United States Environmental Protection Agency

EPA Tools and Resources Webinar:

Multi-Media Modeling of Children's Lead Exposure and Water Lead Monitoring Research to Inform Public Health Decisions

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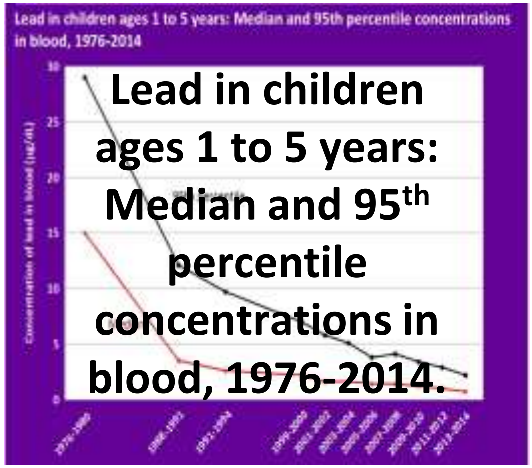
Priority, Multimedia Issue

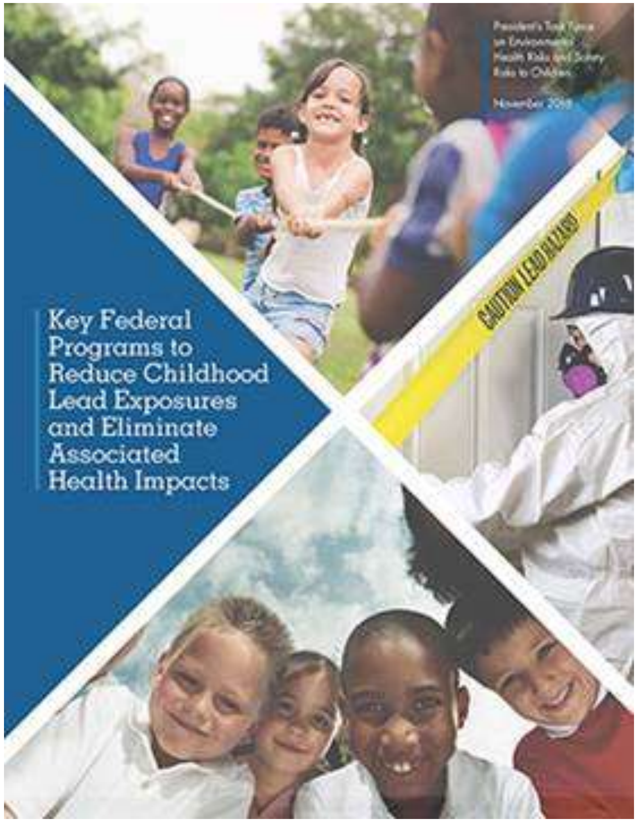
- Lead (Pb) is a toxic legacy contaminant; significant progress but remains a public health priority: no safe level in children
- ~250,000 children have blood lead levels (BLLs) > the Centers for Disease Control and Prevention (CDC) reference level (5 ug/dL)
- Multimedia exposures: water, soil, dust, food and air
- Aging infrastructure (Pb in pipes, paint) is ongoing
- Maximizing risk reductions requires multimedia exposure assessment and coordinated approaches



Federal Programs and Efforts

- 2016 report on Key Federal Programs to Reduce Childhood Lead Exposure and Eliminate Associated Health Impacts

- New federal lead strategy under President's Task Force on Environmental Health Risks and Safety Risks



Areas of Pb Research Being Discussed among Federal Agencies

- Identify highest risk communities across the US

- Identify sources of Pb in children's environments and relative contribution of these sources to BLLs

- Assess relative contribution of various exposure pathways (water, soil, dust, food, air) to BLLs to inform effective exposure reduction strategies

- Identify the most effective approaches to prevent childhood Pb exposure

- Identify effective interventions to mitigate the health effects of Pb exposure

- Evaluate effectiveness of key programs and policies to prevent Pb exposure

Examples of EPA Pb Efforts

EPA Program and Regional Offices

- Federal Pb Strategy *(Office of Children's Health Protection)*

- EPA Pb Disparities Team *(Office of Chemical Safety and Pollution Prevention)*

- Pb priority in EJ2020 Plan *(Office of Environmental Justice)*

- Global Alliance to Eliminate Lead Paint with the World Health Organization and the United Nations Environment Program *(Office of Tribal and International Affairs)*

EPA Office of Research and Development

- Physiologically based pharmacokinetic (PBPK) modeling (e.g., EPA's Integrated Exposure Uptake Biokinetic (IEUBK) model)
- Pb bioavailability and soil/dust ingestion research
- **Water Pb monitoring and modeling**
- **Multimedia Pb exposure-dose modeling: "Children's Lead Exposure: a Multimedia Modeling Analysis to Guide Public Health Decision-Making," *Environmental Health Perspectives*, 2017**

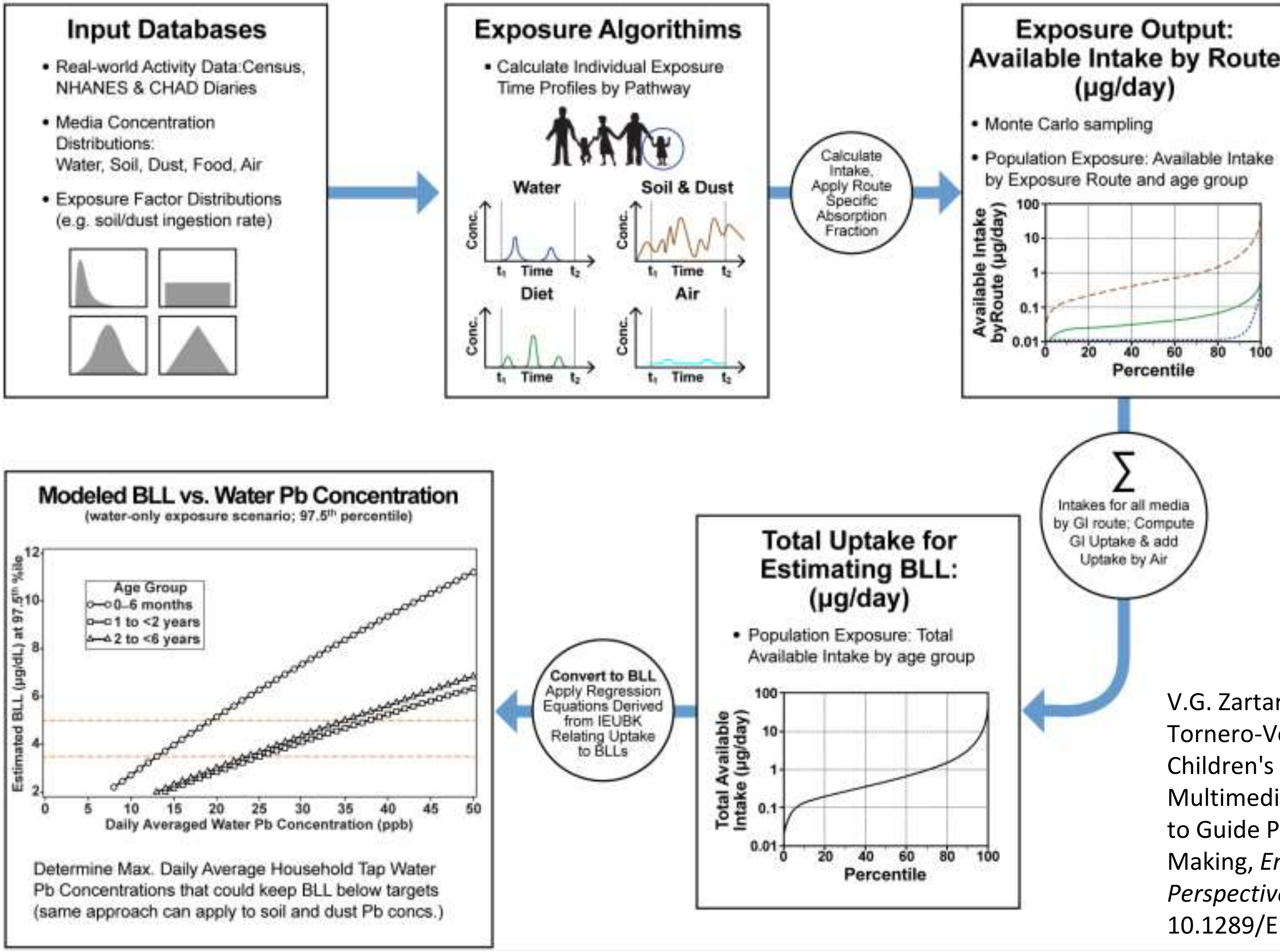
Objectives of Multimedia Pb Exposure-Dose Analysis

- **Develop and apply an innovative Pb modeling approach**, considering the National Drinking Water Advisory Council's recommendation to develop a "Household Action Level" (HAL) for Pb in drinking water

- **Determine drinking water Pb concentrations** that could keep specified percentiles of national BLL distributions of different aged children below specified BLL, for various scenarios.

- **Evaluate** modeled predictions using CDC National Health and Nutrition Examination Survey (NHANES) and other BLL data; **quantify relative contributions** by each media/exposure pathway; **identify key inputs.**

Multimedia Pb Modeling Approach



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.

Summary of Main Model Inputs

Zartarian et al., *EHP*, 2017, DOI: 10.1289/EHP1605.

Variable	Source	Values/Distribution Used
Dietary Pb Intake (ug/day)	Data from FDA Total Diet Study 2007-13 (TDS) & J Spungen, FDA-CSFAN unpublished data for recipe mapping; Method from Xue et al., 2010 *EHP*	

Age	N	Mean	Std	50th	GM	GSD	75th	95th	99th
0-6 Month	1072	0.70	0.98	0.30	0.27	4.75	0.91	2.71	3.47
1 Year	2226	2.58	1.84	2.17	2.00	2.16	3.41	5.83	7.63
2 Year	1788	3.44	2.03	3.06	2.85	1.94	4.49	7.23	8.46
3 Year	1160	3.54	2.06	3.18	2.98	1.89	4.63	7.26	8.43
4 Year	1240	3.57	2.16	3.18	3.00	1.87	4.55	7.25	8.63
5 Year	1066	3.85	2.18	3.43	3.31	1.77	4.83	7.86	9.52
6 Year	1086	3.80	2.02	3.51	3.29	1.76	4.84	7.55	8.30

Variable	Source	Values/Distribution Used
Soil and Dust Pb Concs. (ppm)	Empirical distribution from HUD AHHS 2005-2006 data http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf	

Media	House age	N	Mean	Std	Median	GM	GSD	fited log mean	fitted log Std	75th	95th	99th
dust	before 1950	223	207.7	238.2	113.3	133.9	2.47	4.89	0.88	238.6	706.6	1108.9
dust	after 1950	908	79.0	77.2	64.5	61.3	2.00	4.12	0.63	87.1	195.3	353.1
soil	before 1950	193	532.2	912.6	203.2	221.1	3.89	5.38	1.30	574.5	1841.3	5792.7
soil	after 1950	749	63.7	202.0	19.2	23.0	3.37	3.18	1.05	39.9	207.7	933.3

Variable	Source	Values/Distribution Used
Soil/Dust Ingestion (mg/day)	Ozkaynak et al., 2011, *Risk Analysis*	

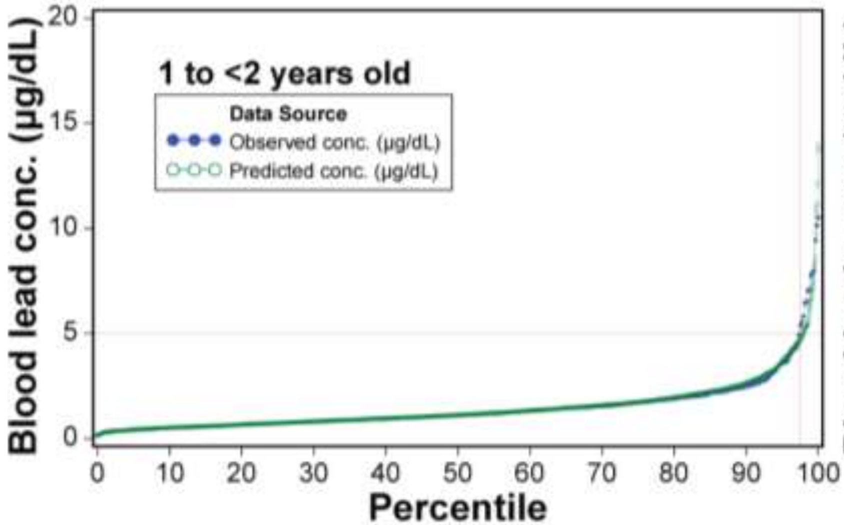
Age	soil/dust	mean	Std	50th	GM	GSD	95th	97.5th	99th
1	mg_total	43.9	54.8	27.8	26.6	2.8	135	188	262
2	mg_total	45.2	58.8	25.8	25.9	3.0	146	201	276
3	mg_total	51.7	64.2	31.1	28.9	3.2	168	220	304
4	mg_total	57.8	75.5	34.0	31.6	3.2	197	268	364
5	mg_total	62.6	79.8	37.9	34.4	3.2	204	270	380
6	mg_total	54.3	76.1	30.4	29.2	3.2	183	252	357

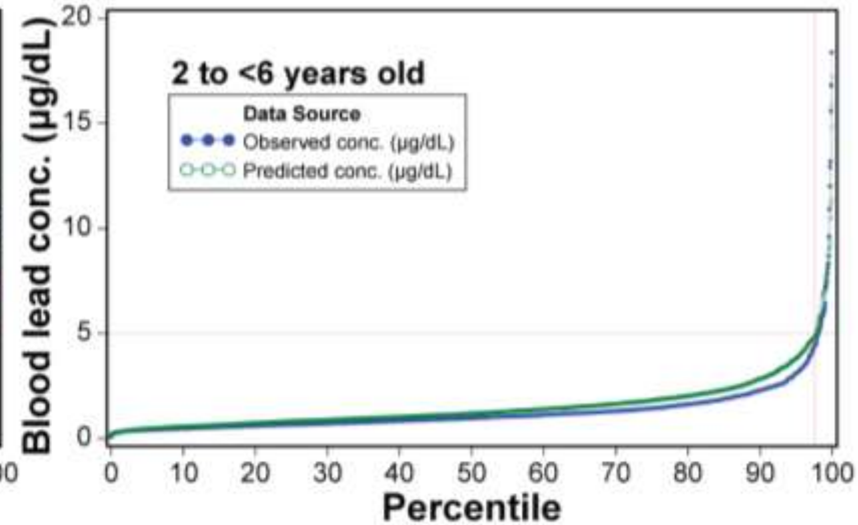
Variable	Source	Values/Distribution Used
Water Consumption (ml/day)	NHANES 2005-20012	

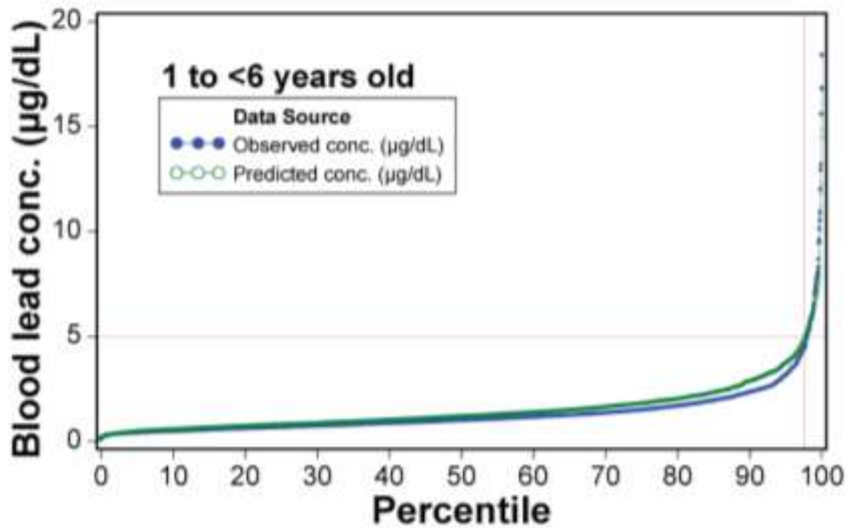
age (years)	N	mean	std	p50	GM	GSD	p75	p95	p99
0-6 months	1246	662	320	630	526	2.5	854	1216	1481
0	2618	581	349	532	410	3.0	806	1172	1489
1	1792	247	247	219	151	3.3	306	690	1148
2	1948	300	312	251	176	3.4	360	909	1424
3	1272	316	313	257	193	3.1	398	917	1640
4	1358	320	333	261	197	3.2	404	874	1434
5	1196	364	366	303	213	3.5	447	1037	1802
6	1306	377	353	332	228	3.5	480	1067	1601

Variable	Source	Values/Distribution Used
Absolute Bioavailability	IEUBK Default	30% for soil&dust; 50% for water&food

Model Evaluation: Multimedia Pb Modeling Approach BLL vs. 2009-2014 NHANES BLL data





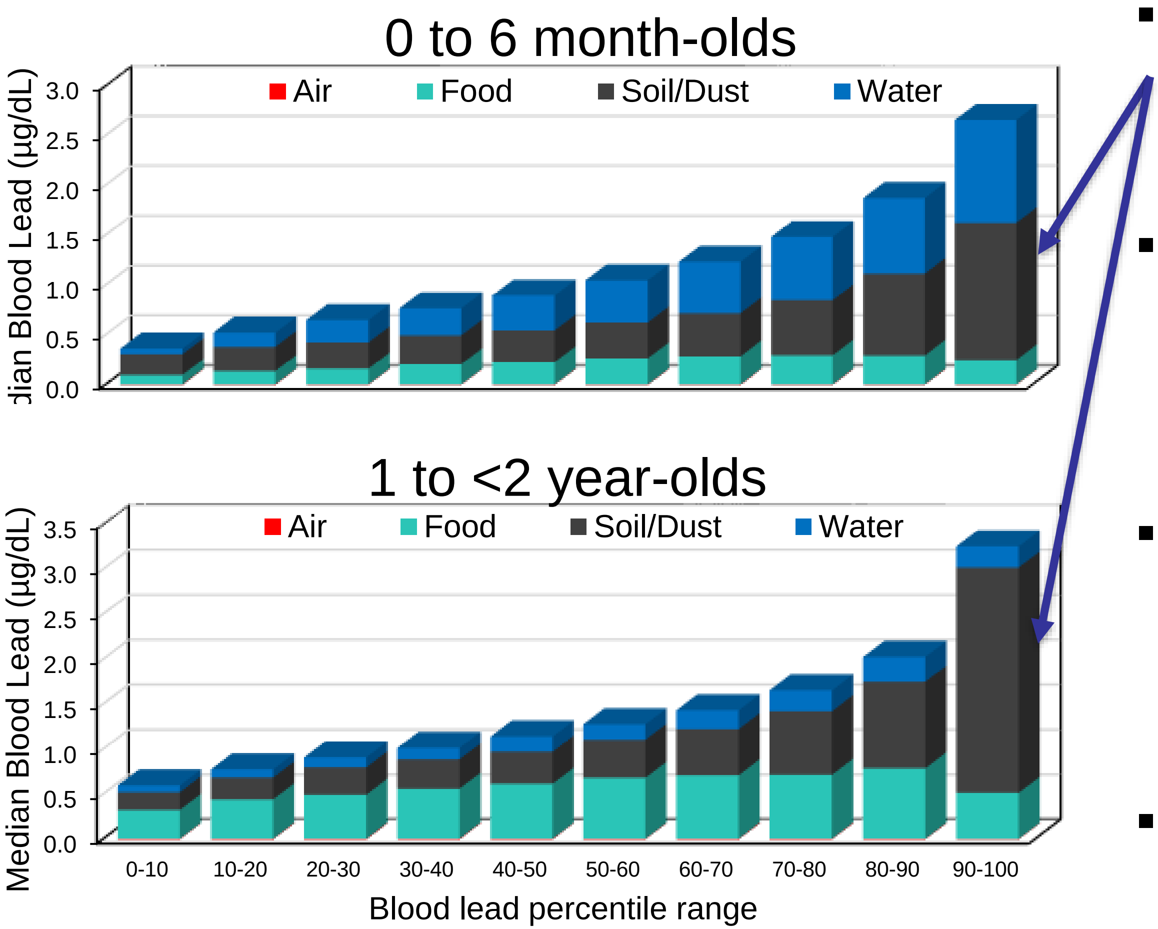


Modeled BLLs compared well with nationally representative BLLs (0–23% relative error).

Zartarian, Xue, Tornero-Velez, Brown, *EHP*, 2017, DOI: 10.1289/EHP1605.

Estimated Contribution of Exposure Pathways to BLL

National-Scale Analysis using Multimedia Pb Modeling



- **Soil/dust ingestion** can be significant for most vulnerable populations at the national scale
- Estimates for **US residential population**; analysis not designed for specific at-risk populations or households
- **Limitations and uncertainties** of this national scale analysis, **including available data** for model inputs
- Contributions from pathways are **highly dependent on scenarios** being considered

Zartarian et al., *EHP*, 2017, DOI: 10.1289/EHP1605.

Multimedia Pb Modeling results for Max. Daily Average Household Tap Water Pb Concentrations that Could Keep BLL Below Specified Values

Age Group	Exposure Scenario	BLL 3.5 µg/dL @ 97.5th %ile	BLL 5 µg/dL @ 97.5th %ile	BLL 3.5 µg/dL @ 95th %ile	BLL 5 µg/dL @ 95th %ile
0 to 6 months old	Water Only	13.1 ppb	19.3 ppb	14.1 ppb	20.8 ppb
	Aggregate	3.7 ppb	15.8 ppb	6.9 ppb	17.4 ppb
1 to <2 years old	Water Only	25.1 ppb	37.7 ppb	30.9 ppb	46.0 ppb
	Aggregate	*	5.4 ppb	2.5 ppb	14.2 ppb
2 to <6 years old	Water Only	23.6 ppb	35.0 ppb	29.4 ppb	43.6 ppb
	Aggregate	*	2.8 ppb	1.1 ppb	12.1 ppb
0 to 7 years old	Water Only	20.1 ppb	29.5 ppb	27.3 ppb	41.0 ppb
	Aggregate	*	4.7 ppb	2.2 ppb	12.9 ppb

** BLL will not be below targets even with 0 ppb Pb in water*

Zartarian, Xue, Tornero-Velez, Brown, *EHP*, 2017, DOI: 10.1289/EHP1605.

Strengths and Limitations of Multimedia Pb Modeling Approach

Strengths

- Represents an advance in science
  - Multimedia Pb analysis uses 2 published, evaluated models
  - Population-based, probabilistic, multimedia approach enhances understanding of relationship between Pb in drinking water and BLLs
  - Uniquely reports percent contribution to children's BLL by exposure pathway, population percentile, and age group
  - Sensitivity analyses identify key factors, media, and exposure pathways
  - Multimedia Pb Modeling estimates compare well against CDC NHANES BLL data
  - Approach can be applied to other environmental media to inform decision-making considering exposures aggregated from multiple media
- Reflects scientific input from external peer reviewers

Limitations

- Requires selecting a BLL benchmark; CDC reference level may change
- Requires detailed input data (e.g., distributions rather than point estimates)
  - Uncertainties and limitations in data for key variables
- Currently intended for national scale analyses

Exposure to Lead

As is the case of other sources of Pb, the exposure to lead in drinking water has many factors

Water quality factors

- Lead dissolution (water quality, treatment changes, pipe conditions (e.g., biofilms))
- Lead particulate release (flow, disturbances)

Plumbing configuration and use factors

- Lead Sources (pipe & plumbing materials)
- Pipe lengths, diameter and arrangements
- Fixtures & appliances (where)
- Customer usage patterns: when, where and by whom; daily/weekly/monthly variations
- Flow rates (how much and stagnation times)

Sampling

There are many ways of sampling for lead in drinking water

Type	Sampling Purpose
First Draw	- Regulatory (US) - Treatment Assessment
Random Daytime Sampling	- Regulatory (UK) - Treatment Assessment
Fixed Stagnation Time	- Regulatory (Ontario) - Treatment Assessment
Fully Flushed	- Lead Source Assessment - Treatment Assessment
Sequential Sampling	- Lead Source Assessment
Automatic Composite Proportional	- Exposure Assessment
Manual Composite Proportional	- Exposure Assessment
Particle Stimulation Sampling	- Lead Type Assessment
Service Line Sampling	- Lead Source Assessment
Whole Flow Capture	- Exposure Assessment

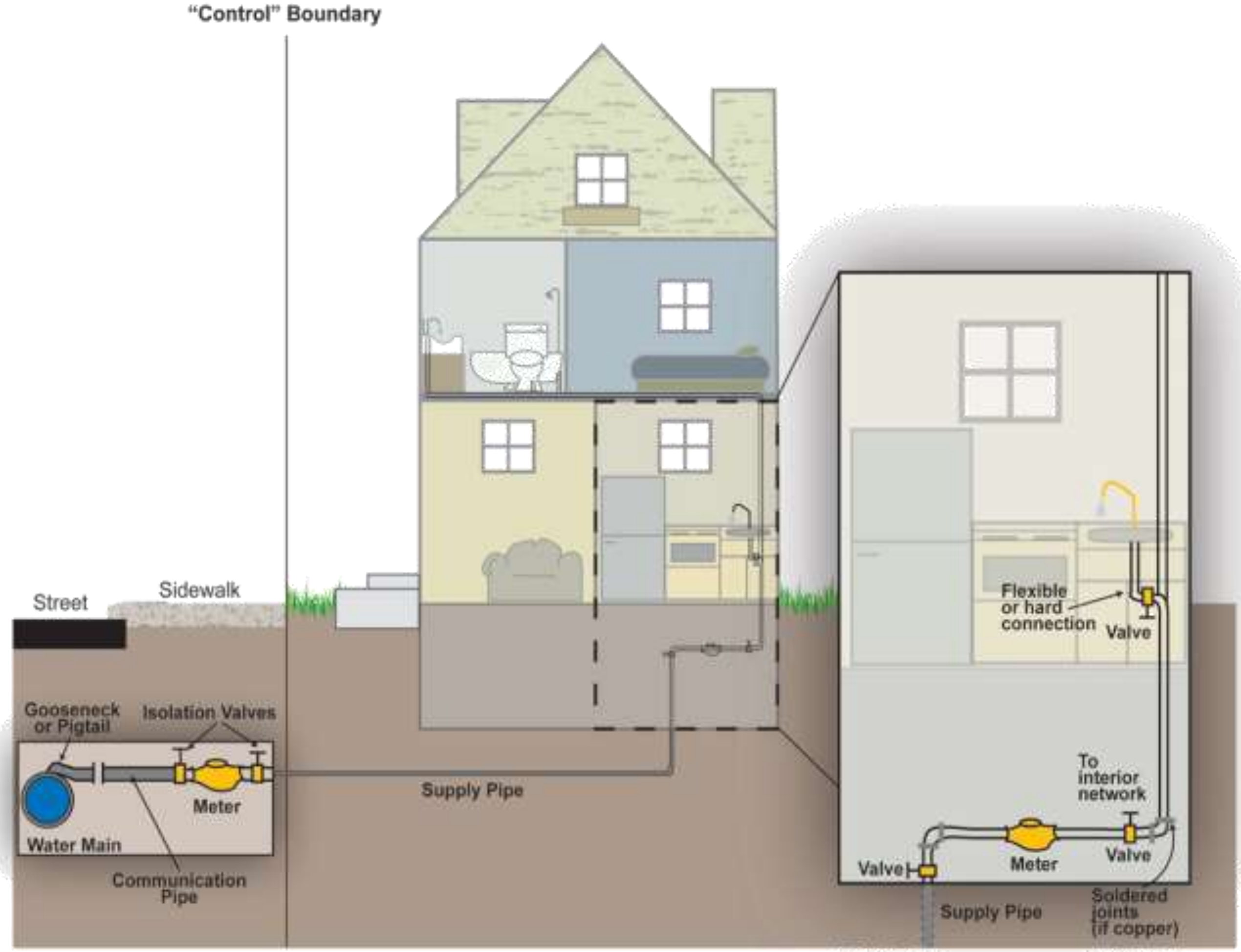
- Each technique tells a different part of the story
- Unfortunately, none of them can fully define exposure, especially of an individual
- An online real-time method does not exist
- Particulate lead is particularly problematic in measuring
- It is important that health effects projects choose the appropriate (best) sampling technique
- Bioavailability questions persist, especially for particulates

Science of Lead in Drinking Water

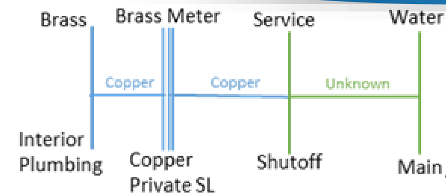
Complex scientific issues remain between water quality and lead scale chemistry

- The highest Pb concentrations come from water that has remained stagnant in the Pb service line for extended periods of time (overnight) or from particulate release events which are highly variable in nature.
- Porosity and solubility of lead scale will differ greatly among utilities.
- Pb can adsorb/desorb from iron or galvanized pipe corrosion scales.
- Corrosion control techniques (e.g., orthophosphate) seem to have different impacts on different Pb sources (service lines, solder and brass fixtures).
- Water quality changes due to treatment or extended stagnation can significantly impact corrosion.
- EPA ORD has analyzed hundreds of pipes and has provided corrosion control advice to communities and states across the country. *How can this unique expertise be better transferred to the states?*

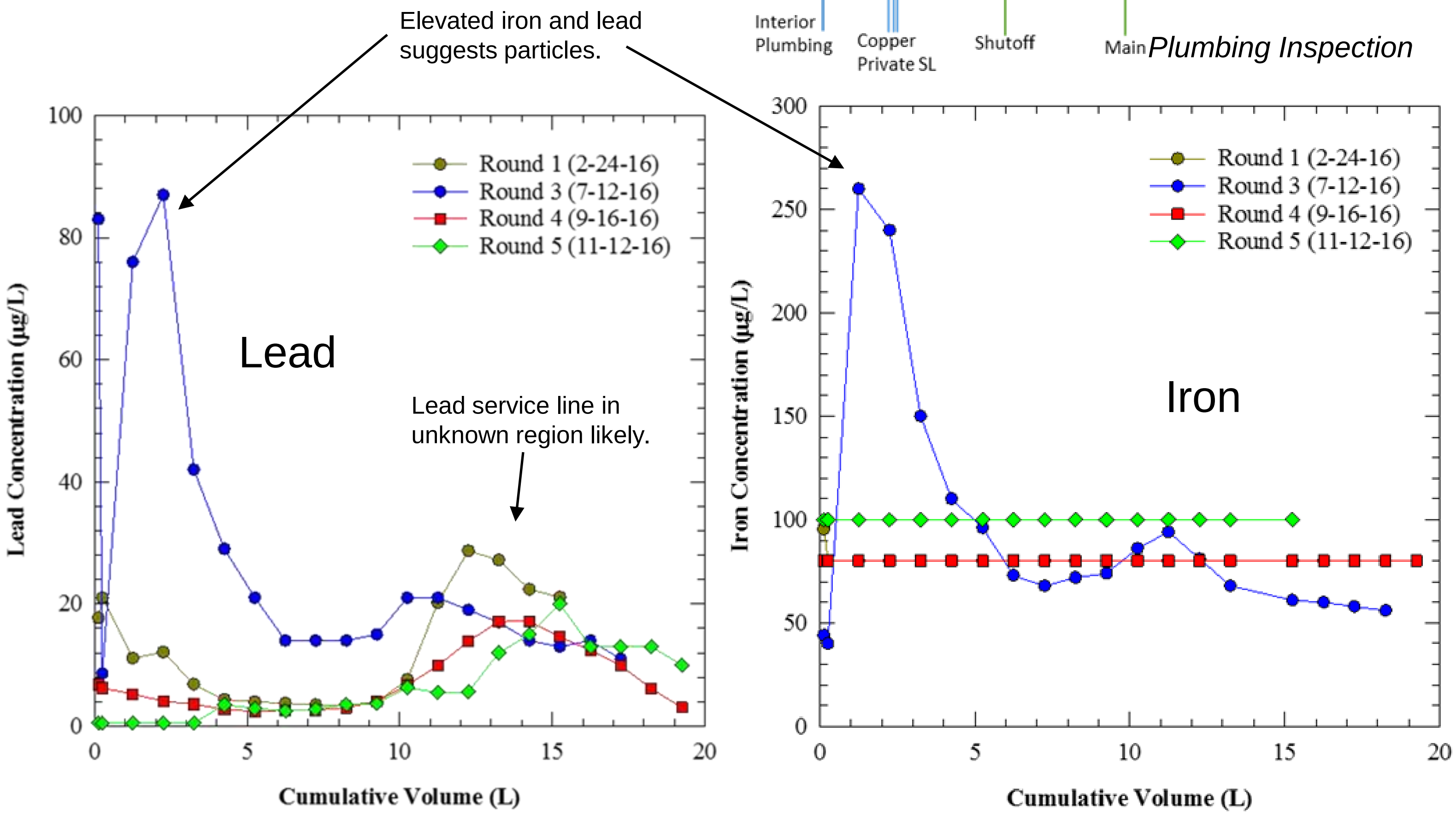
Premise Plumbing Configuration and Lead Sources



Sequential Sampling to Identify Lead Sources

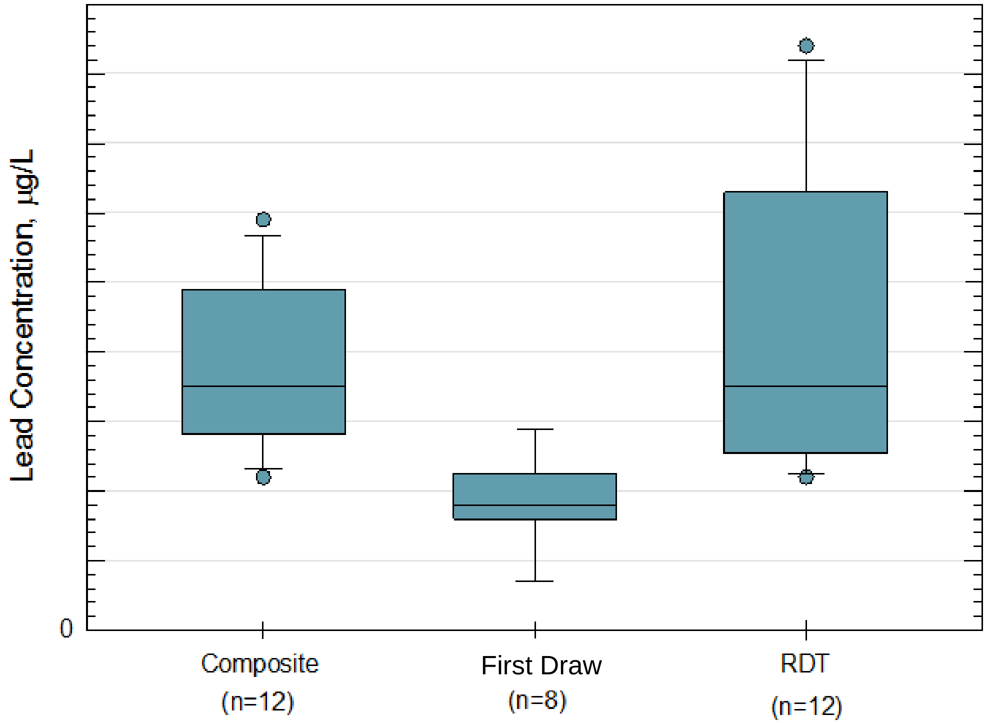


Plumbing Inspection



Two lead sources: 1) Associated with iron corrosion – likely particulate lead, 2) From the lead service line – likely dissolved lead.

Pb Concentrations by Sampling Method



From "A Simulated Household Plumbing System to Understand Water Quality and Corrosion," Cahalan and Lytle, Proceedings of the AWWA Annual Conference, 2017.

Three sampling methods

- First draw results from this limited study are lower because method does not capture water from lead service line
- High variability in results for Composite and Random Daytime sampling, but mean values similar
- These results are for one water quality and one lead scale condition

Situational Issues

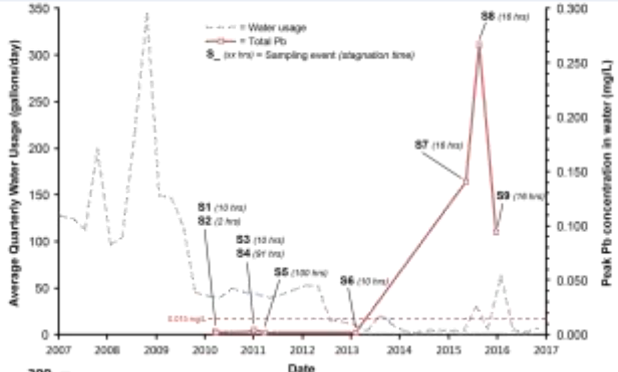
Water Quality Impacts

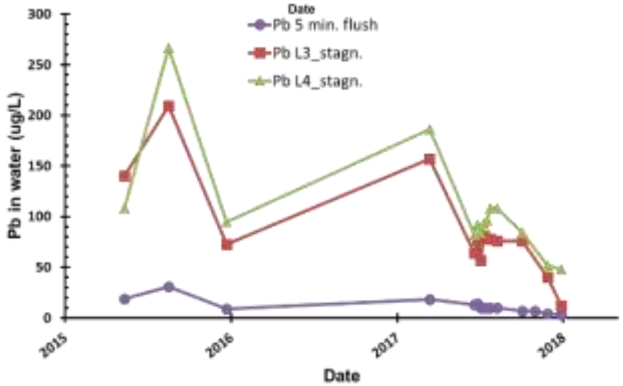
Problem: Water quality changes can result in Pb release

Examples: Abandoned homes and treatment changes

Abandoned homes

- Long term (months to years) stagnation can result in significant Pb corrosion
- The site can return to adequate Pb control but only after an extended period of time (e.g., 3-9 months), but more research is needed





Situational Issues

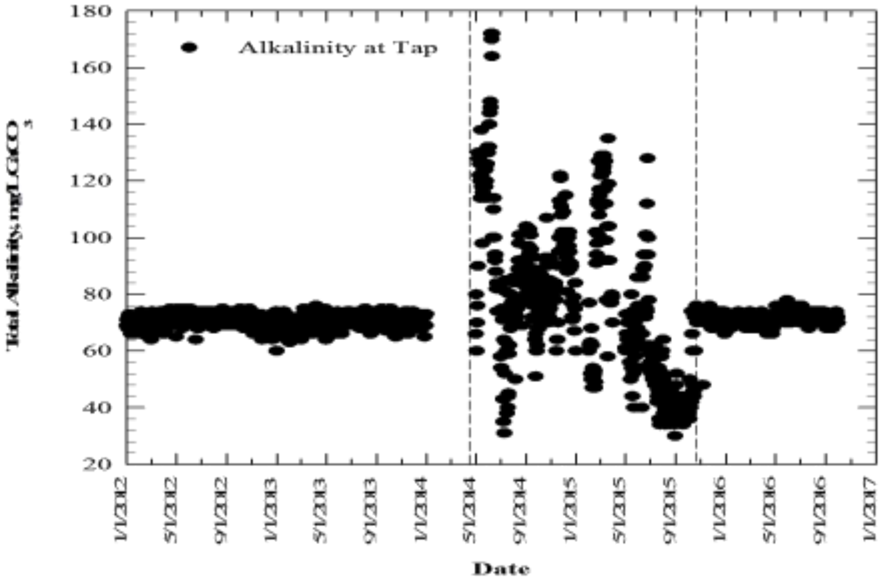
Water Quality Impacts

Problem: Water quality changes can result in Pb release

Examples: Abandoned homes and treatment changes

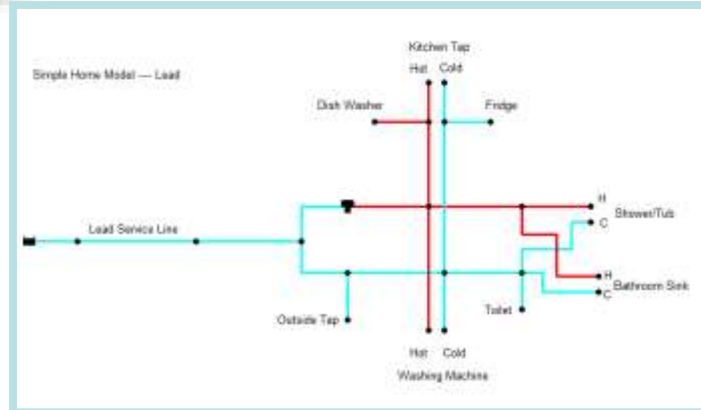
Treatment changes/Variable Water Quality

- Similarly, variations in water quality can also result in significant Pb corrosion



Premise Plumbing Modeling

Modeling water use in homes has potential to incorporate intrinsic uncertainty & variability into exposure predictions



Data → **Models** → **Results**

Data

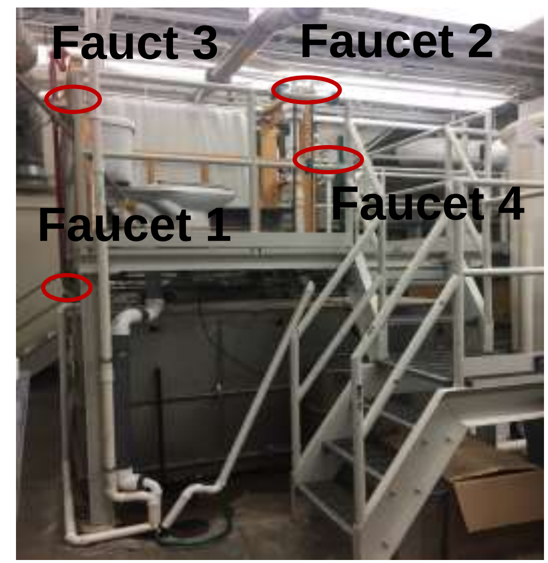
Representative distributions of hydraulic and water quality factors (Pb sources, premise plumbing, appliances, water treatment, water chemistry, pipe conditions)

Models

- EPANET model
- Water usage model
- Pb equilibrium model

Results

Statistical predictions of "average Pb concentrations" & exposure for individuals



Takeaways

- EPA ORD's multimedia Pb modeling analysis **advances scientific understanding** of the relationship between Pb levels in drinking water and BLLs in infants and young children, and it can inform a risk communication for lead in drinking water.

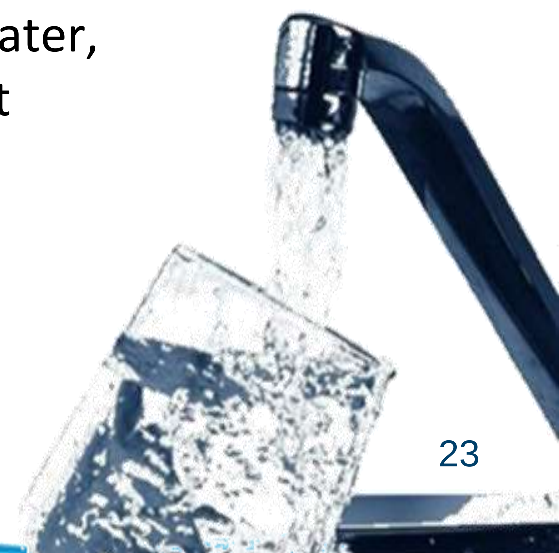
- While model evaluation provides confidence in the results, **more up-to-date data and information on key model inputs and BLLs** would help refine model estimates for quantifying and reducing uncertainties, and focusing on specific at-risk populations.

- Exposure studies with novel water Pb monitoring and modeling approaches are needed to address the spatial and temporal variability of household Pb water concentrations.

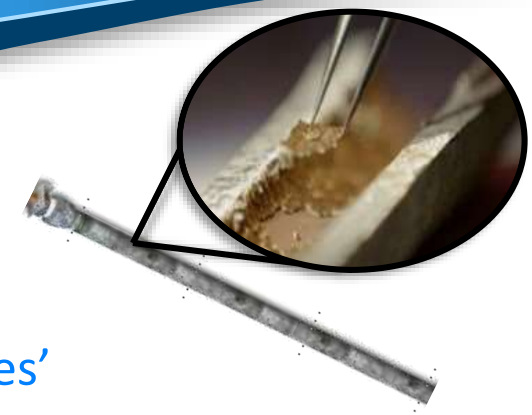
Potential Research Going Forward

- Identifying high Pb risk communities and key factors using available data, models and indices
- Improving multimedia exposures models to better understand contributions from various sources and pathways to blood lead levels

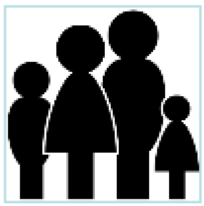
- Improving data (using measurement methods and models) for key model inputs such as water, soil, dust Pb concentrations; water/soil/dust ingestion rates; bioavailability
- Applying models, methods, data to inform decisions for risk prevention, mitigation, communication



Questions for Discussion



- Do these research areas resonate with states' science needs? Are there others?



- EPA ORD has extensive experience in lead research in both sampling and modeling - working at the national, state, community and residence level. How can we better continue to work with states to reduce lead exposure?

Acknowledgments

- EPA ORD collaborators including Jianping Xue, Rogelio Tornero-Velez, James Brown, Michael Schock, Darren Lytle, Regan Murray, Jay Garland
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- External reviewers of Multimedia Pb Modeling Approach methodology
- Colleagues in other federal agencies

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