EPA United States Environmental Protection Agency

Application of the Stochastic Human Exposure and Dose Simulation (SHEDS) probabilistic multimedia aggregate exposure model for lead in soil and dust

EPA-NICEATM Workshop on Advancing Quantitative Analysis in Human Health Assessments through Probabilistic Methods

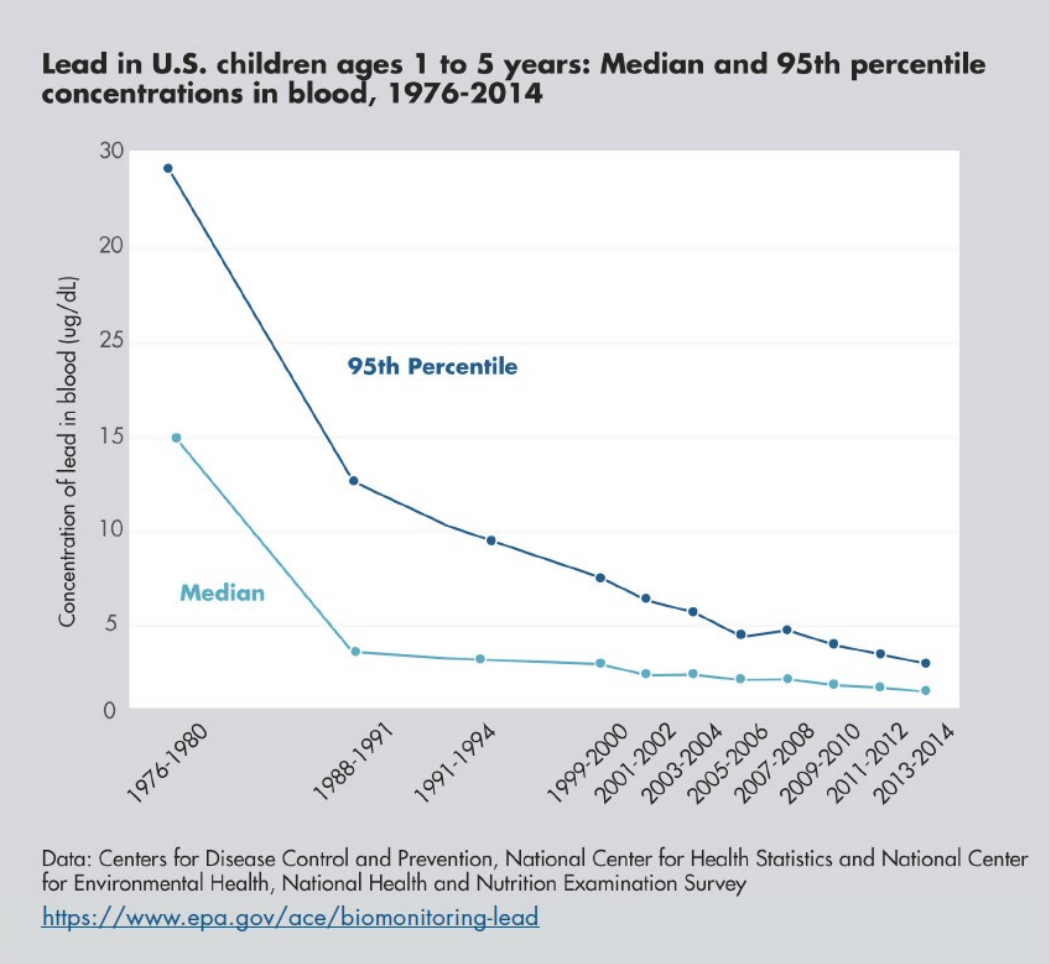
Rogelio Tornero-Velez (EPA/ORD/CCTE)

in collaboration with EPA/ORD SHEDS-Pb Team

ACKNOWLEDGMENTS

- Valerie G. Zartarian, Jianping Xue, Emily Gibb-Snyder, Jessica J. Frank, Lindsay W. Stanek
- James Brown, guidance on Pb biokinetics, IEUBK
- Managers, peer review and QA staff, contractors
- HUD collaborators
- External peer reviewers

Lead (Pb) Exposures have been Trending Downwards



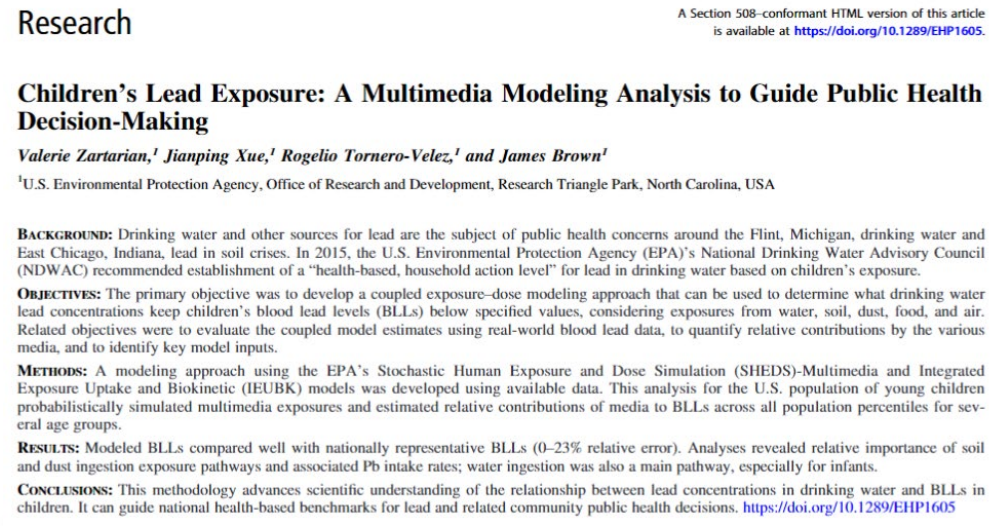
Lead Poisoning Prevention Policies

- Historical regulatory actions driving down Pb
- Federal Lead Action Plan
  https://www.epa.gov/lead/federal-action-plan-reduce-childhood-lead-exposure
- Bipartisan Infrastructure Law
  https://www.epa.gov/infrastructure/water-infrastructure-investments
- EPA Strategy to Reduce Pb Exposure and Disparities in U.S. Communities
  https://www.epa.gov/system/files/documents/2022-11/Lead%20Strategy_1.pdf

Presented at Society of Toxicology Workshop
Get the Lead Out: The Persistent Problem of Lead Exposure from Soil, Dust, and Water
SOT San Antonio, March 13, 2018

Assistance Requests to EPA/ORD

EPA/OW request to determine drinking water Pb concentrations to keep children's blood levels below specified levels



Research

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP1605.

Children's Lead Exposure: A Multimedia Modeling Analysis to Guide Public Health Decision-Making

Valerie Zartarian,[1] Jianping Xue,[1] Rogelio Tornero-Velez,[1] and James Brown[1]

[1]U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, North Carolina, USA

Background: Drinking water and other sources for lead are the subject of public health concerns around the Flint, Michigan, drinking water and East Chicago, Indiana, lead in soil crises. In 2015, the U.S. Environmental Protection Agency (EPA)'s National Drinking Water Advisory Council (NDWAC) recommended establishment of a "health-based, household action level" for lead in drinking water based on children's exposure.

Objectives: The primary objective was to develop a coupled exposure–dose modeling approach that can be used to determine what drinking water lead concentrations keep children's blood lead levels (BLLs) below specified values, considering exposures from water, soil, dust, food, and air. Related objectives were to evaluate the coupled model estimates using real-world blood lead data, to quantify relative contributions by the various media, and to identify key model inputs.

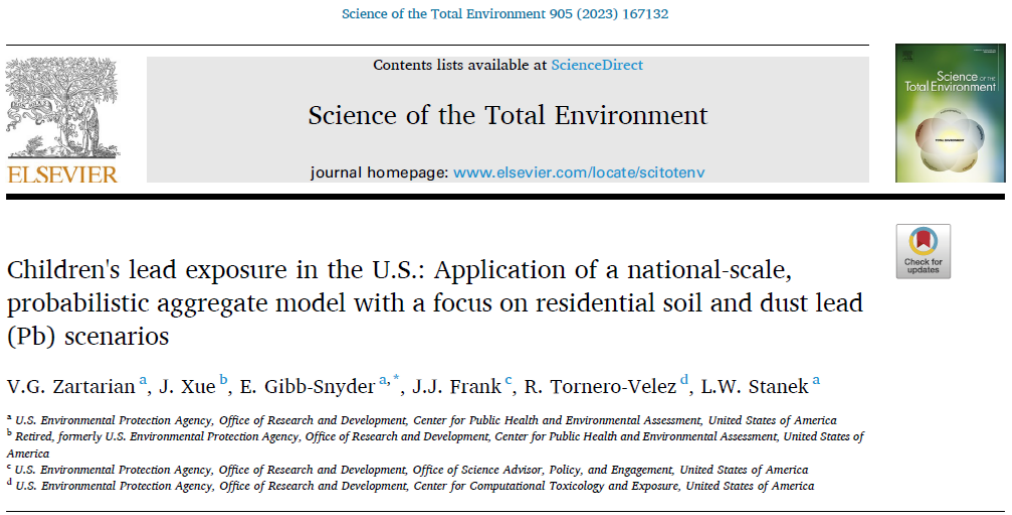
Methods: A modeling approach using the EPA's Stochastic Human Exposure and Dose Simulation (SHEDS)-Multimedia and Integrated Exposure Uptake and Biokinetic (IEUBK) models was developed using available data. This analysis for the U.S. population of young children probabilistically simulated multimedia exposures and estimated relative contributions of media to BLLs across all population percentiles for several age groups.

Results: Modeled BLLs compared well with nationally representative BLLs (0–23% relative error). Analyses revealed relative importance of soil and dust ingestion exposure pathways and associated Pb intake rates; water ingestion was also a main pathway, especially for infants.

Conclusions: This methodology advances scientific understanding of the relationship between lead concentrations in drinking water and BLLs in children. It can guide national health-based benchmarks for lead and related community public health decisions. https://doi.org/10.1289/EHP1605

Zartarian, V., Xue, J., Tornero-Velez, R. and Brown, J., 2017. Children's lead exposure: A multimedia modeling analysis to guide public health decision-making. *Environmental health perspectives*, *125*(9), p.097009.

EPA/OCSPP/HUD.gov request to determine residential Pb in soil and dust concentrations to keep children's blood levels below specified levels



Science of the Total Environment 905 (2023) 167132

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Children's lead exposure in the U.S.: Application of a national-scale, probabilistic aggregate model with a focus on residential soil and dust lead (Pb) scenarios

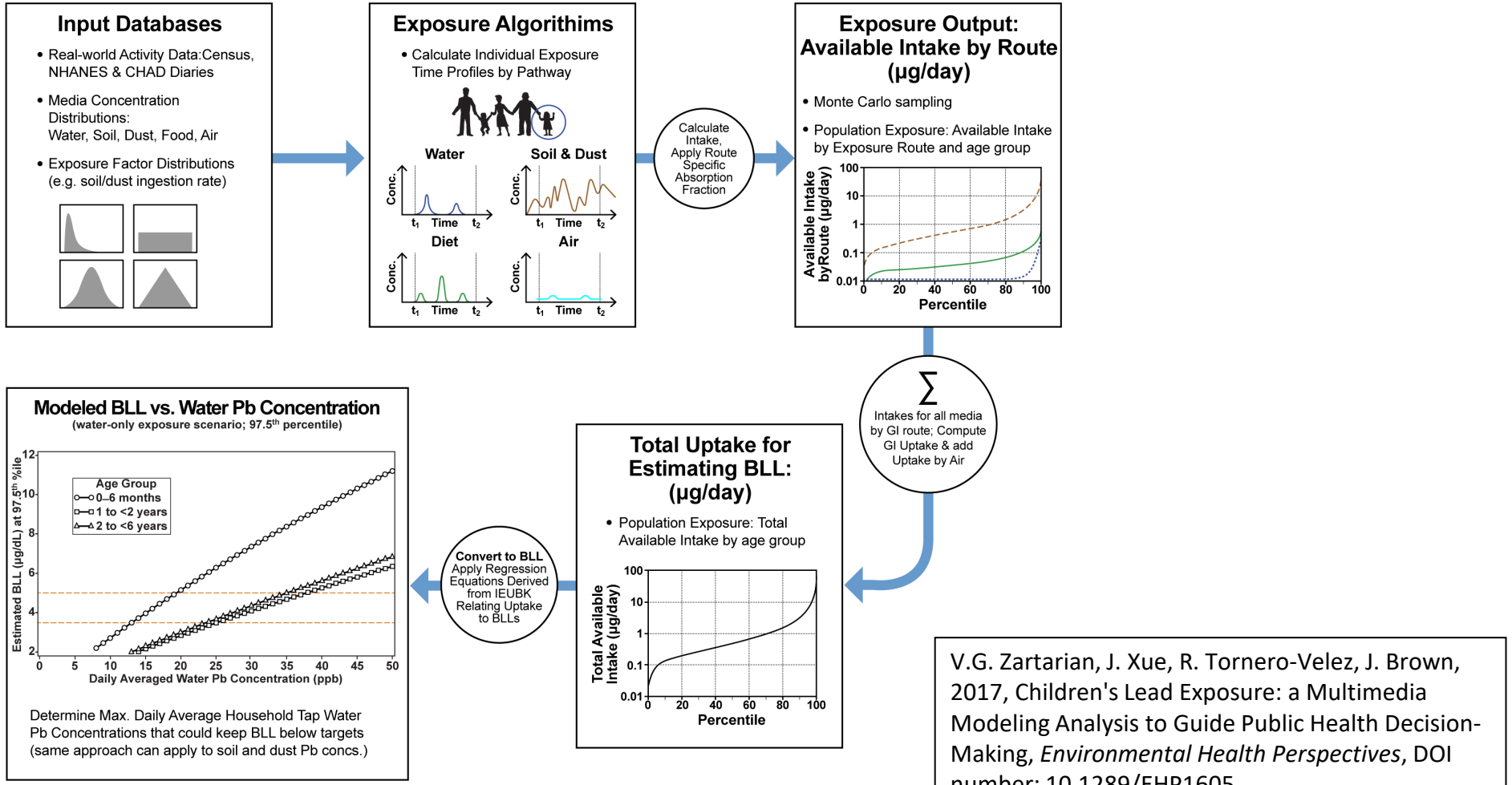
V.G. Zartarian [a], J. Xue [b], E. Gibb-Snyder [a,*], J.J. Frank [c], R. Tornero-Velez [d], L.W. Stanek [a]

[a] U.S. Environmental Protection Agency, Office of Research and Development, Center for Public Health and Environmental Assessment, United States of America
[b] Retired, formerly U.S. Environmental Protection Agency, Office of Research and Development, Center for Public Health and Environmental Assessment, United States of America
[c] U.S. Environmental Protection Agency, Office of Research and Development, Office of Science Advisor, Policy, and Engagement, United States of America
[d] U.S. Environmental Protection Agency, Office of Research and Development, Center for Computational Toxicology and Exposure, United States of America

Zartarian, V.G., Xue, J., Gibb-Snyder, E., Frank, J.J., Tornero-Velez, R. and Stanek, L.W., 2023. Children's lead exposure in the US: Application of a national-scale, probabilistic aggregate model with a focus on residential soil and dust lead (Pb) scenarios. *Science of the Total Environment*, *905*, p.167132.

SHEDS Probabilistic Aggregate Exposure Modeling Approach

(Stochastic Human Exposure and Dose Simulation)

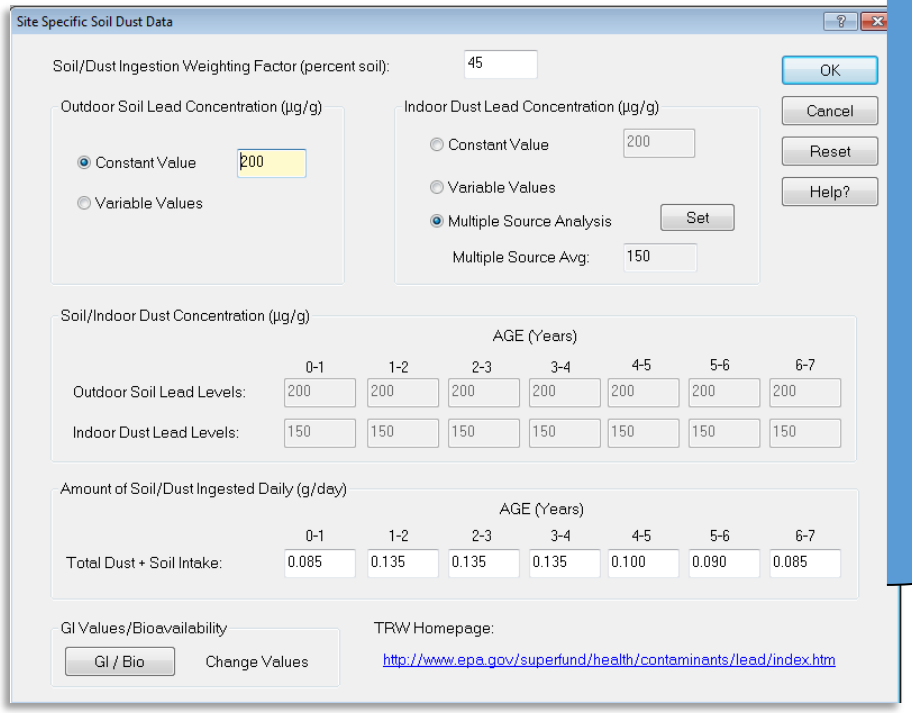


V.G. Zartarian, J. Xue, R. Tornero-Velez, J. Brown, 2017, Children's Lead Exposure: a Multimedia Modeling Analysis to Guide Public Health Decision-Making, *Environmental Health Perspectives*, DOI number: 10.1289/EHP1605.

Determine max. daily average soil, dust, and soil and dust that could keep BLL below reference values

‘Roughly’ Use SHEDS-Multimedia as Probabilistic Input to the Integrated Exposure Uptake Biokinetic Model for Lead (Pb) in children (IEUBK)

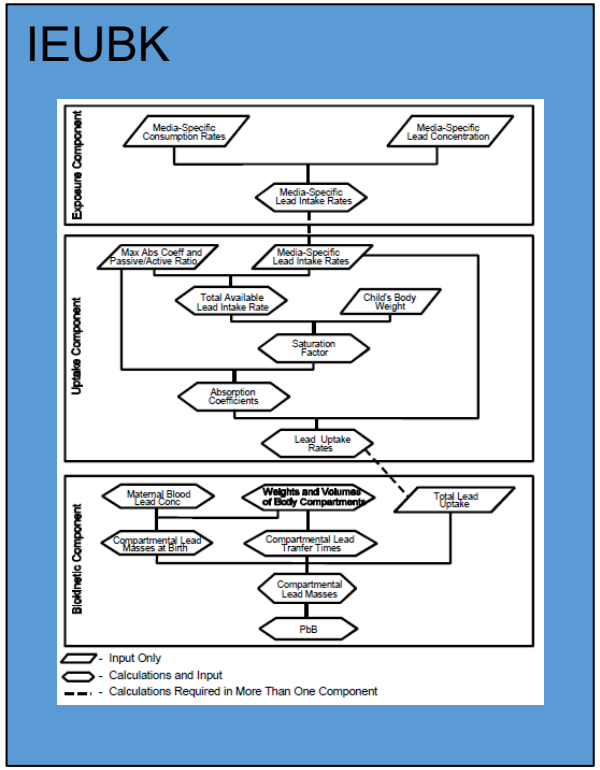
IEUBK Exposure compartment GUI maps
Pb conc to Intake by media,
for different ages.



(1) exposure

(2) uptake

(3) biokinetic



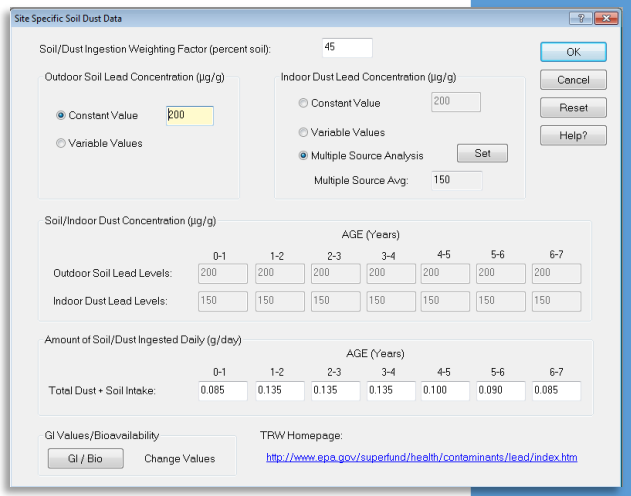
(4) GM centered output,
Apply GSD

https://www.epa.gov/superfund/lead-superfund-sites-software-and-users-manuals#overview

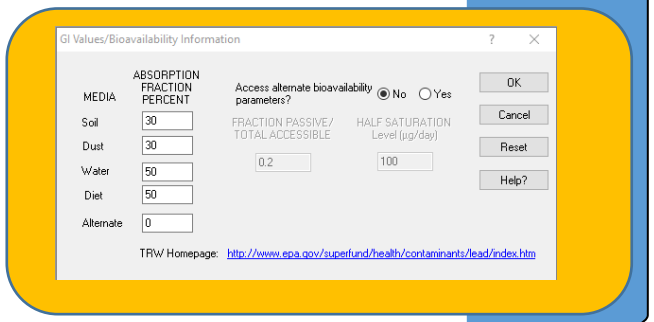
6

SHEDS-Multimedia Provided Probabilistic Input to IEUBK

IEUBK SOIL & DUST GUI (intakes & levels)



IEUBK Bioavailability GUI



Dietary Lead Intake (ug/day)			X	Dietary Absorption Fraction	=	Available Lead Intake (ug/day)
Water Intake (L/day)	X	Lead Water Conc (ug/L)	X	Water Abs Fraction	=	Available Lead Intake (ug/day)
Soil Intake (g/day)	X	Lead Soil Conc (ug/g)	X	Soil Abs Fraction	=	Available Lead Intake (ug/day)
Dust Intake (g/day)	X	Lead Dust Conc (ug/g)	X	Dust Abs Fraction	=	Available Lead Intake (ug/day)

$$\sum \left[SHEDS_{pathway} \left(\frac{\mu g}{day} \right) \quad X \quad ABS_{pathway} \right] \rightarrow$$

Total GI Available Lead Intake (ug/day)

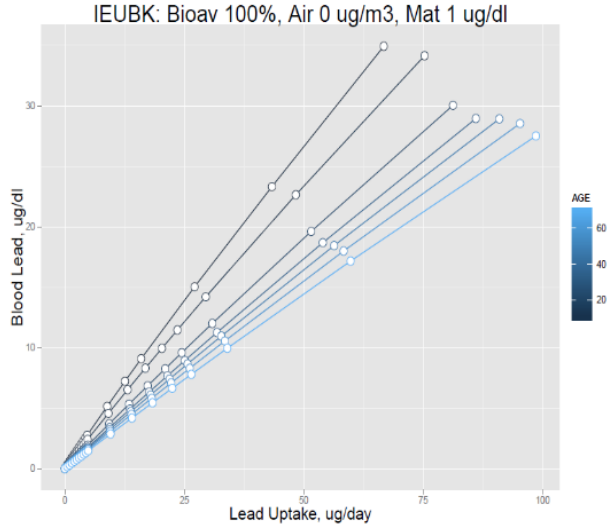
(1) Convert distribution of available intakes (µg/day) to age-specific uptakes (µg/day)

(2) Apply age-specific regression equations to relate uptakes to blood lead levels (µg/dL)

IEUBK Regression Fits by Age (month)

Blood Pb (μg/dL) = β_o + β_1 Uptake + β_2 Uptake^2 + β_3 Uptake^3 + e
R2~ 0.999

IEUBK Age Interval (year)	Age (months)	β_0	β_1	β_2	β3
0.5 - 1	7	1.65E-02	5.76E-01	-0.00153335	8.15E-06
0.5 - 1	8	1.23E-02	5.61E-01	-0.001399098	6.82E-06
0.5 - 1	9	7.86E-03	5.47E-01	-0.001307607	6.01E-06
0.5 - 1	10	7.34E-03	5.33E-01	-0.001183272	4.98E-06
0.5 - 1	11	4.30E-03	5.20E-01	-0.001083946	4.22E-06
0.5 - 1	12	2.25E-03	5.08E-01	-0.001015513	3.81E-06
1 - 2	13	2.42E-03	5.06E-01	-0.000951316	3.28E-06
1 - 2	14	2.04E-03	4.95E-01	-0.000858982	2.59E-06
1 - 2	15	2.96E-03	4.82E-01	-0.00079005	2.25E-06
1 - 2	16	1.10E-03	4.69E-01	-0.000739067	2.03E-06
1 - 2	17	2.27E-03	4.57E-01	-0.000676297	1.70E-06
1 - 2	18	-3.11E-04	4.47E-01	-0.000637203	1.53E-06
1 - 2	19	2.41E-03	4.37E-01	-0.00058901	1.26E-06
1 - 2	20	-1.18E-03	4.30E-01	-0.00058145	1.35E-06
1 - 2	21	7.61E-04	4.21E-01	-0.000532441	1.06E-06
1 - 2	22	5.65E-04	4.14E-01	-0.000514162	1.04E-06
1 - 2	23	-1.68E-03	4.08E-01	-0.000498463	9.98E-07
1 - 2	24	2.72E-04	4.03E-01	-0.0004837	9.56E-07
2 - 3	30	1.23E-03	3.79E-01	-0.000429113	8.45E-07
3 - 4	42	6.58E-04	3.55E-01	-0.000370716	6.24E-07
4 - 5	54	6.36E-04	3.36E-01	-0.000337753	5.44E-07
5 - 6	66	1.65E-03	3.13E-01	-0.00027834	3.57E-07
6 - 7	78	1.32E-04	2.88E-01	-0.000230444	3.08E-07



Single month chosen as representative for each age interval

interval	month
0 – 0.5	*3*
0.5 - 1	*9*
0 - 1	*6*
1 - 2	**18**
2 - 3	**30**
3 - 4	**42**
4 - 5	**54**
5 - 6	**66**
6 - 7	**78**

EPA/OW 2017 https://ehp.niehs.nih.gov/doi/full/10.1289/EHP1605

EPA/OCSPP/HUD.gov request to determine residential Pb soil and Pb dust concentrations to keep children's blood levels below specified levels

- Applied EPA's probabilistic, national-scale aggregate lead (Pb) model: SHEDS-Pb
- Used updated model inputs (e.g. AHHS II data from HUD) and scenarios of interest to HUD and EPA
- Considered 15 combinations of input data sources; focused on 2 scenarios *a priori*
- Objective -- conduct 4 types of analyses:
  1) determine estimated BLLs of children based on aggregate exposures for specified nationally representative background Pb concentrations in multiple environmental media
  2) compare results from 1) vs. CDC NHANES 2009-2016 BLLs for model evaluation
  3) determine the level of Pb in residential soil and dust that can result in a given percentage of children below a specified BLL(s), considering aggregate multimedia Pb exposures
  4) calculate the soil and dust increment for one unit increase in BLLs (2.5 to 3.5 µg/dL or 4 to 5 µg/dL) for soil-only, dust-only and aggregate Pb exposure scenarios

EPA/ OCSPP/HUD.gov https://doi.org/10.1016/j.scitotenv.2023.167132

9

Model Scenarios and Data Sources

AHHS I: 1146 homes, 101 PSU (2005 – 2006)
AHHS II: 700 homes, 78 PSU (2018 – 2019)

Soil Pb concentrations
Dust Pb loadings

Fourth Six-Year Review: data provided by states/primacy agencies through the Information Collection Request (ICR) for Six-Year Review 4 covering from January 2012 through December 2019.

Scenario	Background Soil and Dust Pb Concs.	Background Drinking Water Pb Concentrations	Dust Loading to Concentration (LTC) Conversion	Soil and dust ingestion rates
2022 Initial – S0	AHHS 1 – First American Healthy Homes Survey (HUD, 2011)	Second Six-Year Review of Existing National Primary Drinking Water Regulations- 6YR-2 [c] (EPA, 2010)	Pb NAAQS Risk and Exposure Assessment (EPA, 2007)	Ozkaynak et al. 2011
2022 Sensitivity Analyses – S1	AHHS I [a]	Second Six-Year Review of Existing National Primary Drinking Water Regulations	Bevington et al., 2021 model #16	Ozkaynak et al. 2022
S2	AHHS I	Second Six-Year Review of Existing National Primary Drinking Water Regulations	Pb NAAQS Risk and Exposure Assessment	Ozkaynak et al. 2022
S3	AHHS II [b] - Second American Healthy Homes Survey (HUD, 2021)	Fourth Six-Year Review of Existing National Primary Drinking Water Regulations – 6YR-4 [d] (EPA, 2022b)	Pb NAAQS Risk and Exposure Assessment	Ozkaynak et al. 2022
S4	AHHS II	Fourth Six-Year Review of Existing National Primary Drinking Water Regulations	Bevington et al., 2021 model #16	Ozkaynak et al. 2022
S5	AHHS II	AHHS II (Bradham et al., 2022)	Pb NAAQS Risk and Exposure Assessment	Ozkaynak et al. 2022
S6	AHHS II	AHHS II	Bevington et al., 2021 model #16	Ozkaynak et al. 2022
S7	AHHS I + AHHS II	AHHS II	Bevington et al., 2021 model #16	Ozkaynak et al. 2022
S8	AHHS I + AHHS II	AHHS II	Pb NAAQS Risk and Exposure Assessment	Ozkaynak et al. 2022
S9	AHHS I + AHHS II	AHHS II	Pb NAAQS Risk and Exposure Assessment	von Lindern et al. 2016
S10	AHHS I + AHHS II	AHHS II	Bevington et al., 2021 model #16	von Lindern et al. 2016
S11	AHHS I + AHHS II	AHHS II	Pb NAAQS Risk and Exposure Assessment	Exposure Factor Handbook 2017 (US EPA, 2017b)
S12	AHHS I + AHHS II	AHHS II	Bevington et al., 2021 model #16	Exposure Factor Handbook 2017
S13	AHHS I + AHHS II	Fourth Six-Year Review of Existing National Primary Drinking Water Regulations	Bevington et al., 2021 model #16	Ozkaynak et al. 2022
S14	same as S7 with new SHEDS-IEUBK linkage regression equation based on IEUBKv2			
S15	same as S13 with new SHEDS-IEUBK linkage regression equation based on IEUBKv2			

Model Evaluation Results

Simple statistics for all scenario simulation results, 1 to <2-year-olds

Scenario	Sample size	mean	std	median	75th	95th	97.5th	gm	gsd	Percentage higher than the level 3.5 ug/dl	5 ug/dl
NHANES BLL	641	1.42	1.35	1.03	1.67	3.65	5.54	1.09	1.99	7.0	3.0
S0	3000	1.27	1.25	0.94	1.53	3.17	4.36	0.98	2.01	5.8	1.9
S1	3000	1.58	1.19	1.26	1.92	3.81	4.80	1.29	1.88	9.8	2.1
S2	3000	1.34	1.23	1.03	1.63	3.21	4.23	1.05	1.97	5.9	1.8
S3	3000	1.21	0.98	0.94	1.46	2.96	3.60	0.97	1.91	4.8	0.9
S4	3000	1.44	1.16	1.12	1.80	3.44	4.58	1.16	1.91	7.4	1.8
S5	3000	1.12	0.95	0.87	1.36	2.66	3.47	0.90	1.91	3.5	0.7
S6	3000	1.34	1.06	1.04	1.64	3.29	4.05	1.07	1.94	6.3	1.5
S7	3000	1.39	1.21	1.07	1.67	3.34	4.28	1.10	1.94	6.7	1.7
S8	3000	1.15	0.92	0.91	1.39	2.71	3.52	0.92	1.92	4.0	0.8
S9	3000	1.81	1.98	1.24	2.06	5.19	6.80	1.33	2.09	13.4	5.3
S10	3000	2.24	2.25	1.59	2.61	6.12	8.07	1.67	2.06	19.8	7.8
S11	3000	1.76	1.81	1.21	2.01	4.98	6.75	1.30	2.09	13.0	5.0
S12	3000	2.15	2.08	1.53	2.49	5.72	8.07	1.62	2.03	18.2	7.0
S13	3000	1.45	1.12	1.13	1.77	3.43	4.26	1.17	1.89	7.7	1.5
S14	3000	1.42	1.12	1.11	1.74	3.62	4.63	1.13	1.94	7.6	1.8
S15	3000	1.47	1.15	1.15	1.77	3.59	4.44	1.19	1.89	8.1	1.6

S14=S7 S15=S13 with newIEUBK regression coefficients

EPA/ OCSPP/HUD.gov https://doi.org/10.1016/j.scitotenv.2023.167132

Model Evaluation Results

Relative errors (%) for all scenario simulations, 1 to <2-year-olds

		Relative errors (%)							
Scenario	sample size	mean	50th	92.5th	95th	97.5th	gm	Mid	high
S0	3000	-10	-9	-4	-13	-21	-11	10	13
S1	3000	11	22	20	4	-13	18	17	12
S2	3000	-6	0	0	-12	-24	-4	3	12
S3	3000	-15	-8	-7	-19	-35	-11	12	20
S4	3000	2	9	7	-6	-17	6	5	10
S5	3000	-21	-15	-18	-27	-37	-18	18	28
S6	3000	-6	1	2	-10	-27	-2	3	13
S7	3000	-2	4	4	-8	-23	1	3	12
S8	3000	-19	-12	-14	-26	-37	-16	16	25
S9	3000	27	20	47	42	23	22	24	37
S10	3000	58	54	84	68	46	54	56	66
S11	3000	24	17	52	36	22	19	20	37
S12	3000	51	48	74	57	46	49	50	59
S13	3000	2	10	9	-6	-23	7	6	13
S14	3000	0	8	10	-1	-16	4	4	9
S15	3000	4	12	12	-2	-20	9	8	11

EPA/ OCSPP/HUD.gov https://doi.org/10.1016/j.scitotenv.2023.167132

EPA United States Environmental Protection Agency

Results for maximum daily average household Pb concentrations (ppm) that could keep BLL below specific reference values for Scenario 7

Age group		BLL: 3.5 µg/dL 95th percentile	BLL: 3.5 µg/dL 97.5th percentile	BLL: 5 µg/dL 95th percentile	BLL: 5 µg/dL 97.5th percentile
1 to<2y-old					
	dust	160	140	240	210
	soil	90	70	220	180
	dust & soil	300	210	530	380
2 to<6y-old					
	dust	140	110	210	150
	soil	120	80	220	160
	dust & soil	290	210	470	340

Scenario 7

EPA/ OCSPP/HUD.gov https://doi.org/10.1016/j.scitotenv.2023.167132

Strengths

- SHEDS-Pb can estimate children's BLLs over the range of all population percentiles for multiple children's age groups. Sensitivity analyses can identify key factors, media, and exposure pathways. The modeled BLL results compared well with children's NHANES BLLs for the numerous sensitivity analysis scenarios conducted.

Limitations

- SHEDS-Pb does not capture scenarios of extremely high exposure (e.g., children with pica behavior) because other behavioral factors related to soil Pb and dietary intake (i.e., home or community gardening and homesteading, hunting with Pb-based ammunition, and/or subsistence practices) are not captured.
- Insufficient data to implement 2-stage Monte Carlo

EPA/OW 2017 https://ehp.niehs.nih.gov/doi/full/10.1289/EHP1605
EPA/ OCSPP HUD.gov https://doi.org/10.1016/j.scitotenv.2023.167132

ACKNOWLEDGMENTS

- Valerie G. Zartarian, Jianping Xue, Emily Gibb-Snyder, Jessica J. Frank, Lindsay W. Stanek
- James Brown, guidance on Pb biokinetics, IEUBK
- Managers, peer review and QA staff, contractors
- HUD collaborators
- External peer reviewers

15

REFERENCES

- Bevington, C., Gardner, H.D., Cohen, J., Henning, C. and Rasmussen, P.E., 2021. Relationship between residential dust-lead loading and dust-lead concentration across multiple North American datasets. *Building and Environment*, *188*, p.107359.
- Bradham, K.D., Nelson, C.M., Sowers, T.D., Lytle, D.A., Tully, J., Schock, M.R., Li, K., Blackmon, M.D., Kovalcik, K., Cox, D. and Dewalt, G., 2023. A national survey of lead and other metal (loids) in residential drinking water in the United States. *Journal of exposure science & environmental epidemiology*, *33*(2), pp.160-167.
- Özkaynak, H., Glen, G., Cohen, J., Hubbard, H., Thomas, K., Phillips, L. and Tulve, N., 2022. Model based prediction of age-specific soil and dust ingestion rates for children. *Journal of Exposure Science & Environmental Epidemiology*, *32*(3), pp.472-480.
- Sowers, T.D., Nelson, C.M., Blackmon, M.D., Li, K., Jerden, M.L., Kirby, A.M., Kovalcik, K., Cox, D., Dewalt, G., Friedman, W. and Pinzer, E.A., 2024. United States house dust Pb concentrations are influenced by soil, paint, and house age: insights from a national survey. *Journal of Exposure Science & Environmental Epidemiology*, pp.1-9.
- von Lindern, I., Spalinger, S., Stifelman, M.L., Stanek, L.W. and Bartrem, C., 2016. Estimating children's soil/dust ingestion rates through retrospective analyses of blood lead biomonitoring from the Bunker Hill Superfund Site in Idaho. *Environmental health perspectives*, *124*(9), pp.1462-1470.
- U.S. EPA, 2017. Updates to the EPA Exposure Factors Handbook. https://www.epa.gov/ expobox/about-exposure-factors-handbook.
- U.S. EPA, 2021. IEUBK Lead Model Version 2.0 Build 1.64 (2021). viewed 09/02/2022. https://www.epa.gov/superfund/lead-superfund-sites-software-and-users-manuals.
- U.S. EPA, 2022. Analysis of Occurrence Data From the Fourth Six-year Review of Existing National Primary Drinking Water Regulations. Office of Groundwater and Drinking Water
- Zartarian, V., Xue, J., Tornero-Velez, R. and Brown, J., 2017. Children's lead exposure: A multimedia modeling analysis to guide public health decision-making. *Environmental health perspectives*, *125*(9), p.097009.
- Zartarian, V.G., Xue, J., Gibb-Snyder, E., Frank, J.J., Tornero-Velez, R. and Stanek, L.W., 2023. Children's lead exposure in the US: Application of a national-scale, probabilistic aggregate model with a focus on residential soil and dust lead (Pb) scenarios. *Science of the Total Environment*, *905*, p.167132.