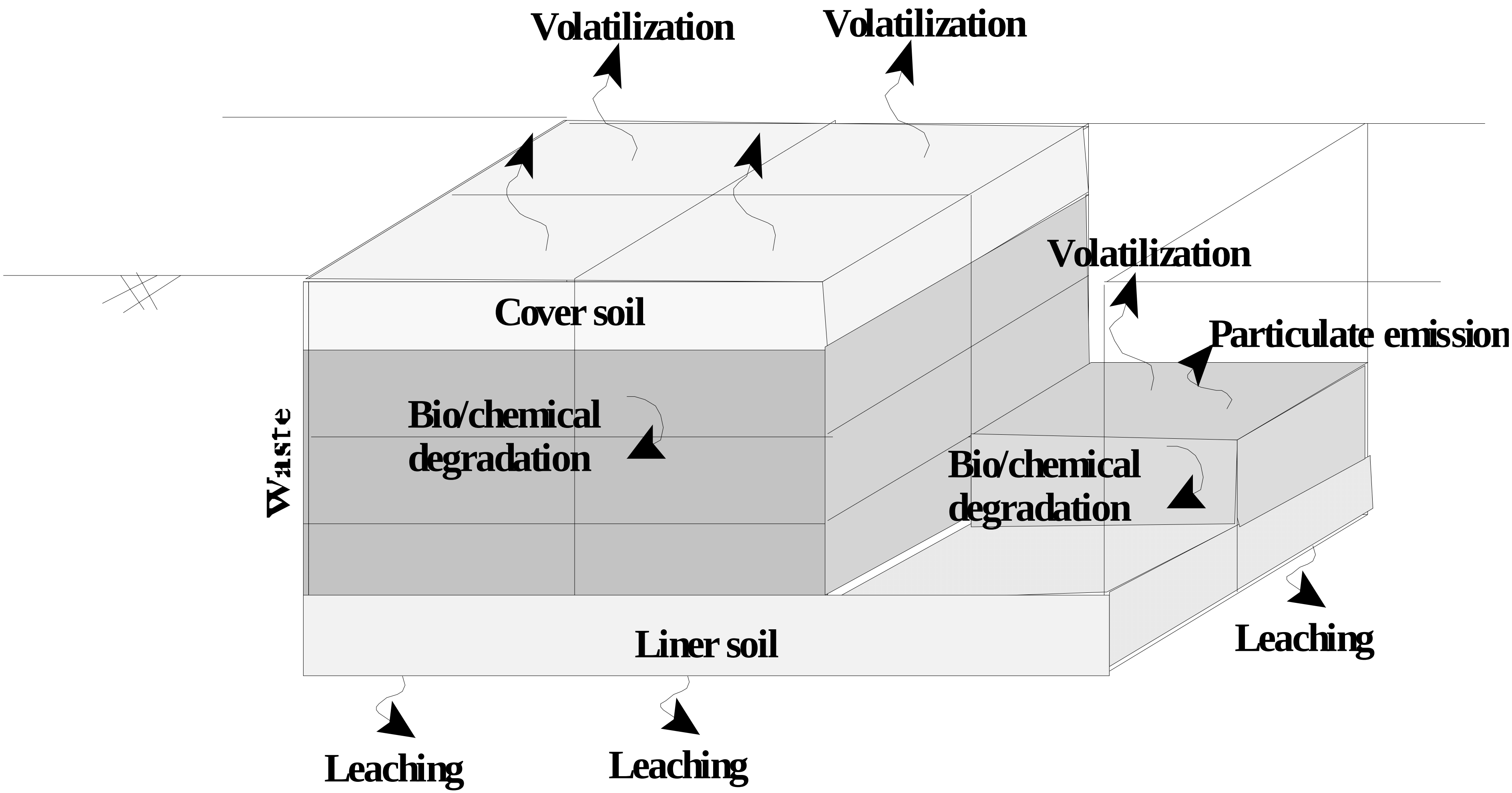
Governing equation:

$$\frac{\partial C_T}{\partial t} = D_E \frac{\partial^2 C_T}{\partial z^2} - V_E \frac{\partial C_T}{\partial z} - kC_T$$



Ref.: Keith W. Little, RTI International, 2003

3MRA Landfill Module



Ref.: Keith W. Little, RTI International, 2003

Classes and Types of Uncertainty

General Classes of Uncertainty
Variability (V)
Empirical Uncertainty (U)
Model Error (ME)
Types of Empirical Uncertainty
Random Error (RE)
Systematic Error (SE)
Sample Measurement Error (SME; see RE, SE)
Input Sampling Error (ISE; see RE)
Output Sampling Error (OSE; see RE)
Inherent randomness
Correlation
Disagreement

Conceptual 3MRA Exit Level Uncertainty Analysis