Scope of Work

Development of a Community-Based Lead Risk and Mitigation Model (project 4965)

Principal Investigator: Cornwell Research Group

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Year Funded: 2018

Objectives

The objective of this research is to further the science of risk assessment and mitigation for lead (Pb) exposure, and to translate this into practices that limit or even eliminate Pb exposure for drinking water consumers, especially children and pregnant women. This will be accomplished through these specific tasks: (1) generation of a risk based computational model that is built on a comprehensive and enhanced national dataset (2) identification of opportunities to mitigate Pb exposure in drinking water, and (3) development of a communication framework to educate stakeholders on risk mitigation opportunities.

Background

US communities face the challenge of effectively managing Pb exposure. Even at very low levels, Pb can cause behavioral, cognitive, and a variety of other negative health effects. Pregnant women and their developing fetus (USEPA 2017f), as well as children six years old and younger, are especially susceptible to the effects of Pb. Pb is typically not found in drinking water sources (Schock and Lytle 2011, Durum et al. 1971, Fishman and Hem 1976) or in drinking water treatment chemicals (Brown et al. 2004, MacPhee et al. 2002). Pb at the customer tap is almost exclusively the result of water contact with Pb containing components (pipes, fittings, fixtures, and solder) in the distribution system, the household plumbing, or service lines connecting water mains to houses. If these materials are present anywhere in the system, Pb can be released in a soluble or insoluble form depending on the water chemistry and local hydraulic conditions.

Various strategies exist to reduce or eliminate Pb release into drinking water, including: removing Pb sources in contact with water in the service lines and customer plumbing, controlling the chemistry of water, installing an additional treatment barrier at the tap (e.g., a point of use filter), preventative removal of particulate Pb by flushing to remove loose scale or particulates, or lining or coating of Pb service lines.

To reduce Pb exposure from water, it is important to understand the water Pb level (WLL)–blood Pb level (BLL) continuum shown in the simplified diagram in Figure 1. The diagram illustrates the key critical points of intervention in the exposure pathways –there must be a source for Pb to enter the water, the Pb must be released into the water, the elevated WLL must be consumed, and the WLL must result in an elevated BLL. If the continuum can be broken at any point then the BLL impact from WLL can be eliminated or at least reduced. Equally important, if waterborne Pb is not the sole contributor to elevated BLLs, analyses can help identify the relative contributions of water, air, soil, paint, food etc. so risk reduction resources are most effectively allocated in the families most at risk. Our aim is therefore to assist in the application of advanced aggregate and cumulative risk methods, and systems analysis, in resource allocation for public health measures for Pb.

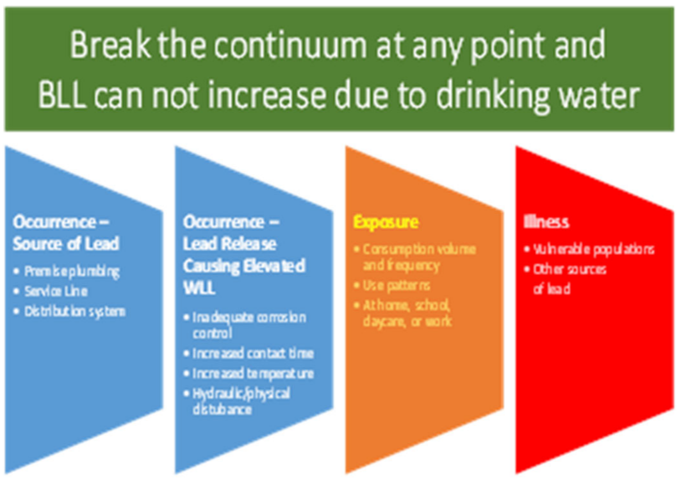

Figure 1. Simplified WLL/BLL Continuum

Unfortunately, it will likely take years to eliminate the source of all Pb in contact with drinking water supplies. Altering water chemistry can make great strides in reducing Pb release into water, but we also know chemistry alone cannot reduce WLL to zero. Utilities in many areas have been able to achieve first draw Pb values in the sub 5 ppb range (Brown et al. 2013). However, even in those cities sample volumes other than the first draw often have higher values. Also, whenever Pb is present, Pb particles will accumulate in scales and plumbing. Particles can be released randomly and Pb levels are often higher when associated with particulates (Brown et al. 2013). Water chemistry can improve upon but not eliminate particulate release.

Approach

Task 1: Modeling

A major effort in our approach is the development of a science and engineering model of water systems coupled to an advanced aggregate, probabilistic risk assessment model for Pb exposures. While the integrated model itself is a major outcome, it is important to note the several standalone offshoots that will come from the model development. The model we propose provides significant advances in the science and engineering analyses required to quantitatively assess strategies of Pb reduction and therefore risk mitigation. This risk reduction element of the model can also be a standalone deliverable and tool that could be applied on the back end of any number of contaminants and engineered systems. Accordingly, our research into probabilistic modeling of risk mitigation strategies – incorporating advanced variability and uncertainty methods – not only is used in the integrated model but can be used by itself to support decisions allocating mitigation resources to most effectively reduce risk. Similar stand-alone elements of our approach include:

- Home plumbing risk reduction research
- Pb isotope research into BLL contributions from paint or other sources versus water
- Cost-benefit analysis of risk reduction through mitigation steps
- Additional research on actual Pb consumption

Figure 2 illustrates the framework for the Quantitative Lead Risk Model (QLRM) that will be constructed. The engineering elements include many key factors that go into predicting Pb levels at the tap that are described in the approach below. The QLRM includes two components. The 1st is the engineering model predicting WLLs for a specific situation and predicting changes to WLLs due to changes in input variables. The second model component predicts BLLs based on the WLL data and other exposure factors.

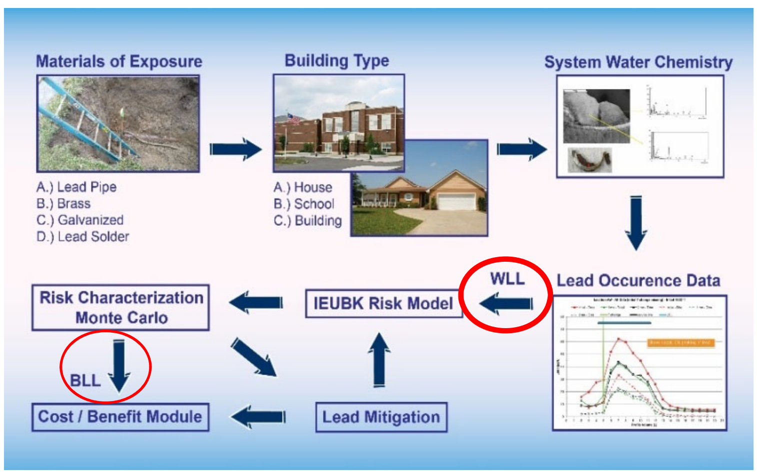

FIGURE 2. QUANTITATIVE PB RISK MODEL (QLRM)

Interrelationships will be built among the engineering variables using nationally collected data described later as well as enhancements to the national dataset as a result of the specific research conducted herein. The model will allow a user to input site specific information. By entering community specific data for conditions identified in the research, statistical relationships coupled with Monte Carlo simulations will allow prediction of WLL. This WLL coupled with the BLL risk model allows for prioritization of areas for intervention and coupled with the cost-benefit tool in the model allows assessment of the best mitigation approach to use for improved public health.

Even an advanced integrated model can only go so far in predicting specific risks or the effects of a remediation action. Therefore, the outcome of this research will also include a strategy and methodology for a community to evaluate their specific situation through more site-specific data, including monitoring of success or failure following remediation, and to update the estimates of risk and remediation effectiveness accordingly. The model will allow for a community or even an individual to input local factors such as type of lead containing materials, home age, presence of lead paint, local water chemistry, etc. Lead reduction strategies can also be entered. Several outputs are available from the model, particularly resultant BLL. The model will also contain a cost/benefit module to allow the community to assess the best lead reduction strategies. This combination of model and future monitoring allows for adaptive management (Linkov et al 2006) in which a path of remediation selected initially on the basis of broad community characteristics may be adjusted as data flows into a project and attention begins to focus onto the most at-risk properties that may not be well represented by existing aggregated data.

We propose five risk metrics to inform remediation decisions. Each will be available as output with and without remediation actions, for each defined population.

- Water Pb Levels (WLL): Percentage and size of population with WLLs above a target value
- Water Pb Exposure Levels (WEL): Percentage of population with WELs above a target value
- Water Blood Pb Levels (WBLL): Percentage of population with WBLLs above a target value
- Total Pb Exposure Levels (TEL) : Percentage of population with TELs above a target value for daily intake of Pb by all pathways
- Total Blood Pb Levels (BLL): Percentage and size of population with BLLs above a target value for blood Pb due to intake of Pb by all pathways

The objective of the engineering side of the model is to improve prediction of WLL. The overall approach is to collect and utilize existing national data, supplemented with additional data collection, and to build relationships among the variables that when coupled with probabilistic analysis allows for better WLL prediction.

Elements of the engineering side of the overall risk model were graphically shown in Figure 2. While not exhaustive the list of required data that will be developed in this project includes:

- National Pb occurrence
  - By structure type –home, building, school
  - LCR first draw Pb data
  - Extrapolation to potential WLL as a function of sampling protocol, including developing a new sampling approach to assess exposure
- Materials of exposure (e.g. Pb, brass, Pb solder, galvanized)
- Home age data
- System water chemistry—to build relationships between Pb levels and chemistry on a national basis to relate CCT or water quality changes to Pb levels

In addition to gathering and analysis of meta-data, our approach includes research elements integrated into the engineering model, including:

- Home level research on factors from the main to the tap that contribute to resident WLL and therefore could be mitigated.
- Determine if national BLL data available from the CDC and WLL data can be integrated as a predictive tool, especially if augmented with other data such as water chemistry and house age.
- Forensic Isotopic Exposure analysis to estimate BLL contribution from water (WBLL) versus other sources (e.g. paint)

As these data are gathered and additional data obtained, a critical component of the engineering model development will be to build the interrelationships among the data sets to allow for predictive modeling of community WLL. Our team recently completed a similar interrelationship model to assess bromide versus DBP formation. Any major gaps found as we gather national data will be supplemented by additional sampling, but we believe that we can minimize the need for additional Pb profile sampling based on our experience.

Lead Isotope Analysis

Historically, we have been unable to distinguish whether elevated BLLs are due to the water or some other source such as soil, dust, or paint. Modeling can be accomplished based on environmental factors, but traditional BLL and WLL testing is only for total Pb concentrations. This does not tell us anything about the source of Pb. In contrast, isotopes tell us about the source. A member our research team, Dr. Kamenov from UF is an expert in forensic Pb isotope analysis, and has been developing an international Pb isotopic database on sources of Pb to humans (Kamenov and Gulson, 2014; Kamenov and Curtis, 2017). His work has shown that by comparing the Pb isotope compositions of samples such as teeth, bone, hair, or blood to the Pb isotopic compositions of possible sources in a given area (or even a single household) one can identify the sources of the Pb accumulated in human body. In absence of man-made point-sources, such as Pb pipes or Pb paint, the overall consensus is that the main source of Pb to the human body is local soil and dust (Kamenov and Gulson, 2014). Furthermore, utilizing high-precision Pb isotope analyses we can quantify the exact amount of Pb contribution from each source, if multiple sources are involved. Figure 3 shows the isotope values for several teeth specimens vs. Pb pipe. While this pipe sample is not paired with any of the teeth it is easy to see from the spread of data in the Figure how paired blood, water lead, paint and soil can be used to identify the blood lead source.

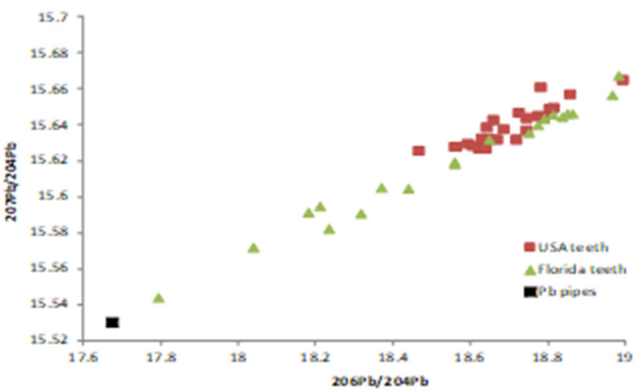

Figure 3. Pb isotope data for adult teeth with an example pipe Pb signature

In contrast to teeth and bones, which provide a long-term (months-years) exposure record, blood provides short-term (days to weeks) exposure record. Therefore, we will perform high-precision Pb isotopes analysis and compare to drinking water Pb to other sources in the area/household to identify the prevalent Pb source. Cornwell has been working with Kamenov over the past year to begin developing a Pb pipe isotope database based on extracted pipe samples. To date, we have found that Pb in LSLs appears to be made from low-radiogenic

Pb (low Pb isotope ratios, Figure 3), which is very different than the MVT (Mississippi Valley Type Pb ore) Pb that was used after 1960 in the USA. In contrast, the majority of the USA teeth show high Pb isotope ratios indicating Pb coming from MVT (Kamenov and Gulson, 2014). Virtually anything after 1960 would be made with MVT Pb (e.g., fixtures, leaded gasoline, and subsequently Pb contaminated soil/dust, etc.) and so it would be easy to identify and quantify Pb coming from old Pb pipes/fixtures (WLL) with Pb isotopes. The only complication with the proposed technique would be if paint or Pb source other than plumbing was made with exactly the same Pb ore as the pipes/fixtures. In such cases we may not be able to distinguish the BLL source. However, using the high-precision Pb isotope technique we think that small differences should be identifiable even in cases with Pb coming from the same ore source due to variations in smelting, manufacturing, or other practices.

We have had preliminary discussions with public health departments indicating they are willing to collaborate on this research project. When the health department collects a child's blood for BLL, if it is elevated over a defined value, they would send a split sample to UF. Under the HUD lead risk program, when BLL is elevated they have protocols to collect a paint chip, soil sample and water sample which can be split with UF. We plan to conduct approximately 60 analyses with five to ten health departments in areas with elevated Pb. The results of this research will be used in two ways. First if successful this testing is relatively inexpensive and would allow a community to actually do its own evaluations to better estimate exposure routes. Secondly, if we find the testing exposure results do not match the risk model results, future work may be needed in redefining the risk model.

Task 2: Lead Reduction Strategies

There are many publications available on lead reduction strategies. They typically target one or more of the following: a) reduction/elimination of Pb content in pipe, solder, fixtures and other materials in contact with water; b) adjustment (improvement) and maintenance of water chemistry in finished water distributed to customers; c) using lead removal filters, d) dislodgement and removal of loose scale and other deposits that contain particulate Pb or sorbed soluble Pb; and e) changing customer water use practices. Our innovative research plan and application of our day-to-day experiences solving corrosion problems will supplement industry understanding of mitigation strategies. We will better define WLL reductions associated with each strategy. We will also verify WLL reduction impacts using several different sampling regimes. Specific interventions will be modeled to determine the degree to which they mitigate particular exposure pathways, allowing customers and members of the public to break the WLL/BLL continuum shown previously.

Including a cost-benefit module is a key component to the final user decision making. The cost–benefits module linked from the mitigation toolbox allows prioritization of mitigation strategies. The benefits side is basically reduced BLL for the selected population of interest. The cost component will include the costs of enacting a given strategy. We will develop the costs for the different mitigations. Users will need to input the selected strategy and number of units—e.g., replace 100 LSLs or provide 100 filters. The Cornwell team is actually already developing many of these cost scenarios under contract with AWWA. Those costs can be modified and supplemented as needed and incorporated in the model.

Task 3: Education and Outreach

Education and outreach on risk factors and opportunities to mitigate those risks will be a central theme of the entire project and will be executed through various pathways. The communication framework will have widespread distribution to vulnerable communities, the general public, water utilities, and other stakeholders. There will be a focus on collaborating with various national and regional organizations dedicated to public health protection.

The effort on outreach will build on existing AWWA assets, collaborations, and communication channels to fulfill the objectives of the project. It will leverage the strategic and practical experience of a national Public Affairs Council that includes communications professionals from water utilities, academia, consulting firms, and other water associations. With 38 sections throughout the United States, AWWA can efficiently disseminate information to water utilities in each geographic region, and by extension, to utility customers. The project findings will also be shared through professional sessions at various water sector conferences.

AWWA has created a web-based Pb Resource Community (AWWA 2017a) and a Pb Communications Toolkit (AWWA 2017b) that are accessible to everyone, including the general public. The Pb communications materials will be updated and extended to reflect and disseminate the findings of the project. At the same time, AWWA can utilize several communications tools to draw attention to the updates, including its e-mail newsletter (available to all website visitors), operator magazine, technical journal and several active social media platforms. The Drinktap.org website is a direct-to-consumer platform for engaging water customers in tap water quality issues.

Social media will be employed for two primary purposes: a) to share risk mitigation opportunities with water consumers who may be at risk from Pb in water, and b) to inform and engage water utilities, public health professionals, plumbers, and other stakeholders on project findings and pathways to risk reduction. AWWA worked with EPA, the US Department of Housing and Urban Development and the US Centers for Disease Control and Prevention in October 2016 to spread the messages they had developed for Pb Poisoning Prevention Week, distributed a radio public service announcement, and engaged in social media. For this project, tactics such as the development of infographics communicating how to protect against Pb exposure through water – as informed by the project - will be used, and AWWA's social media accounts on LinkedIn, Twitter, Facebook, Instagram and Pinterest will help disseminate audience-appropriate information throughout the project's duration.

AWWA, WRF, ASDWA, and NRWA are all members of the Pb Service Line Replacement Collaborative (LSLR Collaborative 2017). Other collaborative members include consumer and environmental advocates, health professionals, home builders, public officials and other stakeholders focused on preventing Pb exposure through water. These established partnerships with organizations representing vulnerable and exposed populations will ensure communication materials are available to those most at risk from lead exposure.

Expected Outcomes

The ultimate expected benefit of this effort is to contribute to reduction in lead exposure through the drinking water pathway. This will be accomplished by developing a risk model that allows for the identification of at-risk locations and also provides guidance on how a community or even a resident can reduce exposure through specific interventions. The findings will be applicable to vulnerable members of the general public as well as small and large communities across the US with varying water quality. Specific outputs will include: (1) a risk based model that is built on a comprehensive and enhanced national dataset (2) mitigation strategies directly applicable to type and severity of risk, (3) advancement of the state-of-the-science understanding of WLL and BLL through several innovative research approaches, and (4) a communications framework to educate stakeholders on risk occurrence and mitigation opportunities.

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