Impact of Exposure and Dose Metrics on the Conduct of Human and Ecological Exposure Assessments

Thomas McCurdy[1], Victoria Sandiford[2], Harvey Richmond[2], Stephen Graham[1], and Jennifer Hutchison[1]

1. National Exposure Research Laboratory, US EPA
2. Office of Air Quality Planning and Standards, US EPA

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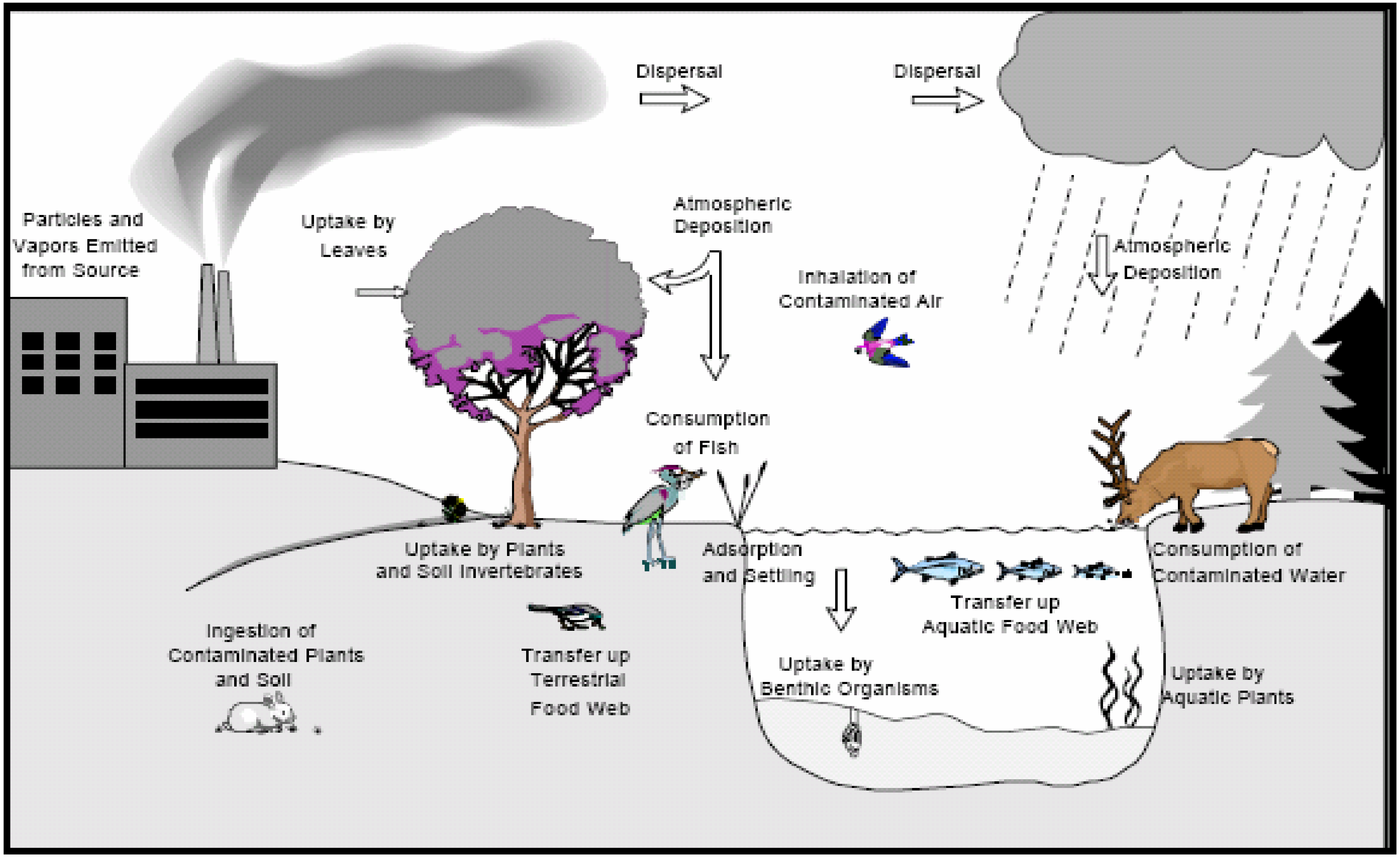
Outline

- Context of human & ecosystem exposure assessments: ozone is used as an example
- The “exposure profile” & dimensions of exposure metrics
- Human and “ecosystem” exposure assessment practices
- Related findings by other scientists
- Conclusions

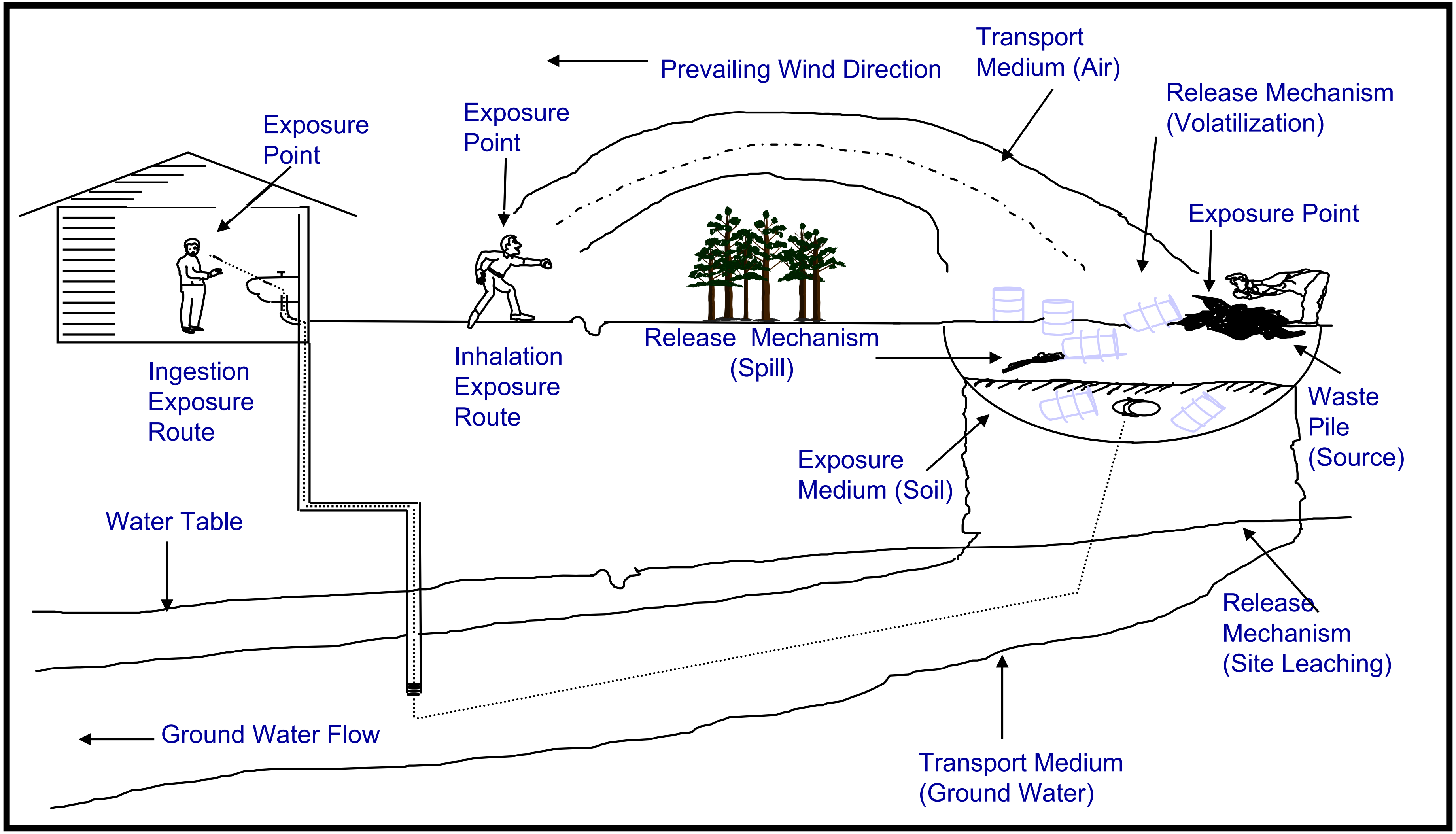
  - Magnitude & significance of health & ecosystem impacts varies greatly depending upon the metric used to describe them
  - Human and non-human exposure metrics are very different
  - The spatial scale of the two exposure assessments is very different
  - These differences preclude undertaking a joint human/eco risk assessment using one exposure assessment method
  - This probably is true for any pollutant whose effects are not well-described by a cumulative (AUC) dose-response relationship

Environmental Context

fate & transport, deposition considerations are similar** in general **for human and ecosystem impact assessments, but …



. . . intervening media often come between humans and environmental concentrations, but do not for "ecosystems"



Activity patterns greatly affect exposures experienced

- Locational considerations (microenvironments)
- Mobility (commuting, travel patterns, residential moving rates, home territories/ranges, migratory pathways)
- Activities undertaken & their "activity levels" (the latter affects dose rate estimates given an exposure)

Health & ecosystem "endpoints" or effects are very different

- Humans: chest tightness & cough (Schonbein 1851)
  - Changes in lung function, physiology & morphology (1950's)
  - Epidemiological evidence: hospital admissions, doctor visits (1967)
  - Cardiovascular impacts (1997)
  - Chronic effects: chronic morbidity & even mortality (1995)
- Vegetation, sensitive crop and tree species:
  - Leaf morphology (Middleton, 1950)
  - Plant lesions (Middleton, 1958)
  - Yield & biomass reduction; photosynthetic processes (Barnett & Waddell, 1973)
    - Carbohydrate production & Allocation
    - Seedling impacts: reduced root growth
- Animals: lung toxicity-inflammation, edema (Hill & Flack 1912)
- Global systems: world-wide O_3 "background" levels & tropospheric cycles
  - Madden & Hogsett (2001). "A historical overview of the ozone exposure problem." Human & Ecological Risk Assessment 7: 1121-1131.

Because of these factors, human & ecosystem exposure assessments are done at different spatial scales

(In general; there is some overlap)

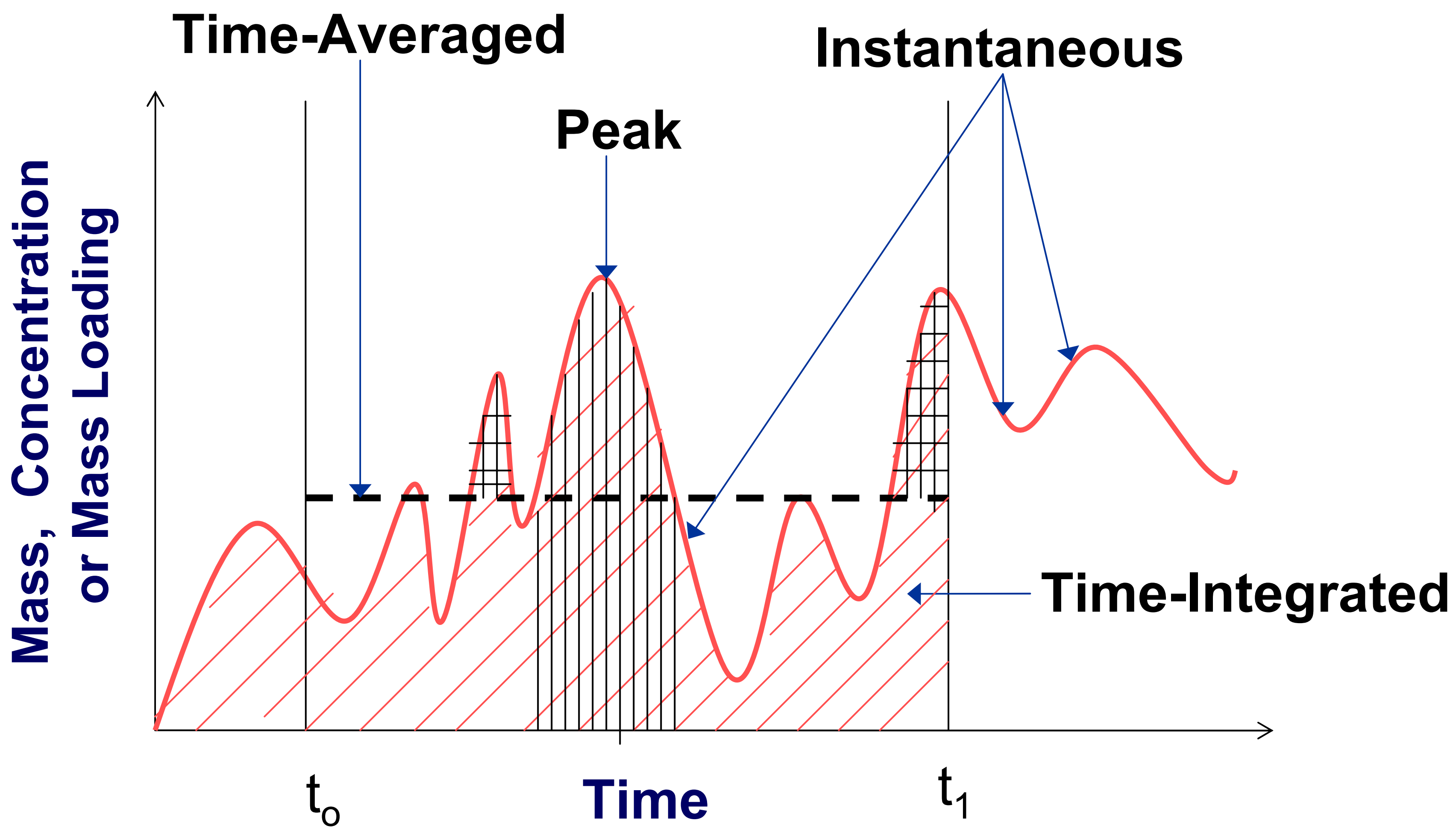
National/State County Level

Community Level

Neighborhood Level

Personal Level

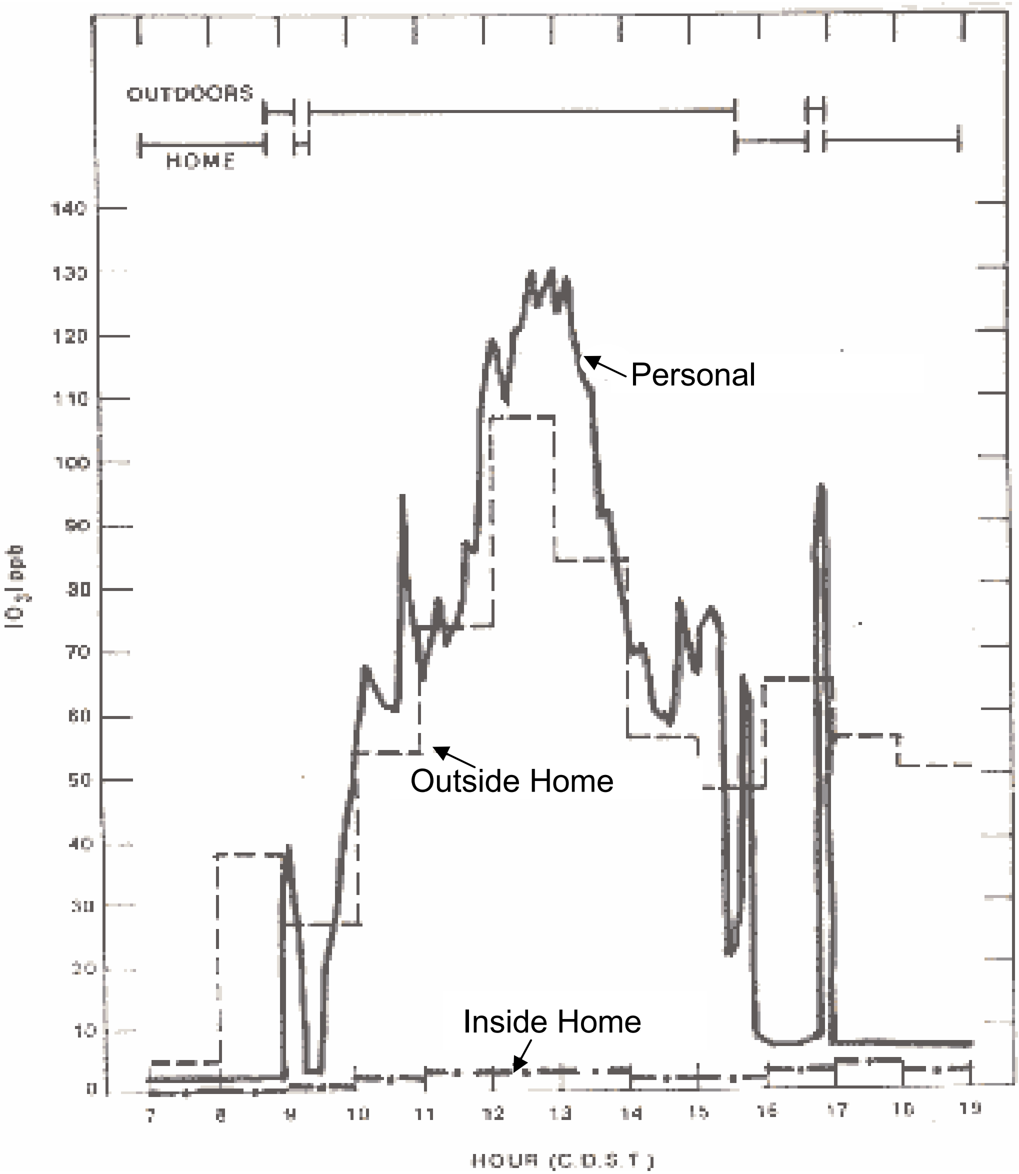
The “exposure profile”



Exposure profile makes a difference

- Same “area-under-the curve” concentration pattern
- At 0.08 ppm exposures ONLY, significant pulmonary function & symptoms were observed over a longer period of time in the triangular exposure protocol
- However, when “background” was removed, there were no significant differences in the two patterns

Source: W.C. Adams: “Comparison of chamber 6.6-h exposures to 0.04-0.08 ppm Ozone via square-wave and triangular profiles on pulmonary response.” **Inhalation Toxicology** 18: 127-136 (2006).



Example of an actual human O_3 exposure profile from a personal monitoring study

Source: Contant et al. "Estimation of individual ozone exposure using microenvironmental measures," pp. 251-260 in: S.D.Lee (ed). **Evaluation of the Scientific Basis for Ozone/Oxidant Standards** (1983).

Generalized dimensions of an exposure metric applicable to both human health and "ecosystem" impact assessments

- Concentration (intensity) level: mass per volume; volume per volume; moles
- Duration (averaging time): minutes, hours
- Frequency (events per specified time period)*
  - One per day, once per week, etc.
- Pattern

*Also known as the temporal aggregation period

Specific dimensions of a O_3 NAAQS for human health and ecosystem impact assessment

- Common to both types of assessments
  - Averaging time basis (one hour)
  - Temporal aggregation period: 8h daily max
  - Data handling and analysis conventions (40 CFR 50 & EPA Guidelines)

- Particular to each assessment
  - Temporal aggregation period: eco: 12 h per day
  - Epoch: (1) health: ozone season; (2) eco: max. consecutive 3 months within ozone season
  - Standard level & “form”: varies—see next slides
  - Violation rate: (1) health: see next slide; (2) eco: not to be exceeded

Alternative 8h daily maximum standards analyzed for human exposure impacts

- Standard levels / allowed exceedances evaluated:
  - 0.084 ppm (3 & 4 allowed exceedances)
  - 0.080 ppm (4 allowed exceedances)
  - 0.074 ppm (3, 4, & 5 allowed exceedances)
  - 0.070 ppm (4 allowed exceedances)
  - 0.064 ppm (4 allowed exceedances)

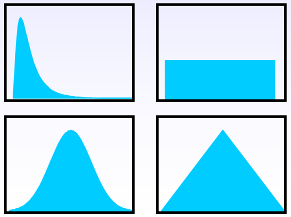
- Thus, there were 8 different NAAQS alternatives that were analyzed

Human Exposure Assessment Practices: general model structure

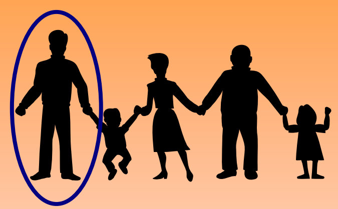
Input Databases

- Census
- Human Activity
- Ambient Conc.
- Food Residues
- Recipe/Food Diary

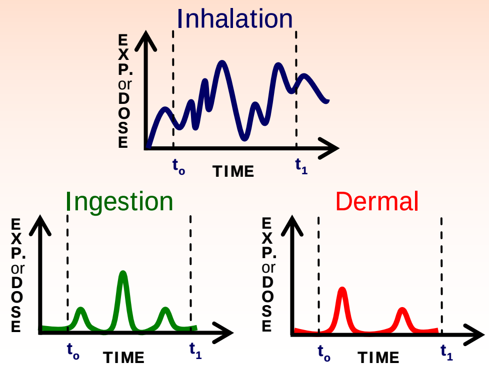
Exposure Factor Distributions



Algorithms

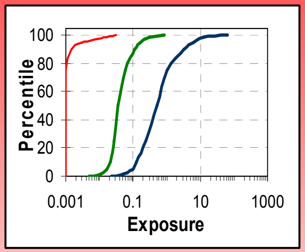


- Calculate Individual Exposure/Dose Profile

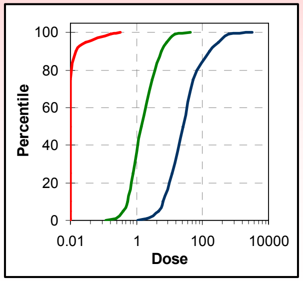


Output

- Population Exposure



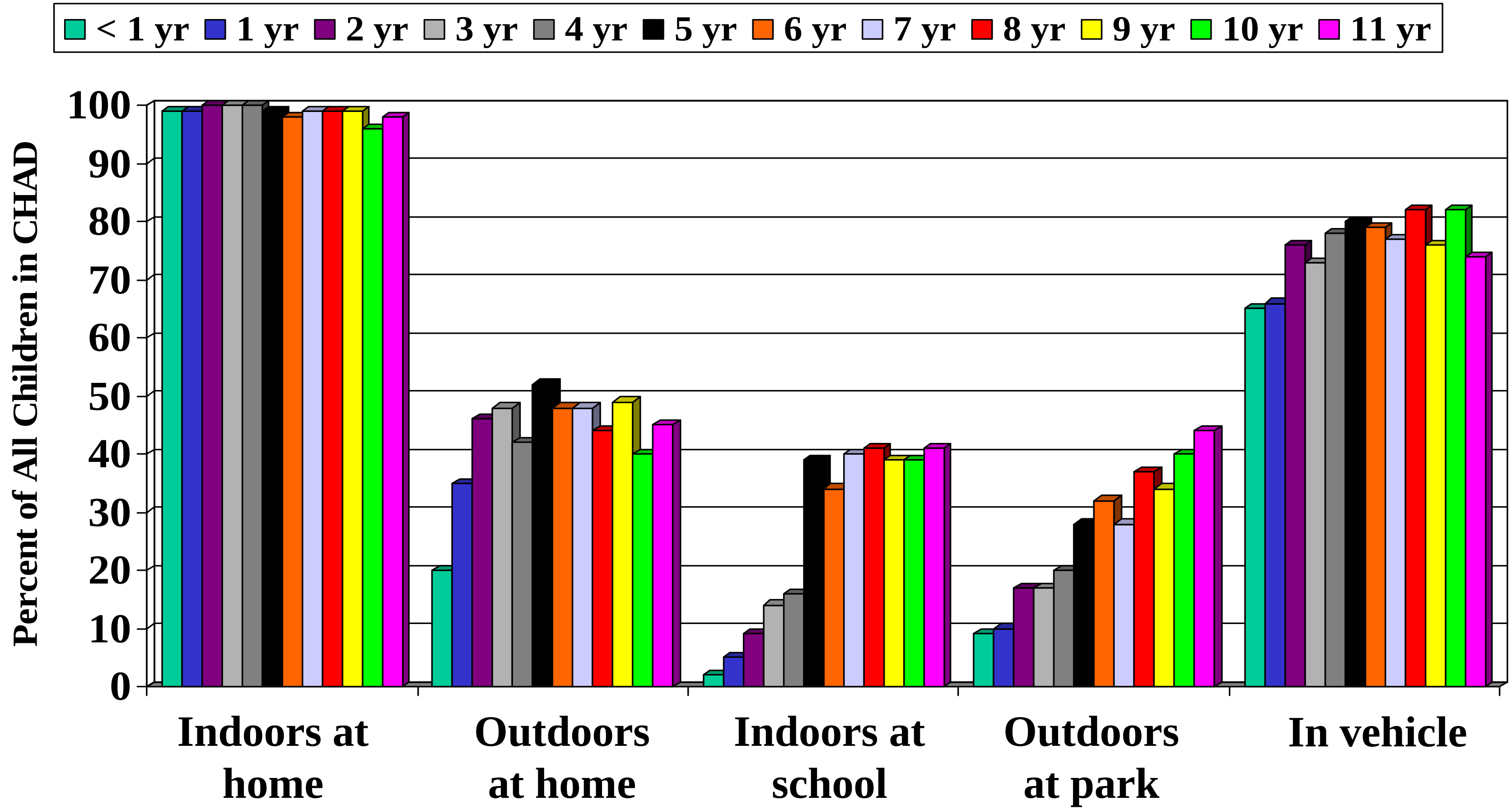
- Population Dose



Human exposure assessments

- Need data on where people live, commuting patterns, activity diaries, breathing rates
- Need air quality data on a census tract+ level
- Data come from different sources: US Census, NERL's Consolidated Human Activity Database, EPA's AIRS database, DOE and other sources of air exchange rate information, etc.
- Usually implemented using an age/gender disaggregated time-series longitudinal simulation model
  - Intra- and inter-individual variability is explicitly addressed
  - Analysis of uncertainty in input data often is addressed

Example of locational differences in children <12 y old, by year of age

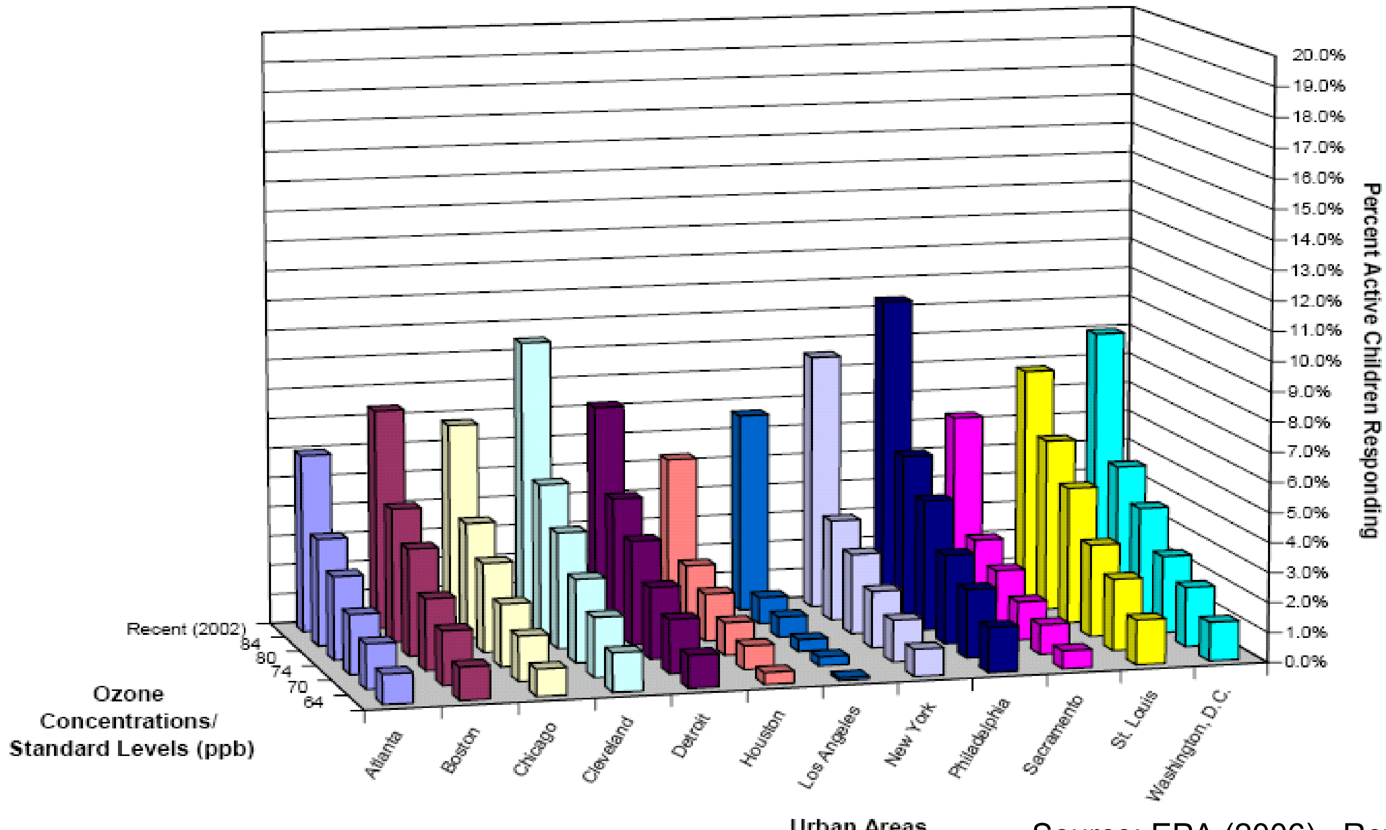


Population groups & exertion levels evaluated in the human exposure assessment

- Four main population groups were evaluated
  - Entire population
  - Children aged 5-18
  - Active children aged 5-18 (PAI>1.74)
  - Asthmatic children aged 5-18

- Evaluation metrics:
  - Numbers of people and “person-occurances” exceeding “standards” at any breathing rate

Percent of active 5-18 y children engaged in moderate exercise estimated to experience 1+ moderate lung function reduction decrements associated with 8 h ozone exposures for alternative air quality scenarios



Source: EPA (2006). Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information (EPA-452/D-05-002).

Alternative "ecosystem" standards for ecosystem impacts

- 3-month SUM06: 15 & 25 ppm-h analyzed
- W126: 13 & 21 ppm-h analyzed—see next slide
- 8-h daily maximum (same form as health standard): 0.070 & 0.084 ppm levels were analyzed
- AOT40 (cumulates O_3 above 0.04 ppm): the European critical level, but EPA did not analyze this form

Form of the W126 metric

$$W126 = \sum_{I \geq 8\text{ am}}^{i < 8\text{ pm}} w(c_i) * C_i$$

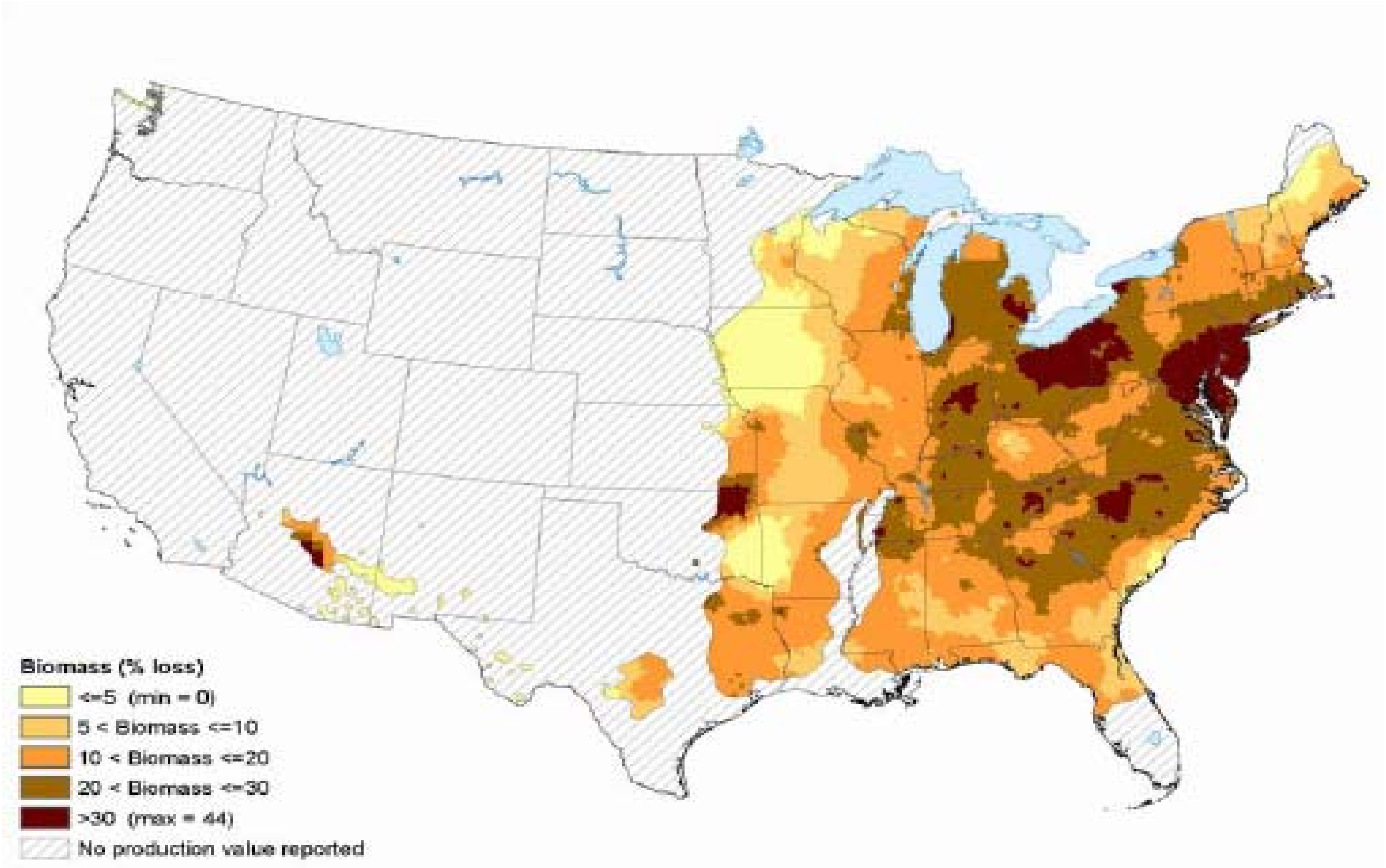
where: C_i = O_3 concentration for hour *i*

$w(c_i)$ = $(1 + 4403 * \exp -0.126\ C_i\ )^{-1}$

Ecosystem “exposure” impact assessments

- Need data on location of the crops, tree species, herbaceous perennials, etc. that will be evaluated
- Need air quality data on at least a county level, especially to quantify area-specific diurnal patterns
- Need species-specific concentration-response (C→R) functions [acts as a surrogate for exposure-response]
- Have to address possible non-air stressors & how they alter the C→R function
- Data come from many sources: EPA’s AQS & CASTNET databases, and the literature, CMAQ and other air quality models; interpolation methods
- Data on effects evidence from: published literature, USDA FS, DOI NPS, other

Example of "ecosystem" exposure output: Black Cherry seedling annual biomass loss



Example of crop yield loss estimates for alternative scenarios

	Air Quality Scenarios				
Crops	**As Is (2001)**	**8-hr, 84 ppb**	**SUM06 25**	**8-hr, 70 ppb**	**SUM06 15**
Kidney Bean	3.8%	1.8%	0.3%	0.3%	0.1%
Grapes	23.5%	20.5%	16.6%	16.7%	15.0%
Lettuce	0.0%	0.0%	0.0%	0.0%	0.0%
Potato	12.6%	8.6%	3.2%	3.3%	2.0%
Rice	18.1	15.7%	11.2%	11.4%	9.8%
Grain Sorghum	1.0%	0.5%	0.1%	0.1%	0.1%
Cantaloupe	23.5%	19.1%	14.9%	14.8%	12.8%
Corn	0.2%	0.1%	0.0%	0.0%	0.0%
Cotton	7.7%	4.8%	1.3%	1.3%	0.7%
Onion	8.1%	7.0%	5.7%	5.8%	5.2%
Peanut	5.4%	3.1%	0.8%	0.7%	0.3%
Soybean	3.4%	1.7%	1.7%	0.8%	0.8%
Valencia Orange	17.0%	15.1%	12.0%	12.1%	10.8%
Tomato Processing	13.8%	11.9%	9.8%	9.8%	8.8%
Winter Wheat	1.4%	0.6%	0.1%	0.1%	0.0%

* Modified from Figures for Yield Loss (5-5) and Yield Gain (5.6 to 5-9) in the draft Environmental Assessment TSD (Abt, 2006)

Comparing 1h & 8h Metrics

- Examined spatial and temporal patterns of exceedances of 1 h & 8 h NAAQS in the southern and middle-Atlantic states
- The 8 h NAAQS was exceeded 2.0-5.2 times more often than the 1 h NAAQS
- The areal extent of the exceedances was 1.8-16.2 times larger for the 8 h NAAQS than the 1 h NAAQS
- "These results imply that a larger population resides in areas with unhealthy O_3 levels than noncompliance with the original 1-hr standard suggests" (p. 1531).

Bell & Ellis. "Comparison of the 1-hr and 8-hr National Ambient Air Quality Standards for Ozone using Models-3." **JAWMA** 53: 1531-1540 (2003)

Comparing Metrics: "Metrics Matter"

- Evaluated 7 emissions/air quality scenarios and ranked them on several indices of O_3 air quality
  - Averaging time, relative versus absolute changes, regional versus global impacts (spatial extent), relative space/time impacts, "thresholds of concern" (peaks) versus entire distribution impacts
- Rankings varied for absolute versus relative metrics, but alternative absolute metrics themselves were highly correlated
- Rankings of peak and average metrics were inversely correlated
- Did NOT, however, investigate SUM06 or other metrics more suitable for ecosystem impacts

Bell et al. "Metrics matter: conflicting air quality rankings from different indices of air pollution." **JAWMA** 55: 97-106 (2005)

Conclusions

- Exposure metrics impacts vary greatly with respect to their "form" (averaging time, temporal aggregation period, epoch, & allowed exceedances), and this holds true for both human and non-human receptors

- Human v. non-human metrics and spatial areas of concern are very different

- The above factors, plus different data inputs needed, obviate "economies of scale" that may occur from undertaking a joint human/ecosystem exposure assessment, at least for O_3

- This probably is true for any pollutant whose effects are not well described by a cumulative (area under the curve) dose-response relationship: i.e., by "Haber's Law"

See: T. McCurdy. "Modeling the dose profile in human exposure assessments: ozone as an example." **Reviews in Toxicology** 1: 3-23 (1997)