Improving Methodologies for Cumulative Risk Assessment: A Case Study of Noncarcinogenic Health Risks from Volatile Organic Compounds in Fenceline Communities in Southeastern Pennsylvania

Johns Hopkins University Team: Peter DeCarlo, **Keeve Nachman**, Tom Burke, Kirsten Koehler, Ana Rule, Ellis Robinson, Mina Tehrani, Sara Lupolt, Andrea Chiger, Carolyn Gigot, Roger Sheu, Amira Yassine, Shivang Agarwal
Widener University: Scott Van Bremer
Aerodyne Mobile Lab Team: Megan Claflin, Edward Fortner, Manjula R Canagaratna, Conner Daube, Benjamin Werden, Joseph R Roscioli, Jordan Krechmer, Harald Stark, Scott C. Herndon, Tara Irene Yacovitch

Goals of the HAP-MAP project

Assess the cumulative burden of pollution and other stressors in fenceline communities

Use state-of-the-art measurement tools to characterize the spatial/chemical/temporal nature of toxic air emissions to

Improve our assessment of air pollution exposure and cumulative risk for fenceline communities

Monroe Refinery

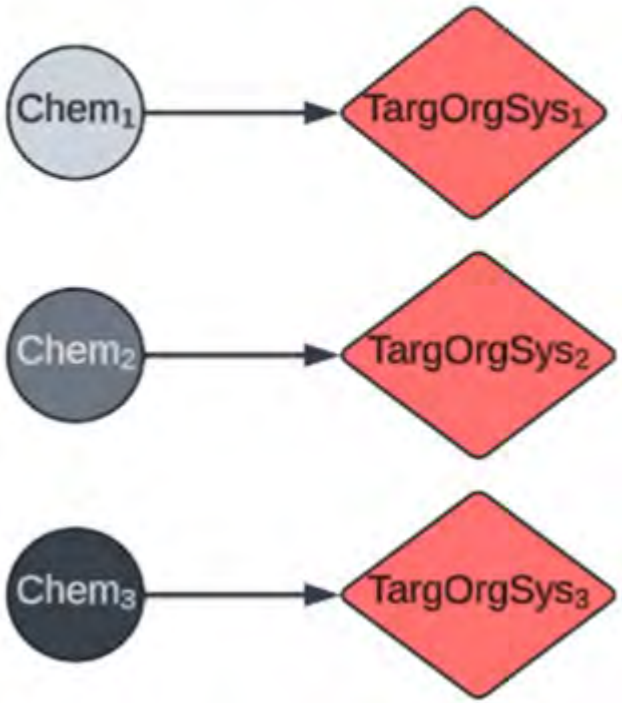
Thesis statements

- Traditional regulatory risk assessments do not adequately account for the population health burden imposed by chemical mixtures

- A more holistic approach to quantifying the impact of exposures will better characterize population health burdens

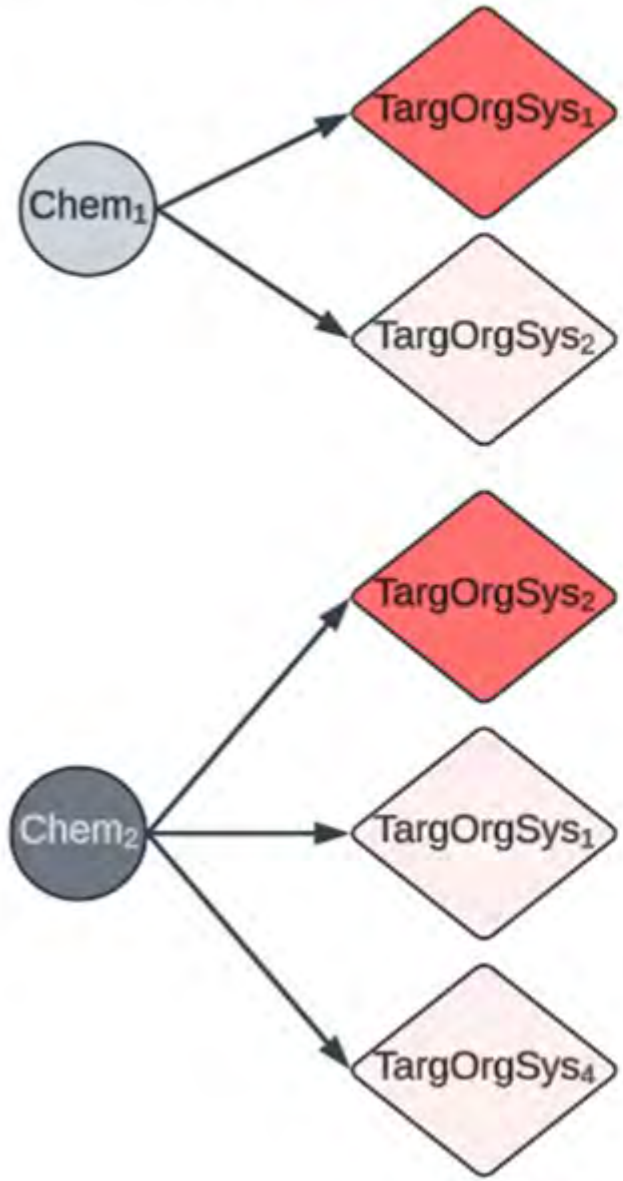
- Applying this kind of approach may lead to different conclusions about risk and support more aggressive risk management

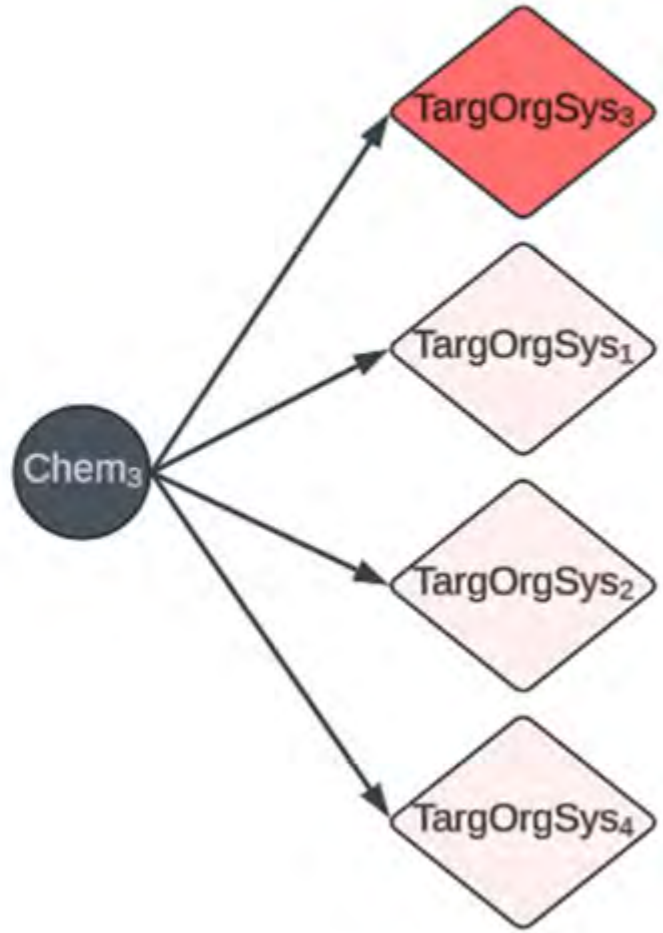
A: Traditional



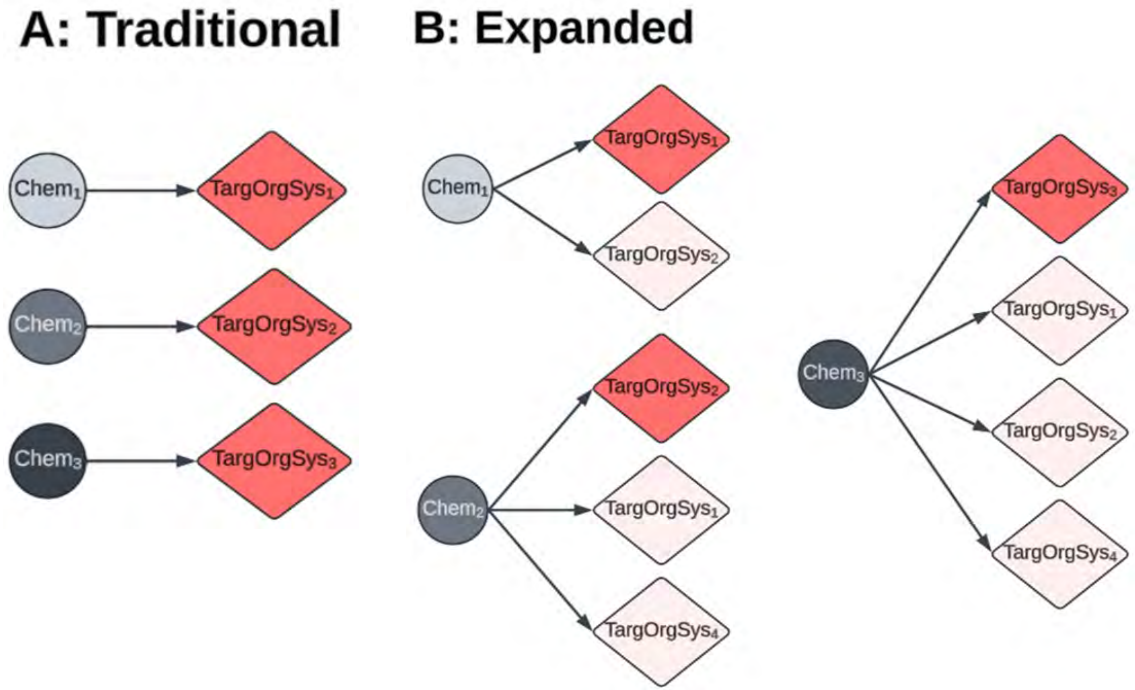
Only the most sensitive organ system (health effect) for each chemical is considered; other effects are ignored.

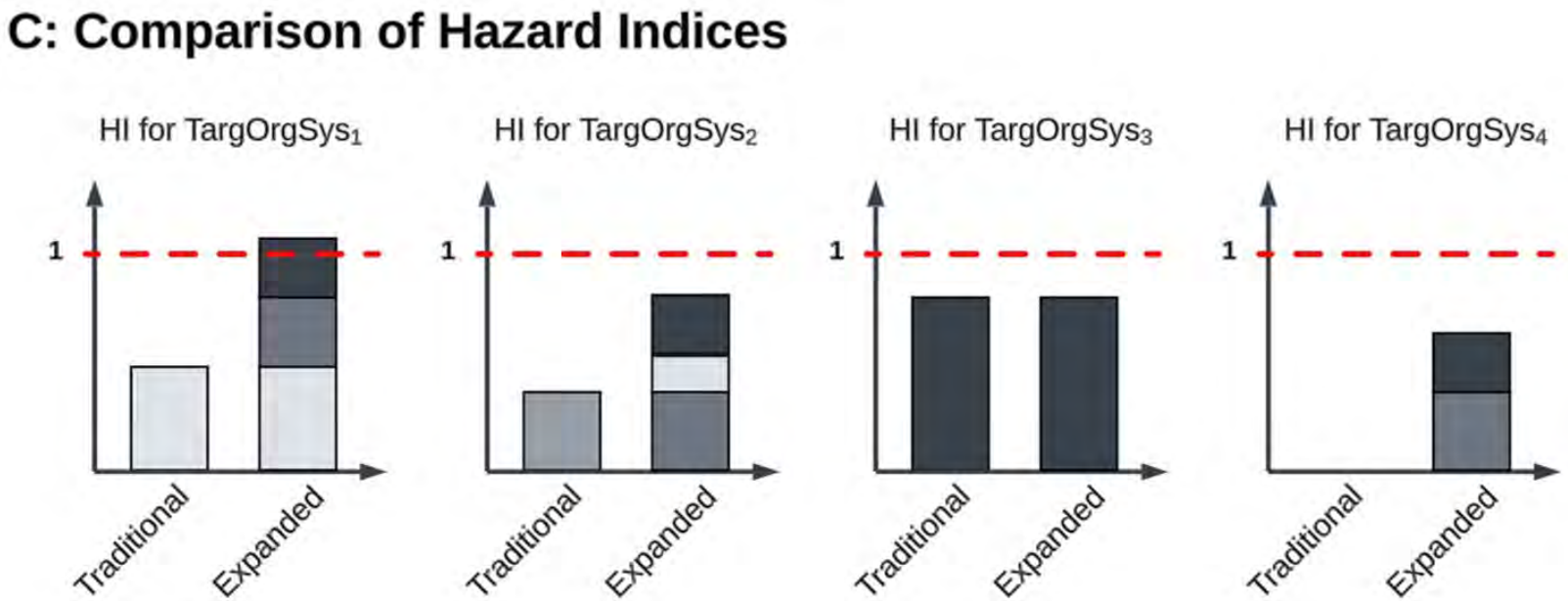
B: Expanded

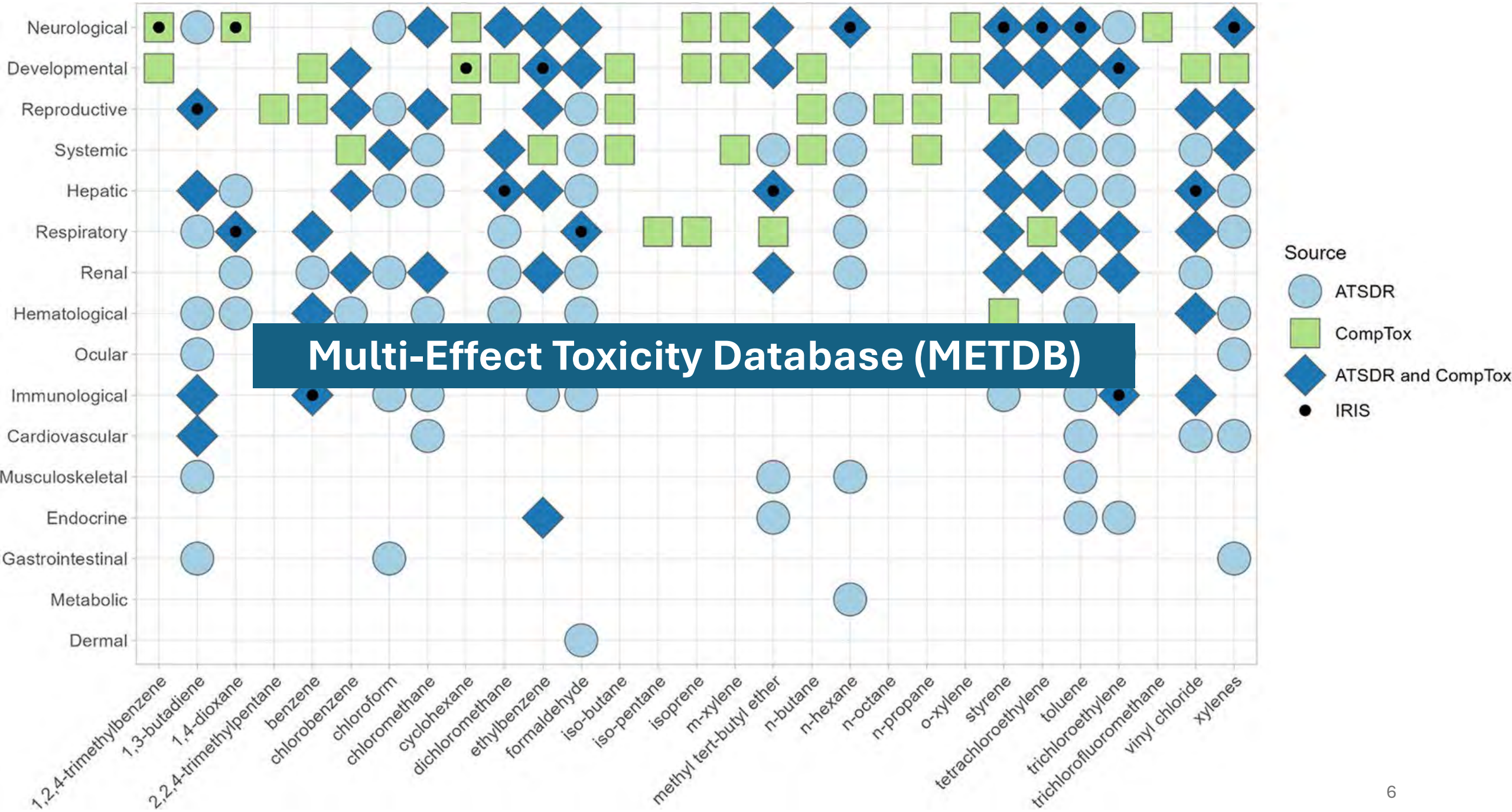




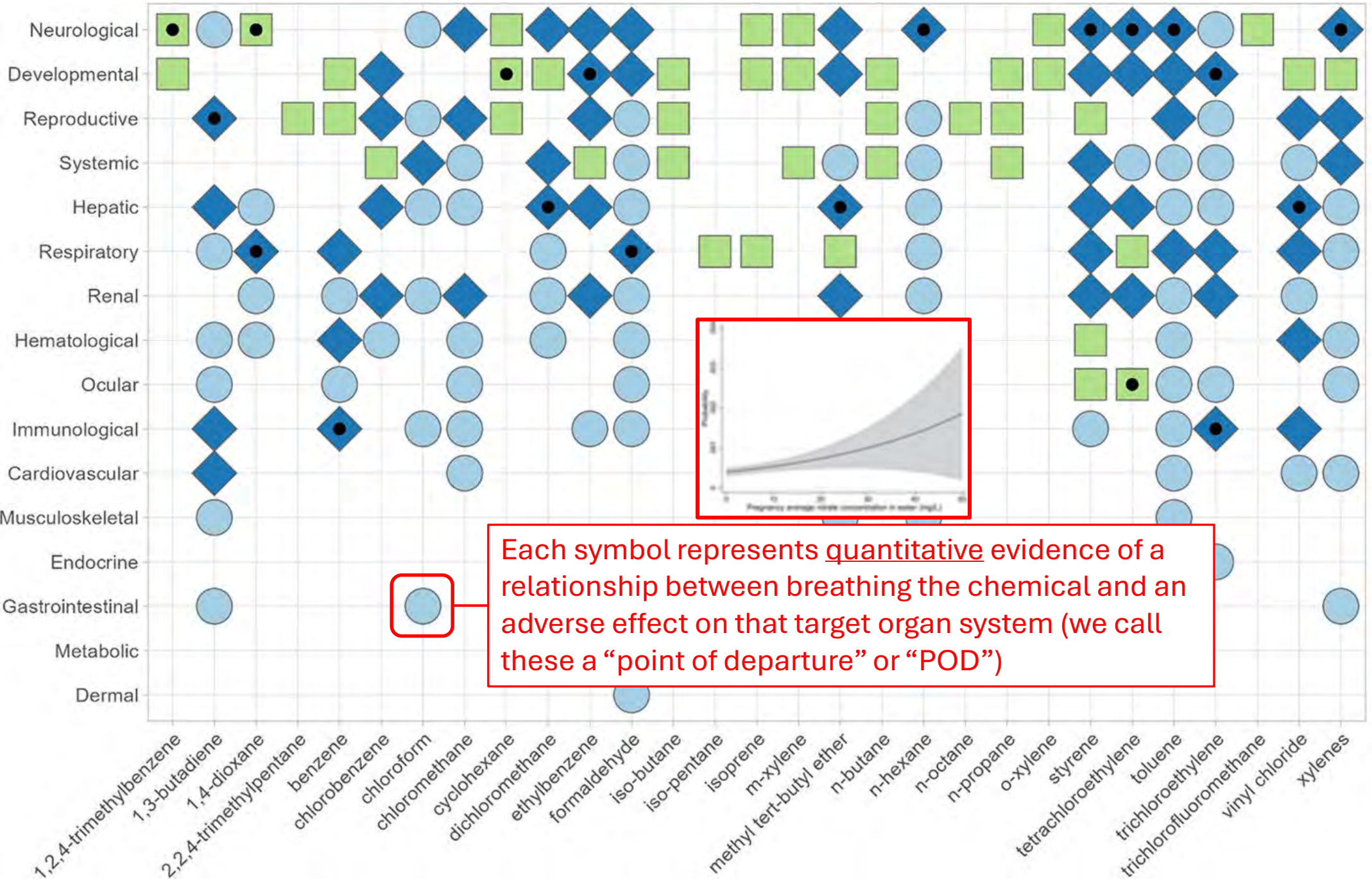
All of the organ systems affected by each chemical are considered


A: Traditional
B: Expanded
Chem1
Chem2
Chem3
TargOrgSys1
TargOrgSys2
TargOrgSys3
TargOrgSys4

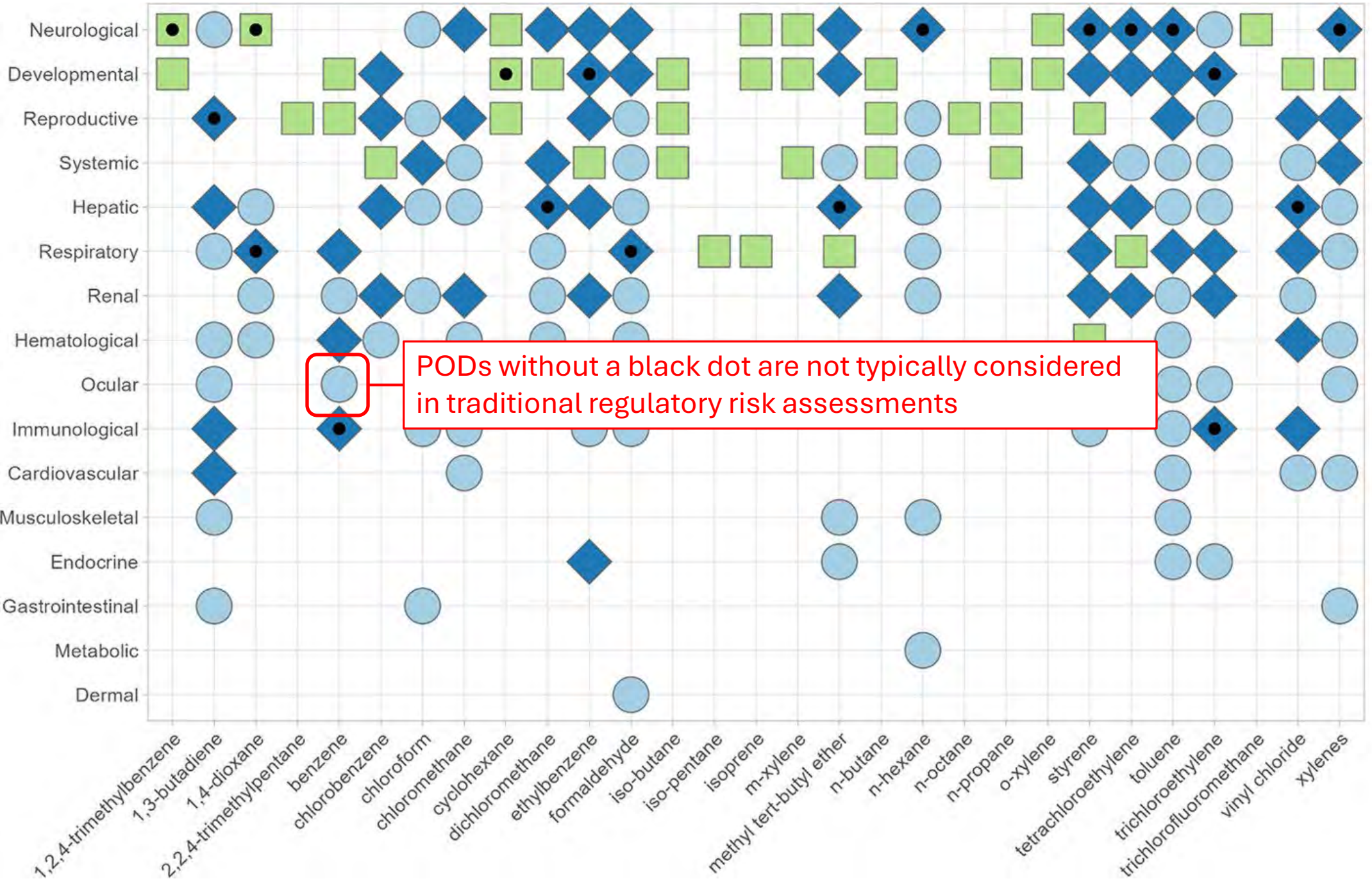

C: Comparison of Hazard Indices
HI for TargOrgSys1
HI for TargOrgSys2
HI for TargOrgSys3
HI for TargOrgSys4
1
Traditional
Expanded

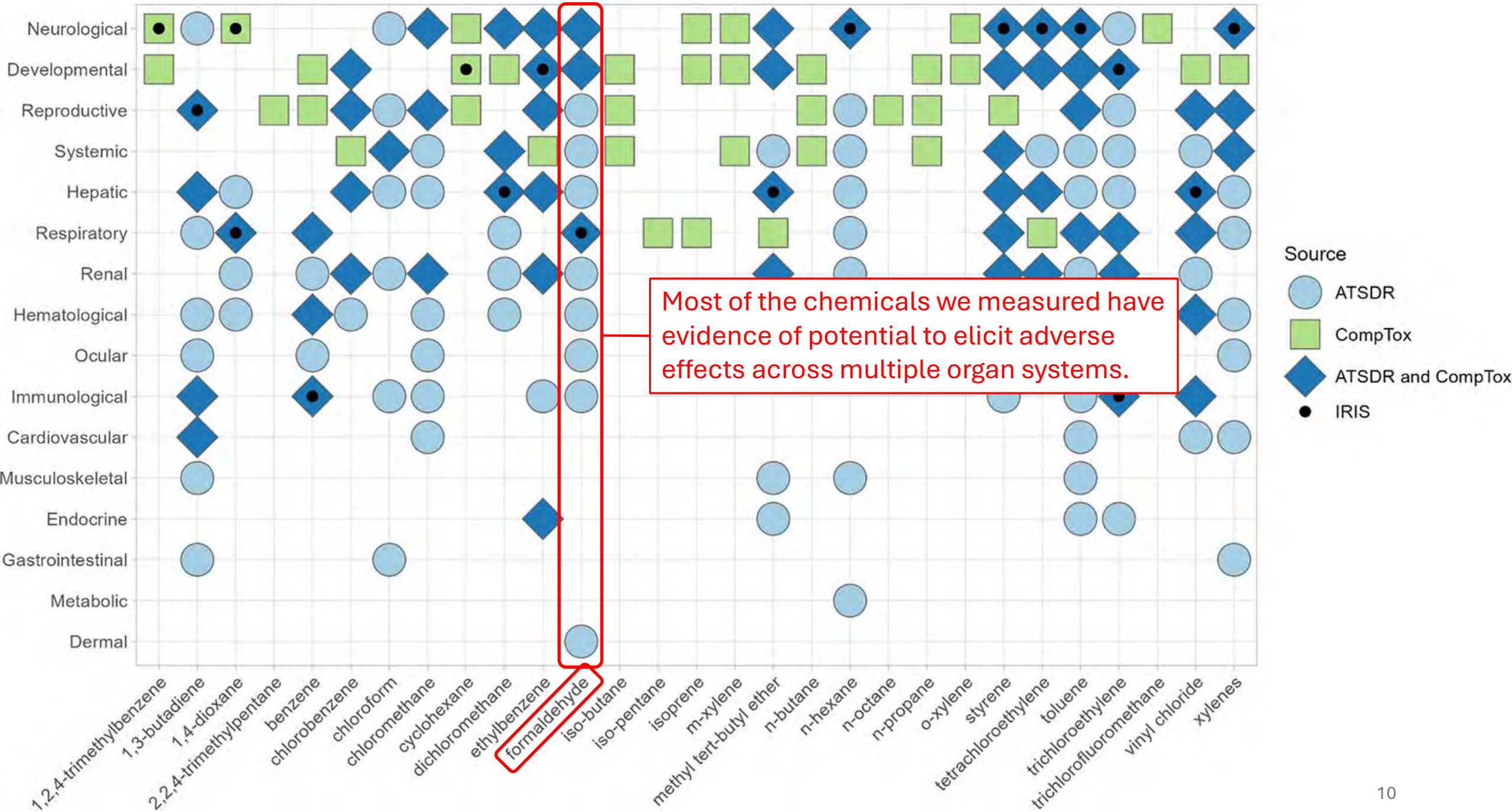


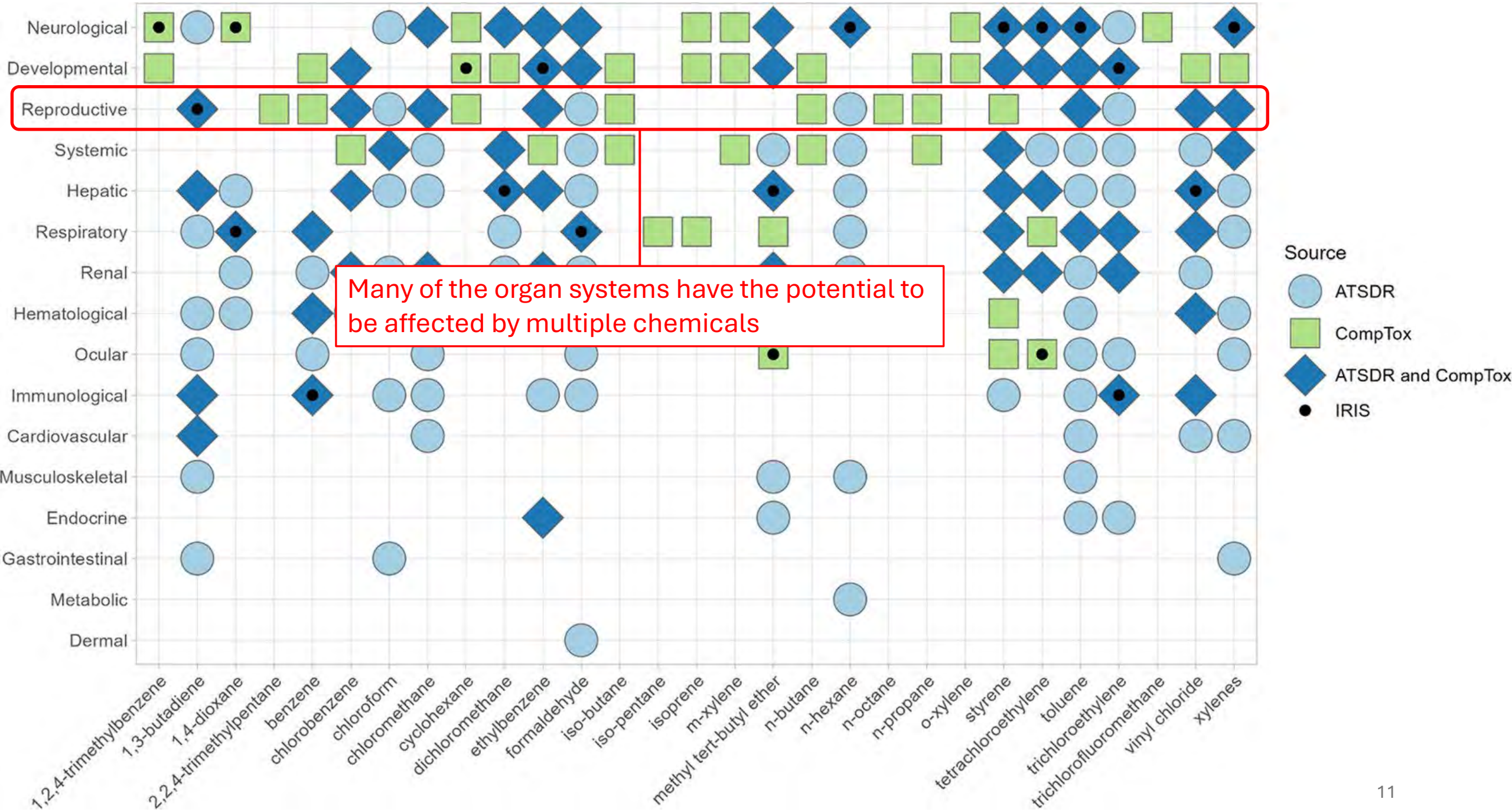
Multi-Effect Toxicity Database (METDB)

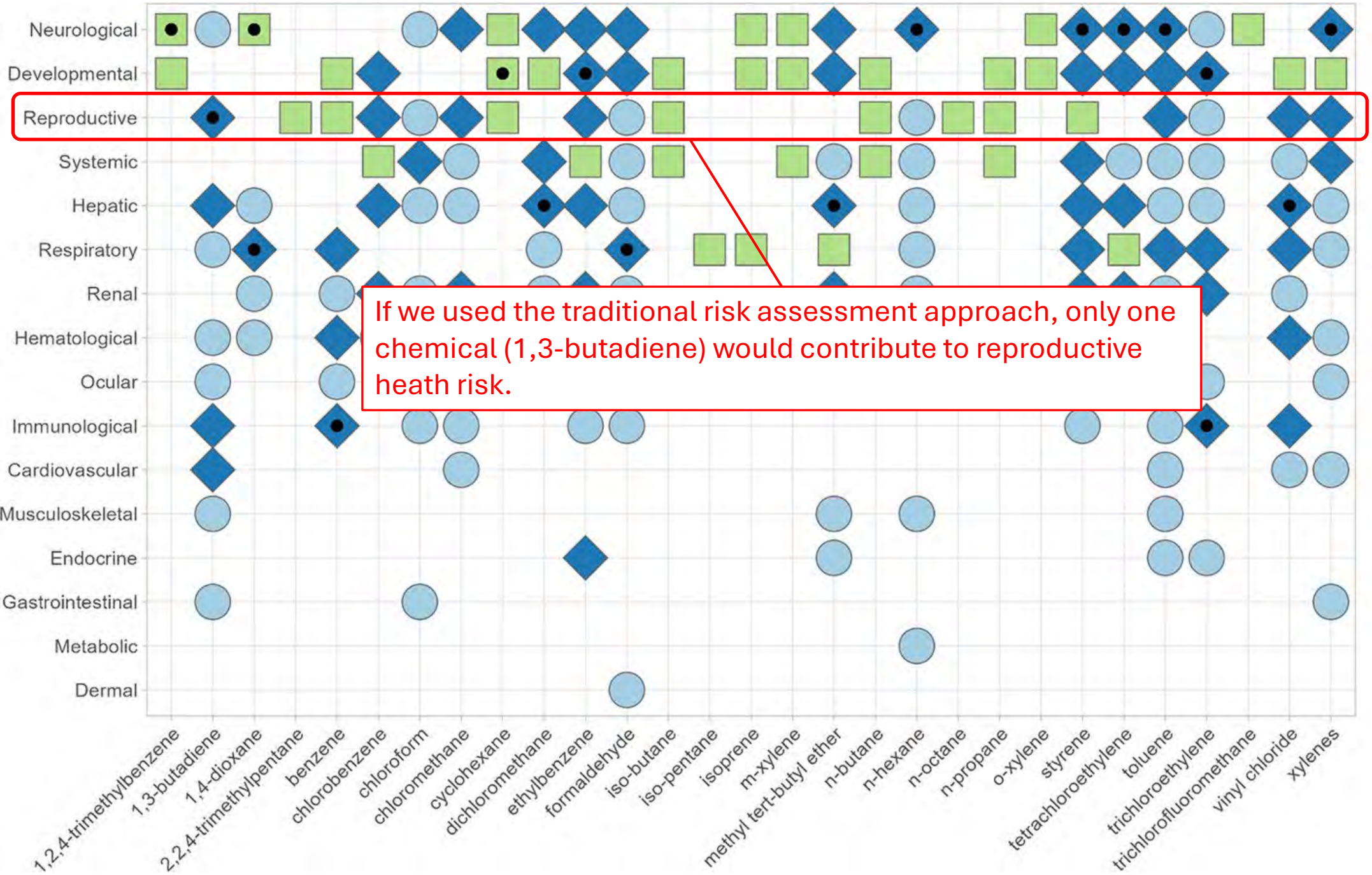

Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS
Each symbol represents quantitative evidence of a relationship between breathing the chemical and an adverse effect on that target organ system (we call these a “point of departure” or “POD”)

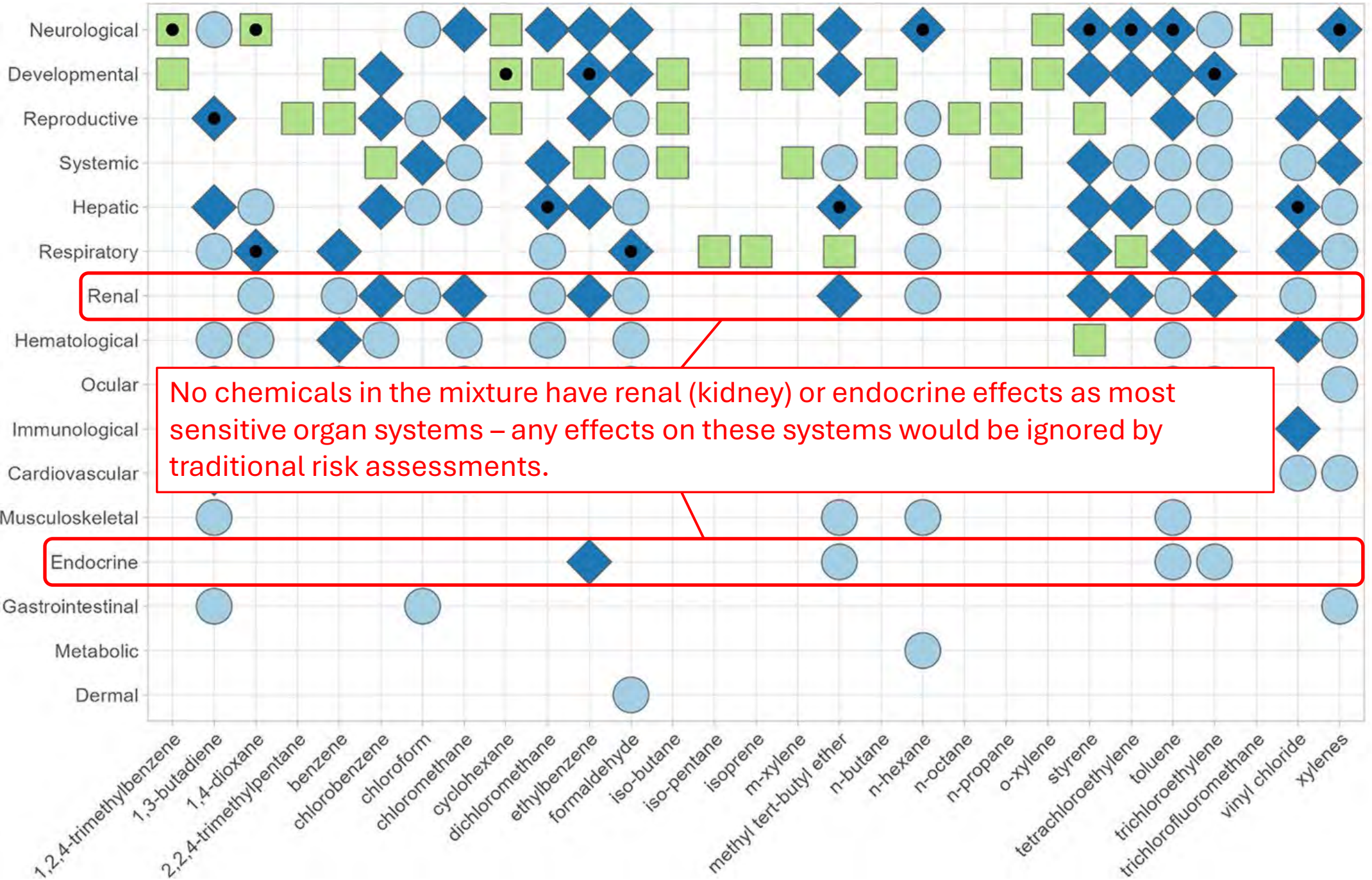

Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
PODs that have a black dot in them would be used as the basis for the traditional regulatory approach to risk assessment.
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS

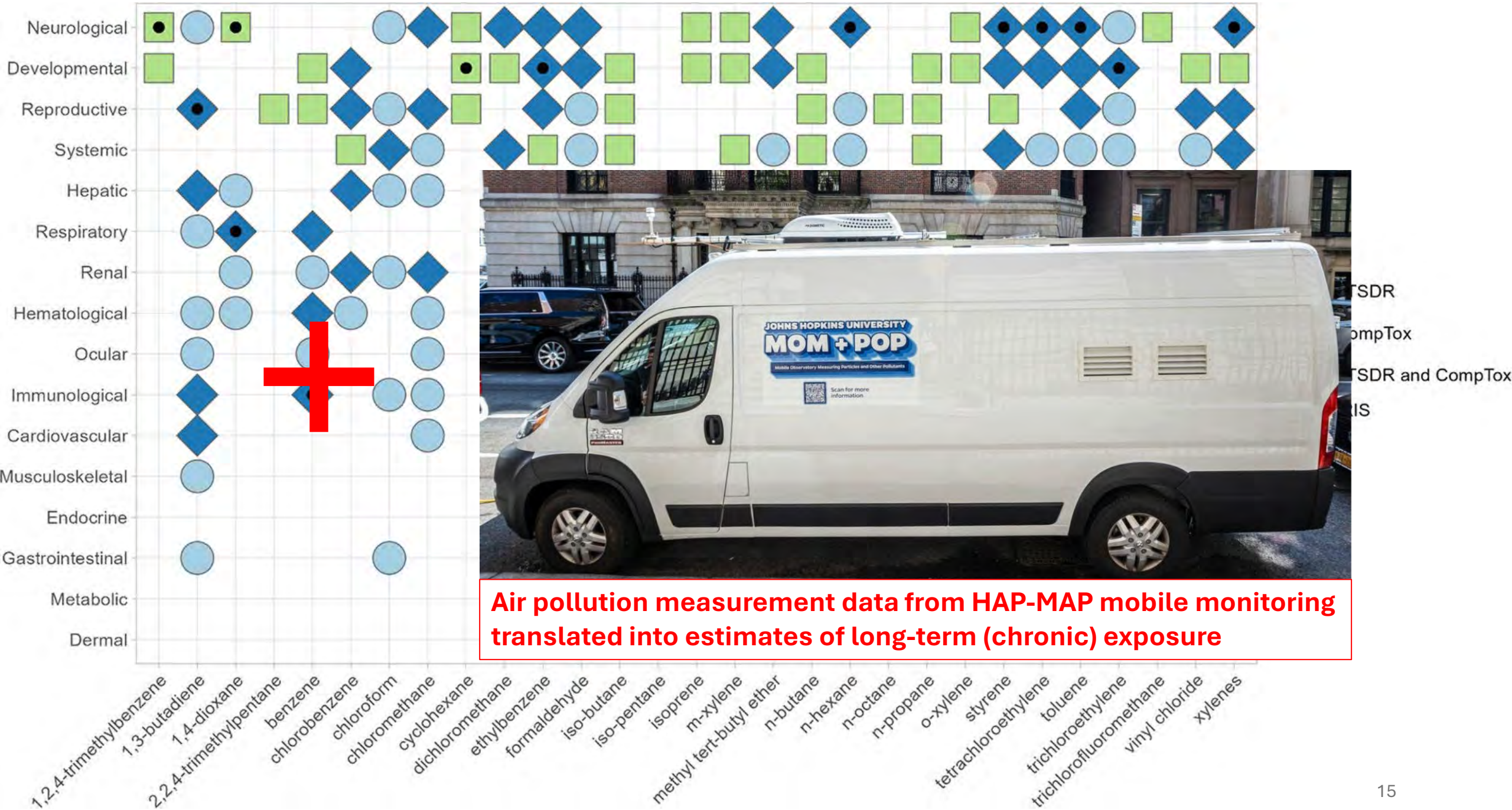

Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
PODs without a black dot are not typically considered in traditional regulatory risk assessments
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS


Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
Most of the chemicals we measured have evidence of potential to elicit adverse effects across multiple organ systems.
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS


Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
Many of the organ systems have the potential to be affected by multiple chemicals
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS


Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
If we used the traditional risk assessment approach, only one chemical (1,3-butadiene) would contribute to reproductive heath risk.
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS


Neurological
Developmental
Reproductive
Systemic
Hepatic
Respiratory
Renal
Hematological
Ocular
Immunological
Cardiovascular
Musculoskeletal
Endocrine
Gastrointestinal
Metabolic
Dermal
No chemicals in the mixture have renal (kidney) or endocrine effects as most sensitive organ systems – any effects on these systems would be ignored by traditional risk assessments.
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
m-xylene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
Source
ATSDR
CompTox
ATSDR and CompTox
IRIS



Air pollution measurement data from HAP-MAP mobile monitoring translated into estimates of long-term (chronic) exposure

Characterizing risk for each chemical

We want to determine whether a population's exposures will increase their risk of an adverse effect

We do this by calculating a Hazard Quotient (HQ) for each chemical-organ system combination

The HQ is calculated by dividing the chemical's concentration in air by the corresponding target toxicity concentration (from METDB)

Interpretation:

HQ ≥ 1: Increased risk of effect

HQ < 1: Effect assumed unlikely

Characterizing cumulative non-cancer risk

For each organ system in the body, we want to account for the collective action of all of the chemicals in the mixture.

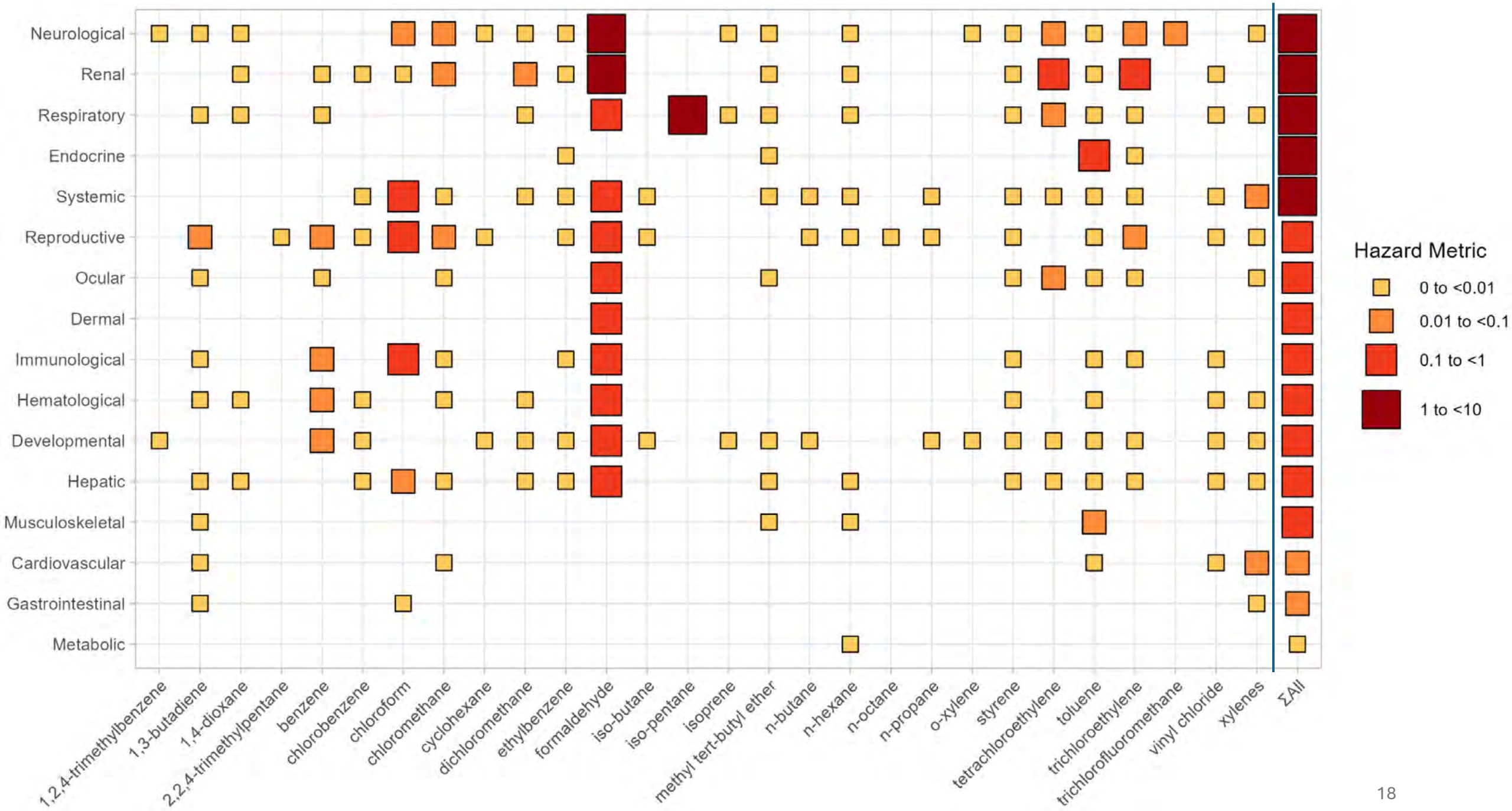
To do this, we calculate a Hazard Index (HI) for each organ system.

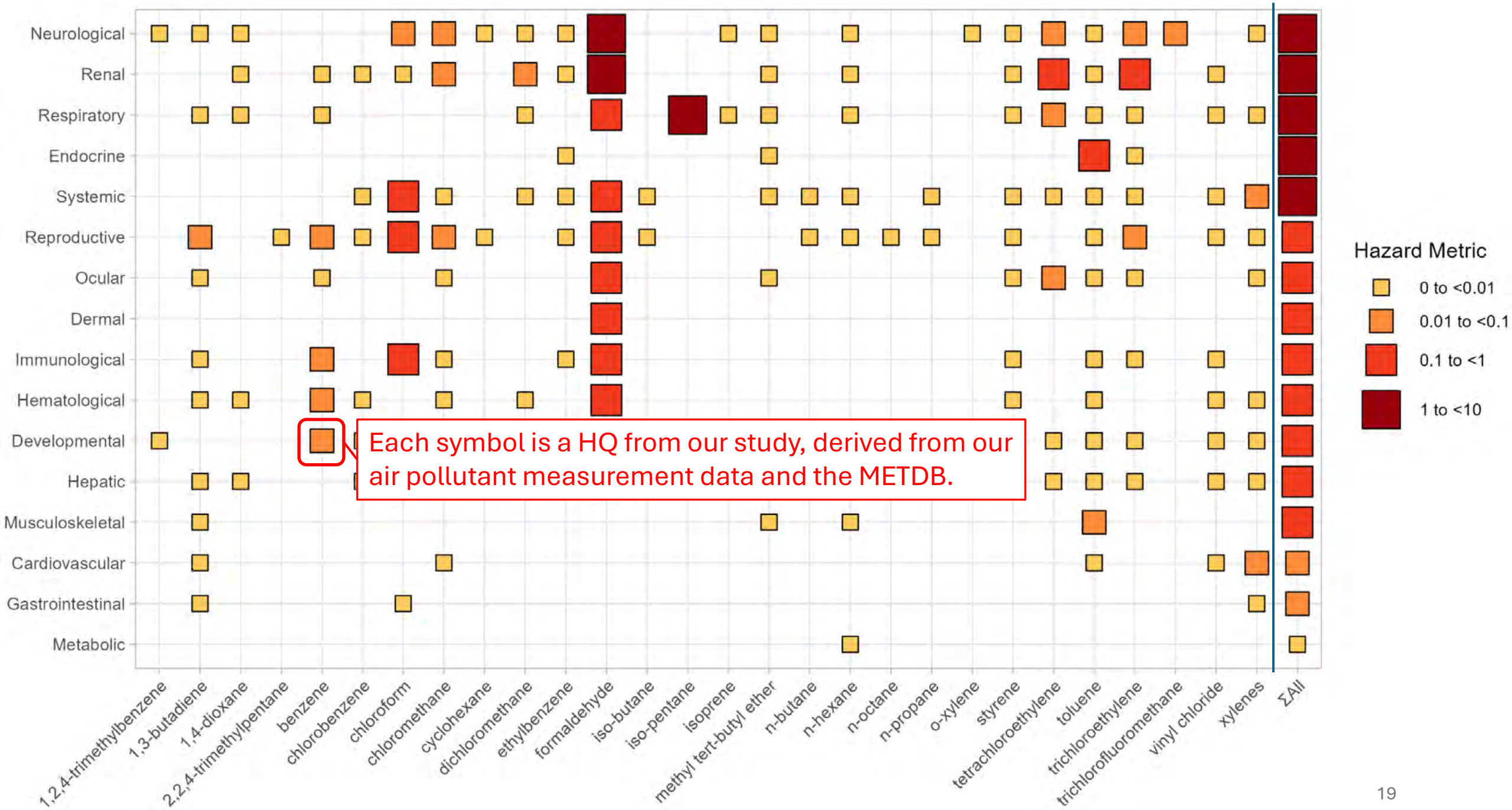
The HI is the sum of all of the HQs for a given organ system.

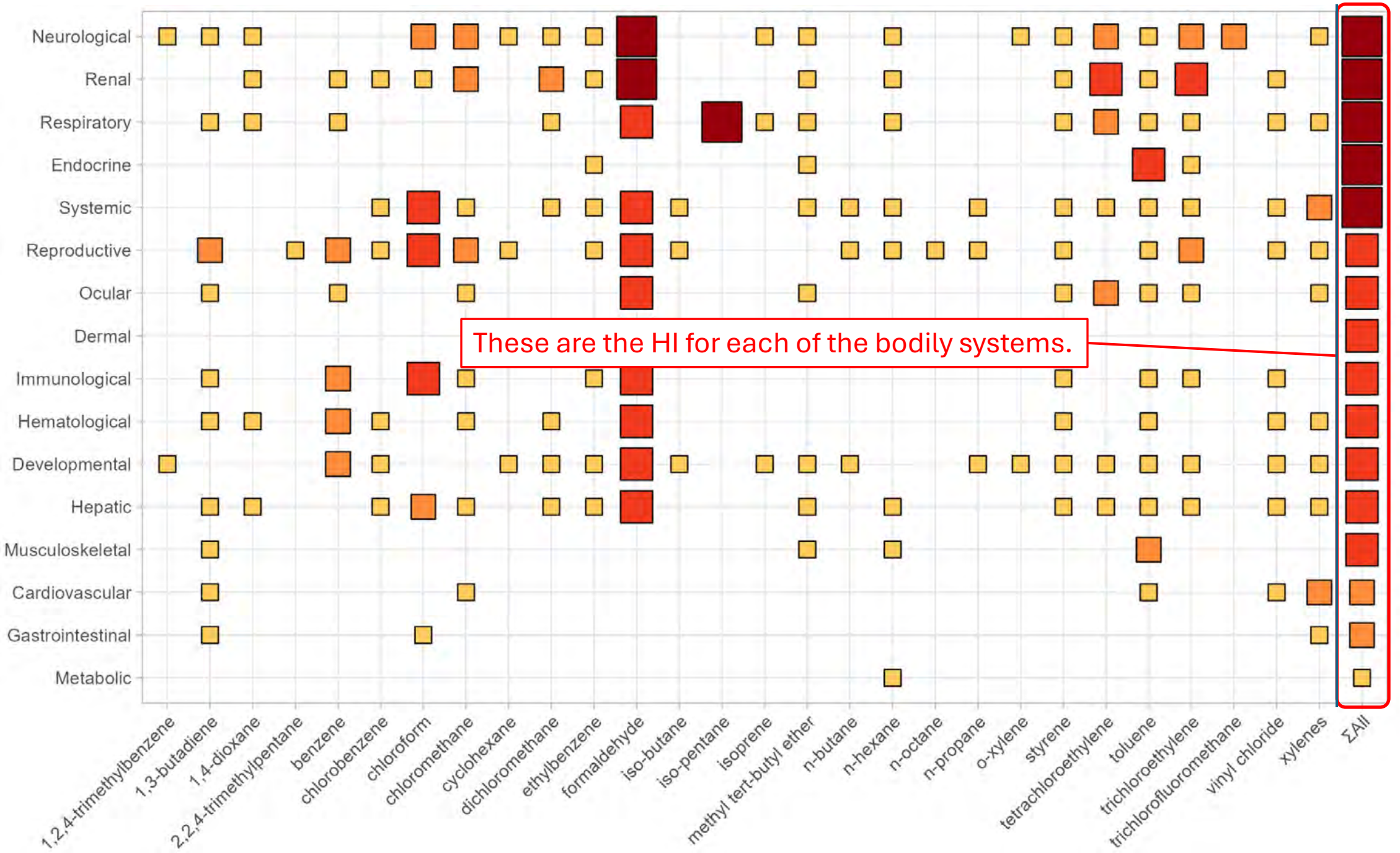
Interpretation:

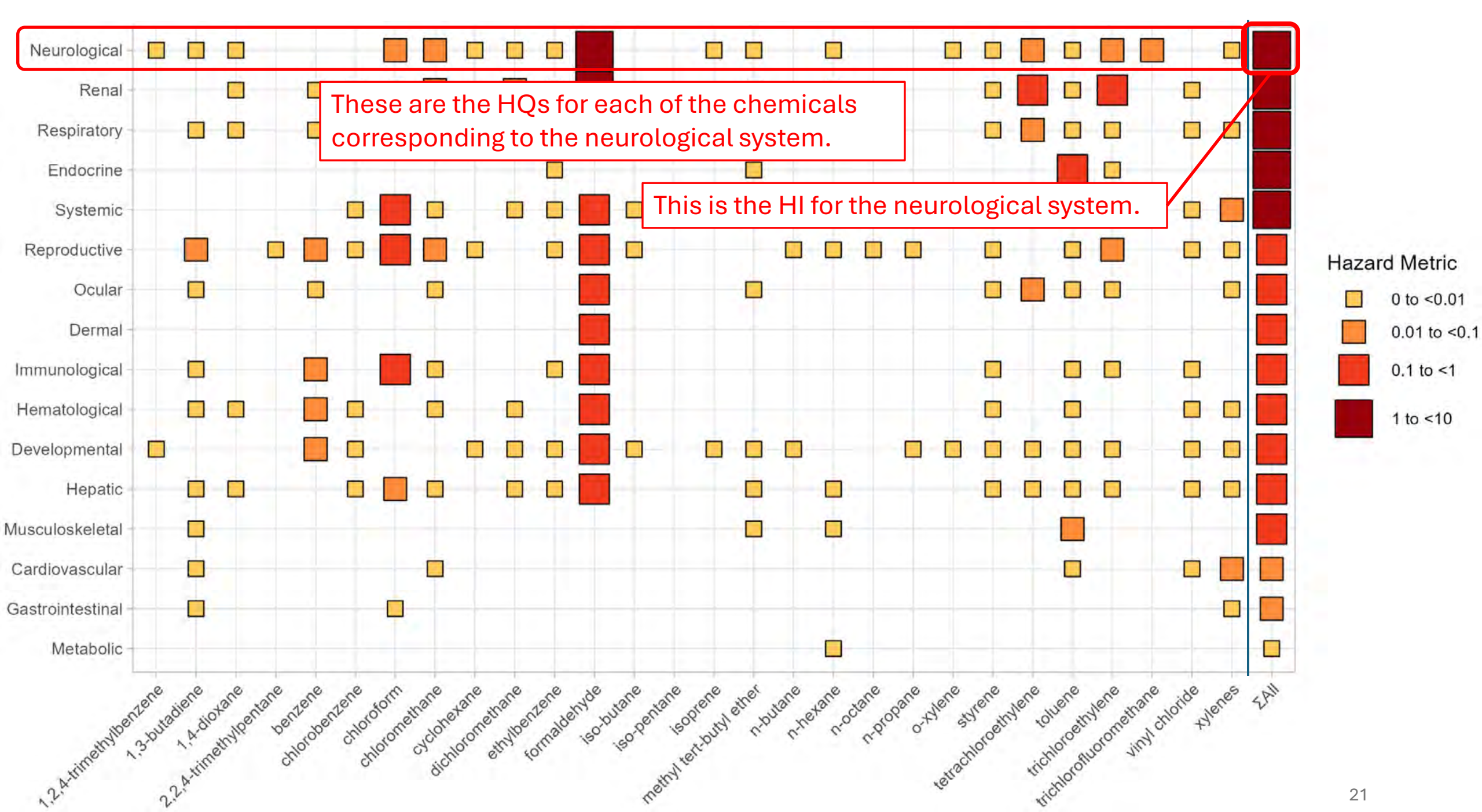
HI ≥ 1: Increased risk of effect

HI < 1: Effect assumed unlikely


Neurological
Renal
Respiratory
Endocrine
Systemic
Reproductive
Ocular
Dermal
Immunological
Hematological
Developmental
Hepatic
Musculoskeletal
Cardiovascular
Gastrointestinal
Metabolic
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
ΣAll
Hazard Metric
0 to <0.01
0.01 to <0.1
0.1 to <1
1 to <10


Neurological
Renal
Respiratory
Endocrine
Systemic
Reproductive
Ocular
Dermal
Immunological
Hematological
Developmental
Hepatic
Musculoskeletal
Cardiovascular
Gastrointestinal
Metabolic
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
ΣAll
Each symbol is a HQ from our study, derived from our air pollutant measurement data and the METDB.
Hazard Metric
0 to <0.01
0.01 to <0.1
0.1 to <1
1 to <10


Neurological
Renal
Respiratory
Endocrine
Systemic
Reproductive
Ocular
Dermal
Immunological
Hematological
Developmental
Hepatic
Musculoskeletal
Cardiovascular
Gastrointestinal
Metabolic
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
ΣAll
These are the HI for each of the bodily systems.
Hazard Metric
0 to <0.01
0.01 to <0.1
0.1 to <1
1 to <10


These are the HQs for each of the chemicals corresponding to the neurological system.
This is the HI for the neurological system.
Neurological
Renal
Respiratory
Endocrine
Systemic
Reproductive
Ocular
Dermal
Immunological
Hematological
Developmental
Hepatic
Musculoskeletal
Cardiovascular
Gastrointestinal
Metabolic
1,2,4-trimethylbenzene
1,3-butadiene
1,4-dioxane
2,2,4-trimethylpentane
benzene
chlorobenzene
chloroform
chloromethane
cyclohexane
dichloromethane
ethylbenzene
formaldehyde
iso-butane
iso-pentane
isoprene
methyl tert-butyl ether
n-butane
n-hexane
n-octane
n-propane
o-xylene
styrene
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane
vinyl chloride
xylenes
ΣAll
Hazard Metric
0 to <0.01
0.01 to <0.1
0.1 to <1
1 to <10

(HI)

Table 2. Comparison of hazard indices calculated using traditional (IRIS RfC only) and expanded (METDB) approaches to cumulative risk assessment.

	Hazard indices[a]				
End point	Traditional approach (IRIS RfCs[c] only)	Expanded approach (METDB[b])	CompTox excluded	Chronic assumption	Total uncertainty factor <3,000
Neurological	0.04				
Renal	—				
Respiratory	0.38				
Endocrine	—				
Systemic	—				
Reproductive	0.09				
Ocular	0.02				
Dermal	—				
Immunological	0.10				
Hematological	—				
Developmental	0.05				
Hepatic	0.00				
Musculoskeletal	—				
Cardiovascular	—				
Gastrointestinal	—				
Metabolic	—				

No HI>1

Note:—, no data; IRIS, Integrated Risk Information System; RfC, reference concentration; METDB, Mult-Effect Toxicity Database; US EPA, US Environmental Protection Agency.
[a]A Hazard index above 1 indicates adverse effects are possible.
[b]METDB, multi-effects toxicity database.
[c]IRIS RfC, Reference concentrations from the US EPA's IRIS.

Interpretation?
No effects expected.

(HI)

Table 2. Comparison of hazard indices calculated using traditional (IRIS RfC only) and expanded (METDB) approaches to cumulative risk assessment.

	Hazard indices[a]				
End point	Traditional approach (IRIS RfCs[c] only)	Expanded approach (METDB[b])	CompTox excluded	Chronic assumption	Total uncertainty factor <3,000
Neurological	0.04	9.22[a]			
Renal	—	4.16[a]			
Respiratory	0.38	1.54[a]			
Endocrine	—	1.43[a]			
Systemic	—	1.09[a]			
Reproductive	0.09	0.74			
Ocular	0.02	0.64			
Dermal	—	0.60			
Immunological	0.10	0.58			
Hematological	—	0.46			
Developmental	0.05	0.44			
Hepatic	0.00	0.40			
Musculoskeletal	—	0.10			
Cardiovascular	—	0.02			
Gastrointestinal	—	0.01			
Metabolic	—	0.01			

Note:—, no data; IRIS, Integrated Risk Information System; RfC, reference concentration; METDB, Mult-Effect Toxicity Database; US EPA, US Environmental Protection Agency.
[a]A Hazard index above 1 indicates adverse effects are possible.
[b]METDB, multi-effects toxicity database.
[c]IRIS RfC, Reference concentrations from the US EPA's IRIS.

No HI>1

Interpretation?
No effects expected.

HI>1

Interpretation?
Increased risk of neurological, renal, respiratory, endocrine, and systemic outcomes. Management of risk likely warranted.

What it means

- Regulatory risk assessments often rely on lower quality air pollutant measurement data and overly simplistic consideration of complex chemical mixtures

- Our novel approach to characterizing non-cancer risks paints a more holistic and realistic picture of burdens faced by fenceline communities

- A fuller characterization of these cumulative burdens could support management of risks for fenceline communities that truly reflect the science and protect public health.

Research

Environmental Health Perspectives

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP14696.

Improving Methodologies for Cumulative Risk Assessment: A Case Study of Noncarcinogenic Health Risks from Volatile Organic Compounds in Fenceline Communities in Southeastern Pennsylvania

Andrea A. Chiger,[1,2] Carolyn Gigot,[1] Ellis S. Robinson,[1] Mina W. Tehrani,[1] Megan Claflin,[3] Edward Fortner,[3] Harald Stark,[3] Jordan Krechmer,[3] Manjula R. Canagaratna,[3] Scott Herndon,[3] Tara I. Yacovitch,[3] Kirsten Koehler,[1] Ana M. Rule,[1] Thomas A. Burke,[1,2,4] Mary A. Fox,[1,2,4] Peter F. DeCarlo,[1] and Keeve E. Nachman[1,2,4]

[1]Department of Environmental Health and Engineering, Johns Hopkins University, Baltimore, Maryland, USA
[2]Risk Sciences and Public Policy Institute, Johns Hopkins University, Baltimore, Maryland, USA
[3]Aerodyne Research Inc., Billerica, Massachusetts, USA
[4]Department of Health Policy and Management, Johns Hopkins University, Baltimore, Maryland, USA

Background: Cumulative risk assessment (CRA) is key to characterizing health risks in fenceline and disadvantaged communities, which face environmental pollution and challenging socioeconomic conditions. Traditional approaches for inclusion of mixtures in CRA are limited and only assess the most sensitive target organ system for each chemical.

Methods: We developed an expanded approach to cumulative risk assessment that considers all known target organ systems associated with a chemical. Specifically, we created a multi-effects toxicity database by *a*) compiling toxicological and epidemiological data from the Agency for Toxic Substances and Disease Registry's (ATSDR) Toxicological Profiles and the Environmental Protection Agency (US EPA) CompTox Chemicals Dashboard; *b*) developing a tiering system to prioritize identified data for use in developing toxicity values; and *c*) accounting for uncertainty to create toxicity values for additional target organ systems. We demonstrated differences between the traditional approach and our expanded approach by using state-of-the-art mobile

Thank you!

Keeve E. Nachman, PhD, MHS (he/his)
Robert S. Lawrence Professor of Environmental Health and Engineering
Johns Hopkins Bloomberg School of Public Health
615 North Wolfe Street, Room W-7007
Baltimore, MD 21205-2179
knachman@jhu.edu
Phone:410-502-7576
https://www.jhsph.edu/faculty/directory/profile/2394/keeve-e-nachman

AGENDA: 3

Cumulative Risk Assessment and Air Quality

Rima Woods, PhD

Air Toxicology and Risk Assessment Section

Office of Environmental Health Hazard Assessment

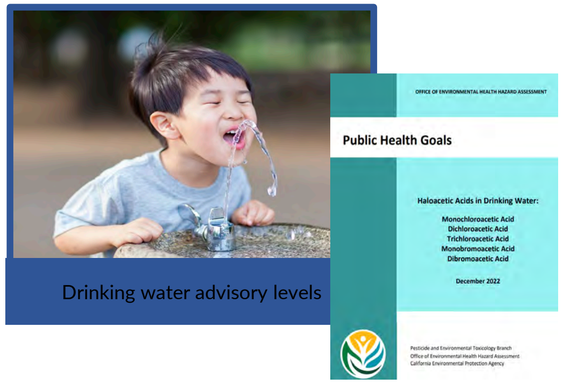
Outline

- Introduction to OEHHA
- Development of Health Guidance Values for air toxics
- Application of Hazard Index approach in our work
- Cumulative Impacts
- New Approach Methodologies (NAMs)
- Opportunities for collaboration

OEHHA's mission is to protect and enhance the health of Californians and our state's environment through scientific evaluations that inform, support and guide regulatory and other actions.

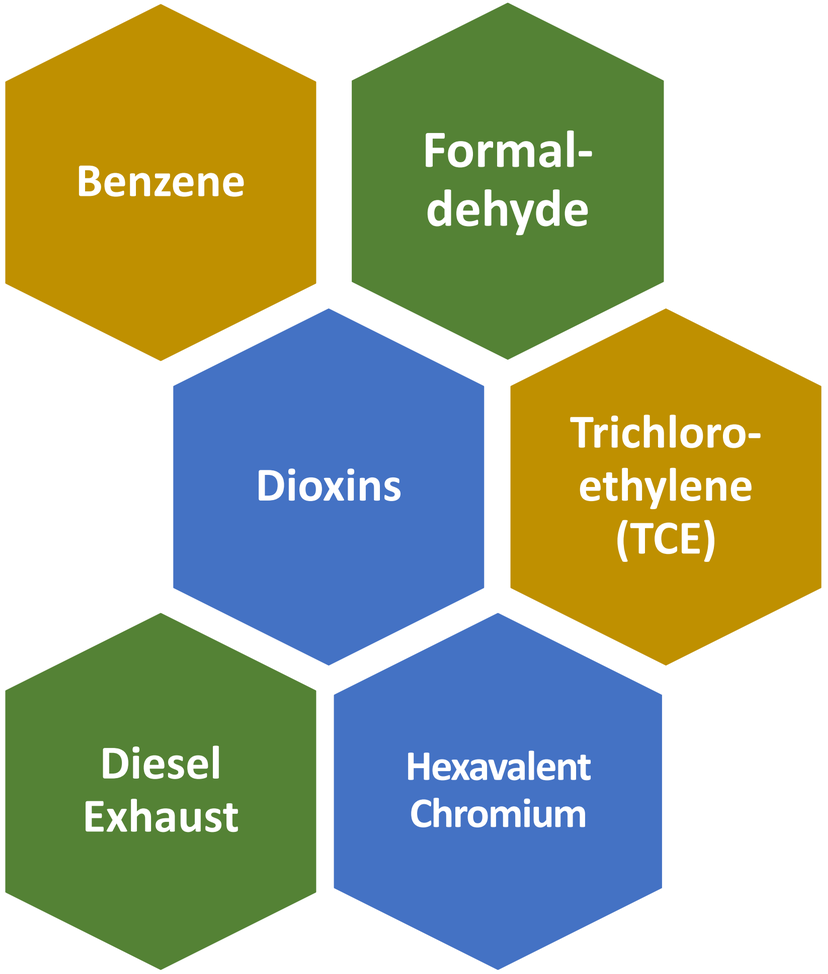
OEHHA: What we do

- Lead state agency for conducting human health risk assessments for contaminants in air, water, and soil (cancer and noncancer)
- Implements Proposition 65 (the state's right-to-know law)
- Epidemiological research on health effects of heat and air pollution
- Climate change research and evaluations
- Cumulative impacts and community science



Air Toxics Health Guidance Values

- OEHHA evaluates airborne chemicals that may pose a present or potential hazard to human health including cancer
- 200+ air chemicals have been evaluated for cancer and non-cancer health effects to date
- OEHHA develops and adopts health guidance values for risk analysis purposes for the State of California
  - Reference Exposure Levels (RELs) are used to calculate risk of noncancer health effects
  - Cancer Slope Factors and Unit Risks are used in the cancer risk assessment of carcinogenic chemicals released into the air



Air Toxics "Hot Spots" Program

- This program informs and protects communities from air pollution emitted by nearby stationary sources

Facilities that release chemicals into the air must report emissions → **Emissions are used to determine risk to people living and working nearby** → **The public is notified of any excess risk, and corrective actions may be taken**

- OEHHA reviews health risk assessments submitted by facilities and develops guidelines for conducting health risk assessments
  - OEHHA's health guidance values are used to estimate risk
  - Hazard Index approach is used to estimate the risk of noncancer health effects

Development of noncancer RELs

- Derived according to methodologies contained in Technical Support Document for Developing Noncancer Reference Exposure Levels (2008)
  - Most sensitive endpoint (i.e., lowest dose at which statistically/biologically significant health effect is observed) – identify target organ
  - Apply uncertainty factors → REL
  - If additional endpoints are within a factor of ~3, the included may also be included as target organs

TABLE H1. EXAMPLES OF TARGET ORGANS OR SYSTEMS USED IN ACUTE, 8-HOUR AND CHRONIC HAZARD INDEX CALCULATIONS

Hazard Index target organ catergories	Specific health effects currently used in deriving at least one acute REL	Specific health effects currently used in deriving at least one chronic REL
Hematological System	Hemolysis; anemia; platelet abnormalities; adverse effects on hematopoietic stem cells	Lowered red and white blood cell counts
Cardiovascular System	Aggravation of angina	Elevated carboxyhemoglobin levels
Nervous System	Abnormal electroencephalograph (EEG) results; altered performance on neurobehavioral or neuropsychological tests; lightheadedness; clinical neurological exam; headache	Abnormal EEG results; astrogliosis; altered performance on neurobehavioral tests; tremor; lightheadedness; memory disturbances; headache
Eyes	Irritation; histological changes to eye tissue	Irritation of eyes
Alimentary Tract	Hepatotoxicity; nausea; vomiting	Hepatotoxicity; kidney lesions; urinary porphyrins; liver enzymes
Immune System	Abnormal lymphocyte proliferation; impaired host resistance to infection	Macrophage hyperplasia
Reproductive	Anovulation; decreased ovulation, preimplantation loss; altered copulatory behavior; azoospermia; oligospermia; spontaneous abortion	Testicular degeneration

Development of Noncancer RELs

- Most RELs list a single target organ, but several have two or more

OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary[1]					
Substance	REL type[1]	Inhalation REL (ug/m^3)	Oral REL (ug/kg BW^{-day})	Hazard Index Target Organs	Species[2]
Dichlorobenzene (1,4-) (106-46-7)	**A**	8,700		Development	R
	8	5		Respiratory system; Male Reproductive system	R, M
	C	10		Respiratory system; Male Reproductive system	R, M
Trimethylbenzenes (25551-13-7): 1,3,5- (108-67-8), 1,2,4- (95-63-6), 1,2,3- (526-73-8)	**A**	2400[4, 5]		Nervous System	R
	8	8[4, 5]		Nervous system	R
	C	4[4, 5]		Nervous system	R

Application of Hazard Index – Hot Spots Health Risk Assessments

- Stationary facilities may be required to conduct an HRA
  - Identify and quantify chemicals emitted
  - Specify Target Organ(s) for each chemical

Substance Name	CAS No.	Acute Target Organs													Chronic Target Organs													8-Hour Chronic Target Organs												
		CV	CNS	IMMUN	KIDN	GILV	REPRO	RESP	SKIN	EYE	BONE	ENDO	HEM	ODOR	CV	CNS	IMMUN	KIDN	GILV	REPRO	RESP	SKIN	EYE	BONE	ENDO	HEM	ODOR	CV	CNS	IMMUN	KIDN	GILV	REPRO	RESP	SKIN	EYE	BONE	ENDO	HEM	ODOR
Cumene	98828																																							
Toluene	108883		X					X		X													X													X				
Ethyl Benzene	100414																	X	X	X					X															
Xylenes	1330207		X					X		X						X					X		X																	
Naphthalene	91203																				X																			
p-DiClBenzene	106467															X		X	X		X																			
o-Xylene	95476		X					X		X						X					X		X																	
TriMeBenzns	25551137																																							
2MeNaphthalene	91576																																							
Diethanolamine	111422																				X						X													
Chlorine	7782505							X		X											X																			
Acrolein	107028							X		X											X															X				
Benzene	71432			X			X						X													X												X	

Application of Hazard Index – Hot Spots Health Risk Assessments

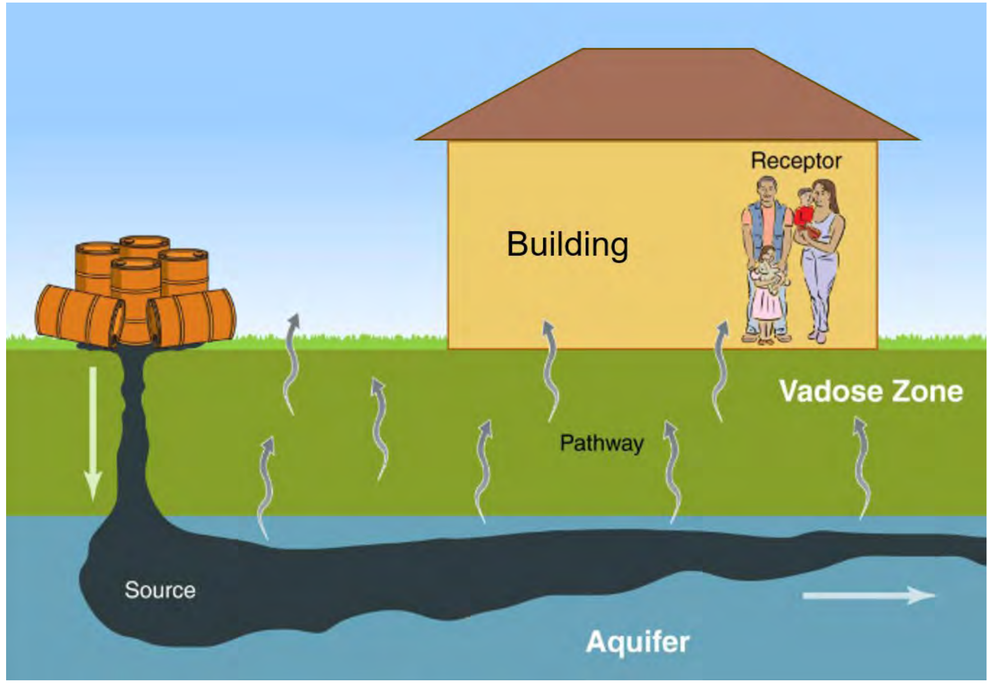
- Stationary facilities may be required to conduct an HRA
  - Calculate acute, 8-hour, and chronic Hazard Index for residents and off-site workers
  - Current methods limit the Hazard Index to a **single REL value** per chemical/exposure duration

Chemical Name	CAS	Average Annual Concentration (µg/m^3)	Cardiovascular System	Central Nervous System	Immune System	Kidney	GILV	Reproductive System	Respiratory System	Skin	Eye	Bone/ Teeth	Endocrine System	Blood	Odor	Max Target Organ	Total Chronic HI @ Max Target Organ	Contribution[1]
Arsenic	7440382	3.48E-04	2.26E+00	2.26E+00	0.00E+00	0.00E+00	0.00E+00	2.26E+00	2.26E+00	2.26E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		2.26E+00	95.74%
Manganese	7439965	1.39E-03	0.00E+00	1.55E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Beryllium	7440417	2.03E-06	0.00E+00	0.00E+00	2.90E-04	0.00E+00	1.30E-05	0.00E+00	2.90E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		2.90E-04	0.01%
Mercury	7439976	1.30E-05	0.00E+00	1.78E-03	0.00E+00	1.78E-03	0.00E+00	1.78E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
2,2,4TriMePentn	540841	1.15E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Hexane	110543	8.60E-05	0.00E+00	1.23E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
DieselExhPM	9901	4.10E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		8.20E-04	0.03%
Cr(VI)	18540299	4.71E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.72E-07	0.00E+00		2.36E-07	0.00%
Lead	7439921	4.43E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Aluminum	7429905	1.49E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Chromium	7440473	4.41E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Cadmium	7440439	1.09E-06	0.00E+00	0.00E+00	0.00E+00	1.14E-04	0.00E+00	0.00E+00	5.46E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		5.46E-05	0.00%
Copper	7440508	3.29E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Nickel	7440020	3.68E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.25E-04	2.63E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E-02	0.00E+00		2.63E-02	1.11%
Selenium	7782492	2.77E-06	3.12E-05	3.12E-05	0.00E+00	0.00E+00	3.12E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Zinc	7440666	4.58E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Silica, Crystln	1175	1.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.18E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		6.18E-02	2.62%
Barium	7440393	4.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Cobalt	7440484	2.85E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
Acrolein	107028	3.17E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.06E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		9.06E-06	0.00%
1,3-Butadiene	106990	1.46E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.31E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
1,2,4TriMeBenze	95636	2.22E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00%
		Total:	**2.26E+00**	**2.28E+00**	**2.90E-04**	**1.89E-03**	**4.53E-05**	**2.26E+00**	**2.36E+00**	**2.26E+00**	**1.52E-06**	**0.00E+00**	**6.14E-08**	**2.80E-02**	**0.00E+00**		**2.36E+00**	**100.00%**

1. Contribution by pollutant is based on the target organ with the maximum chronic hazard.

Application of Hazard Index – Contaminated Site Assessments

- OEHHA provides risk assessment and toxicological support for about 100 sites undergoing investigation and cleanup each year.
- Examples of sites: Dry cleaners; aerospace manufacturing, metal plating; printing facilities
- Common chemicals of concern: Dry cleaning related chemicals, such as tetrachloroethene (PCE) and trichloroethene (TCE); heavy metals; starting to see PFOA & PFOS
- Media assessed includes indoor air (vapor intrusion) & soil gas, soil, groundwater, tap water



Vapor intrusion diagram

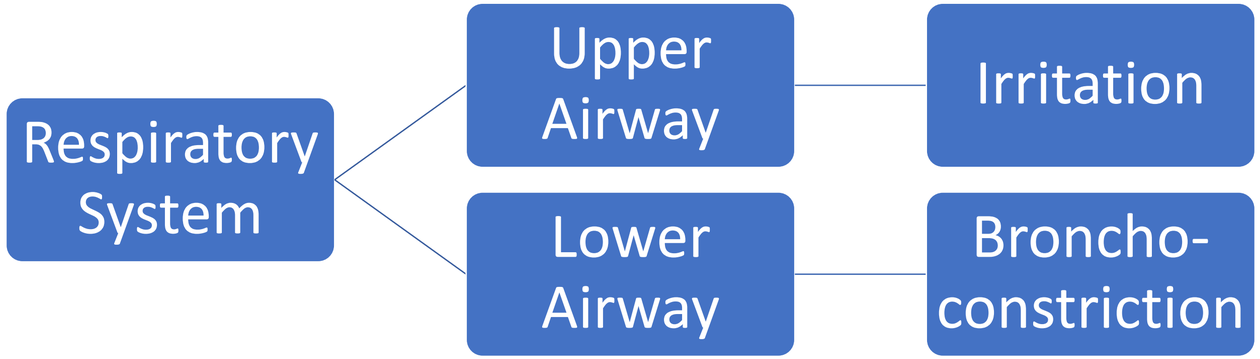
Contaminated Site Assessments

Hazard quotient - signals whether chronic non-cancer health effects are likely from exposure to a chemical

- Hazard index (HI) = sum of hazard quotients from individual chemicals
- If HI ≤1, an adverse effect is unlikely (acceptable threshold)
- Guidance supports separation of hazard quotients based on the target organ
- Screening-level risk assessment may not separate based on target organ

Considerations for Hazard Index approach

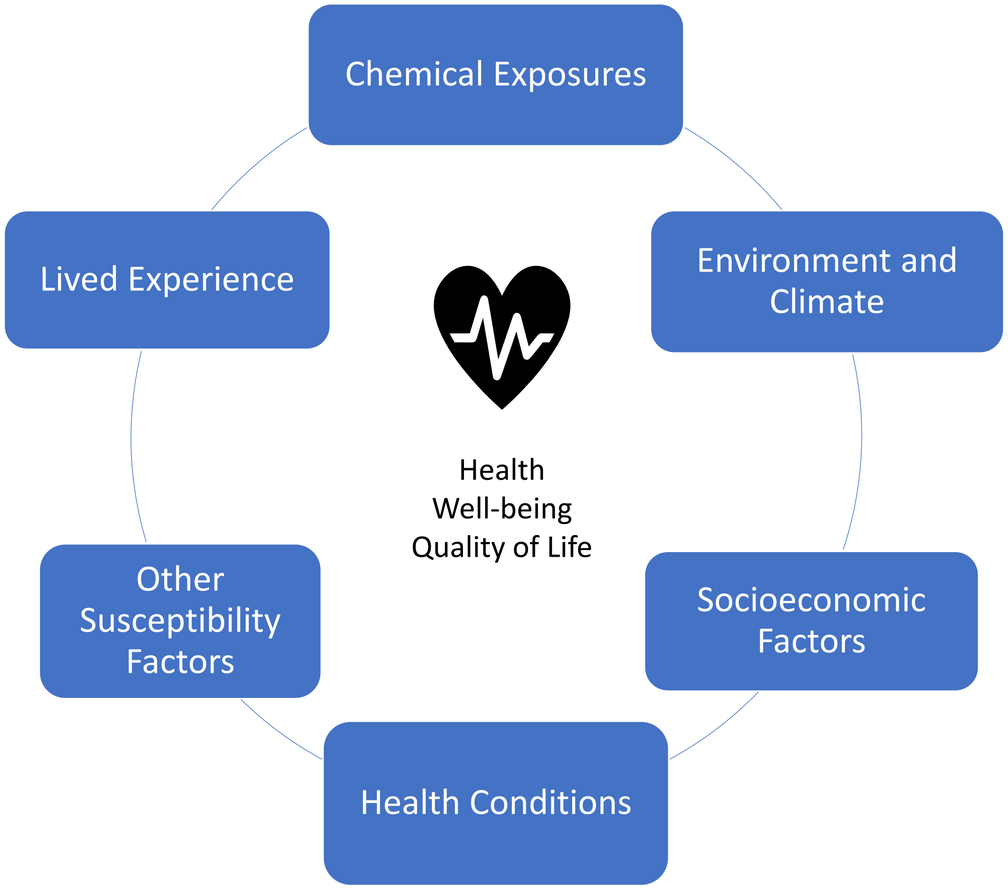
- SB25[1] required OEHHA to consider the “interaction between multiple pollutants”
  - Hazard Index approach using ‘same’ toxicological endpoint based on anatomical unit
- Target organs or systems can include multiple tissue types and multiple effects

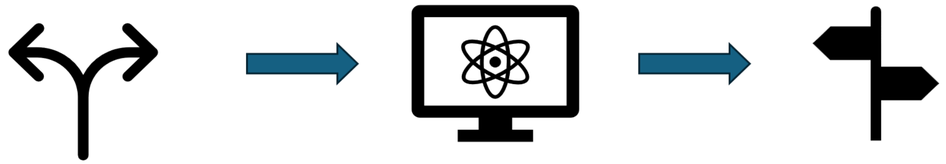


- Assumes additivity on the target organ or biochemical target
  - Could be independent, synergistic, or antagonistic
- Does not account for potential impacts of non-chemical stressors

[1] SB 25, Escutia. (1999) Environmental health protection: children.

Cumulative Impacts Assessment



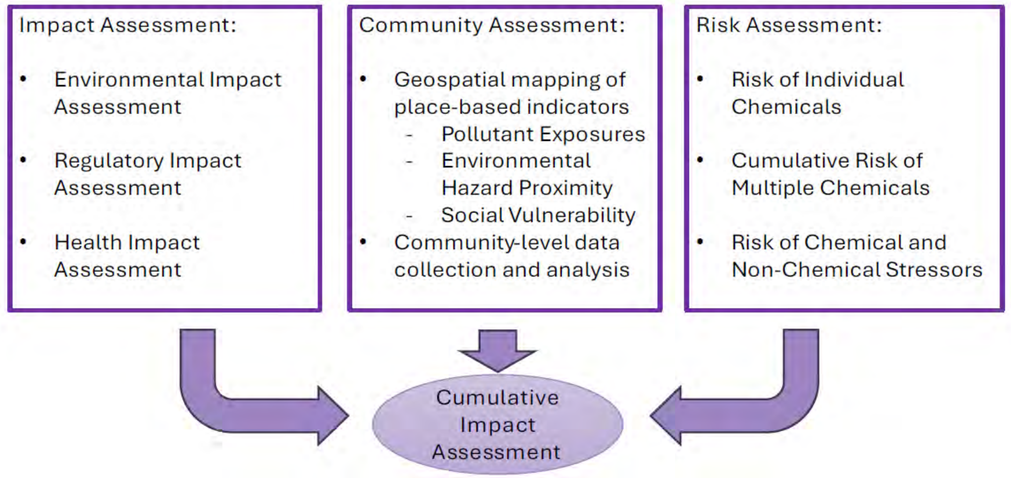


Decision context
- Rulemaking and standard setting
- Permitting
- Etc.

CI Assessment
- Fit-for-purpose
- Community input and lived experience

CalEnviroScreen

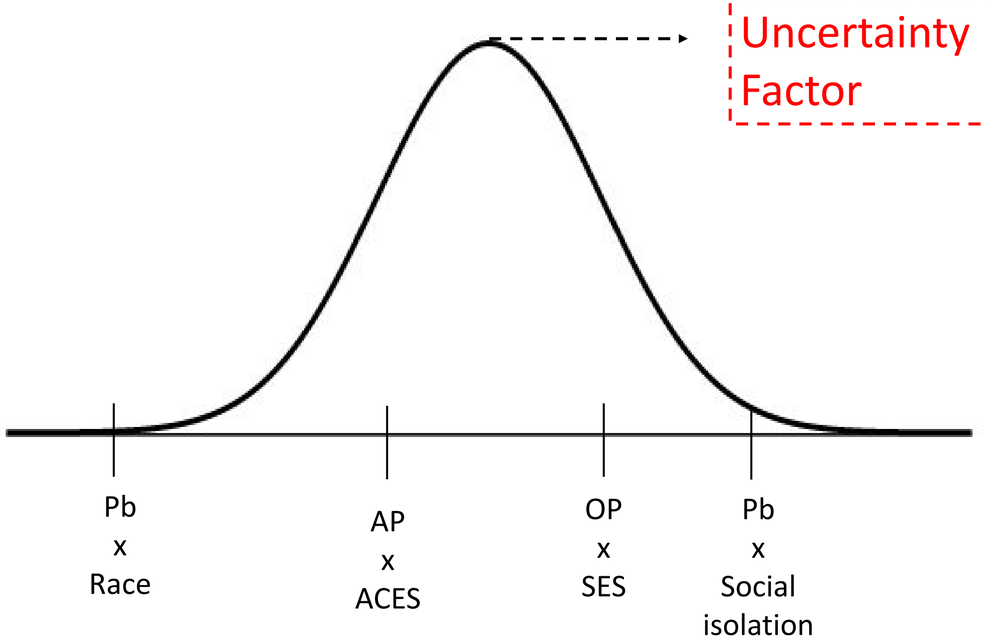
Action
- Reduce CI or avoid increasing CI → equity
- Prioritize highly-impacted populations



National Academies of Sciences, Engineering, and Medicine. 2025. State of the Science and the Future of Cumulative Impact Assessment. Washington, DC: The National Academies Press. https://doi.org/10.17226/29182.

Quantifying psychosocial stressors in risk assessment

Program on Reproductive Health and the Environment



Psychosocial stressors (racism, poverty, etc.)

UF = strength of arrow

Prenatal/early life chemicals (Pb, etc.)

Neurodevelopment

Computational Toxicology

- Computational Toxicology (CompTox) and New approach methodologies (NAMs) are becoming part of landscape of tools for informed decision-making for data-poor chemicals
- OEHHA created a New Toxicology Evaluations Section in 2023 to build expertise and collaborate with academics and external stakeholders
- Tools under development for use in risk assessment:
  - Read-across approaches to inform risk assessments for data-poor chemicals
  - Quantitative structure activity relationship (QSAR) models
  - Toxicokinetic models
  - Bioinformatics analysis (e.g., transcriptomic data)
  - Molecular docking approaches

Future Opportunities

- Hazard Index is a useful tool for determining potential noncancer health effects from exposure to multiple chemicals
  - Requires identification of target organ or system
  - RELs are often limited to the most sensitive target organ(s)

- Expanding list of target organs beyond the most sensitive can better protect public health
  - Better understand the risk to overburdened communities

Thank you!

AGENDA: 4

Bay Area Air District

Considerations for Cumulative Impacts Approaches

Advisory Council Meeting

December 8, 2025

Gregory H. Nudd
Deputy Executive Officer of Policy

Outline

- Current Landscape
  - Current policy to address of cumulative impacts in Air District permitting
  - Adequacy of data on background exposure and baseline health conditions
- Considerations for Future Place-Based Policy Mechanisms
  - Identification
  - Thresholds
  - Community input

Bay Area Air District

Current Landscape: Policy and Assessment Tools

Current Cumulative Impacts-Driven Policy

Permitting:

- Amendments adopted in 2021 in response to community concern about cumulative impacts in overburdened communities (OBCs)
- Lower cancer-risk thresholds for projects in OBCs
  - Cancer risk threshold ≤6 in a million for OBCs vs. ≤10 in a million otherwise
  - OBC defined as: Area located within a census tract identified by CalEnviroScreen 4.0 as having a score at or above the 70th percentile or within 1,000 feet of any such census tract

Considerations from Current Implementation

Existing Permitting Program:

- Relies on currently mapped OBCs – new rulemaking is required to respond to demographic and environmental changes
- Current map of OBCs leaves out some areas of concern/where large facilities are located (e.g. some parts of West Oakland)
- Does not explicitly consider facility-by-facility assessments
- Only applicable in permitting decisions where toxic/cancer causing emissions are above the threshold, does not consider particulate matter (PM)

Considerations: Health and Demographic Data

Demographic Data:

- How recent is it?
- Is it reliable at the census tract level? How about census block?

Health Data

- How often is it updated?
- How does the geographic resolution compare to census tracts and blocks?
- What health endpoints are covered?

Assessment Approaches

Current Practice:

- Screening/mapping assessment
- Risk Assessment

Potential Future Approaches

- Facility specific assessment based on background concentrations
- Potential for monitoring-based approaches to recommend further focus on different areas/facilities

Assessment: PM Exposure

Existing Understanding

- Annual average fine particulate matter ($PM_{2.5}$) exposure modeling updates underway associated with attainment planning (expected Quarter 2 (Q2) 2026)

More Work Needed

- Currently Air District staff has estimates for 24-hour $PM_{2.5}$ although annual modeling is more robust
- Impacts of PM_{10} and Ultra-Fine Particulate Matter
- Impacts of intermittent PM exposure (dust)

Assessment: Toxics

Existing Understanding

- Regional modeling (could be outdated), newer CARB state-wide work
- Recent modeling for regional diesel particulate matter exposure from roadways
- Modeling completed and ongoing for Assembly Bill (AB) 617 communities; includes mobile and stationary sources

More Work Needed

- Comparison of monitoring network data with existing modeling
  - Some detailed, neighborhood-scale work has been done or will be done soon in AB 617 communities

Considerations/Staff Recommendations

- Air District staff intends to move forward in evaluating toxics and PM but no other pollutants for cumulative impact analysis
- Air District staff to evaluate improvement of assessments and merging of monitoring and modeling information to improve understanding

Bay Area Air District

Considerations for Future Policy Mechanisms

Place-Based Approach

Identification

Build on existing permitting framework

- Considerations:
  - Permit backlog and maintaining resource efficiency, especially if individualized assessments are considered
  - Potential for tiered evaluation including stricter requirements in “excessively overburdened” areas
  - Very strict risk limits could have the effect of a localized permit moratorium and require consideration of exceptions
  - Need to evaluate other sources for drawing maps or complimentary data sets to CalEnviroScreen, consideration of community input (and recognition there likely will not be consensus)

Thresholds for Permit Issuance

Threshold

Evaluate Options for:

- No net increase in PM
- Toxic risk approach
- Exceptions to thresholds for “essential” services – recognition that this may be difficult to define and different communities may have different perspectives

Community Participation in Permit Actions

Action

Potential Avenues for Involvement:

- Early intervention (meeting or application) ideally at time of city land use permit to ensure awareness of requirements and early community notification
- Facility-led informational meeting prior to permit process
- Community benefits agreement – would have to determine who would be party to this and who would enforce it

Discussion

Are there other factors Air District staff should be considering?

Is there additional data the Advisory Council needs from Air District staff in order to inform the Council's work?

Questions & Discussion

For more information:

Gregory Nudd | Deputy Executive Officer for Policy | gnudd@baaqmd.gov