LEAD REDUCTION PROGRAM PLAN

APPENDICES

VOLUME 1 OF 2

DENVER WATER

APPENDIX I.A – PUBLIC COMMENT FORM RESPONSES

September 2019

DENVER WATER

Appendix 1.A. Public Comment Form Responses

Denver Water conducted a public comment period from July 12 to Aug. 7 to gather feedback on the program benefits, filter preferences, communication preferences and overall support. The information was distributed through a variety of different engagement channels such as newsletters, targeted emails to stakeholders and customers who have expressed an interest in Denver Water's lead reduction efforts, TAP news site distribution, social media, distributors, neighborhood groups, etc. During this four-week period, Denver Water received 406 comments from unique IP addresses that have indicated that more than 98% of respondents support the Lead Reduction Program, emphasizing benefits for future generations, environmental health and protecting infants and children. Full results are below.

Breakdown of Most Common Respondent Zip Codes and Corresponding Results

Zip Code	Neighborhoods	Number of Respondents	Percentage of Total Respondents	Top way to make the use of filters more convenient and accessible	Percentage of Program Support (Strongly support and more likely to support)
80220	Crestmoor, East Colfax, Hale, Hilltop, Montclair, Northeast (NE), Park Hill, South Park Hill, Southeast (SE)	50	12%	Offer at-home consultations with a Denver Water representative on filter use and maintenance, as well as installation if needed.	98%
80210	Cory Merrill, Platte Park, Rosedale, Southeast (SE), University, University Park, Washington Park, Washington Park West, Wellshire	42	10%	Offer at-home consultations with a Denver Water representative on filter use and maintenance, as well as installation if needed.	100%
80205	Ballpark, City Park, City Park West, Clayton, Cole, Curtis Park, Five Points, North Capitol Hill, Northeast (NE), Skyland, Uptown, Whittier	38	9%	Provide option for filter pick-up or at-home delivery. Provide option for replacement cartridge pick-up or delivery through a cartridge voucher system.	100%
80207	North Park Hill, Northeast (NE), Northeast Park Hill, Park Hill, South Park Hill, Stapleton	38	9%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	100%

80209	Belcaro, Bonnie Brae, Cherry Creek, Country Club, Polo Grounds, Southeast (SE), Speer, Washington Park, Washington Park West	32	8%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	100%
80211	Berkeley, Highland, Jefferson Park, Northwest, Sloan Lake, Sunnyside, West Highland	27	7%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	100%
80212	Barkeley Village, Berkeley, Berkeley Gardens, Berkeley Industrial Park, Berkeley Village, Lowell, Mastin Industrial Park, Northwest, Regis, Regis Place, Saint Claire, Sloan Lake, Sunnyside Manor, Tennyson Industrial Park, West Highland	26	6%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	100%
80206	Cheesman Park, Cherry Creek, City Park, City Park West, Congress Park, Country Club, Southeast (SE), Uptown	25	6%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	96%
80204	Auraria, Baker, Barnum, Barnum West, CBD (Central Business District), Civic Center, Colfax, Downtown (Central Business District), Golden Triangle, Lincoln Park (La Alma), Lower Downtown (LoDo), Sheridan Boulevard, Sloan Lake, Southwest (SW), Sun Valley, Union Station, Valverde, Villa Park	16	4%	Offer at-home consultations with a Denver Water representative on filter use and maintenance, as well as installation if needed.	93%

80223	Athmar Park, Baker, College View, Overland, Ruby Hill, South Platte, Southwest (SW), Valverde	14	3%	Provide customers with the option to select a preferred filter type (i.e. pitcher filter, refrigerator, etc.).	100%
80218	Alamo Placita, Capitol Hill, Cheesman Park, City Park West, Country Club, Five Points, North Capitol Hill, Speer, Uptown	12	3%	Offer at-home consultations with a Denver Water representative on filter use and maintenance, as well as installation if needed.	100%

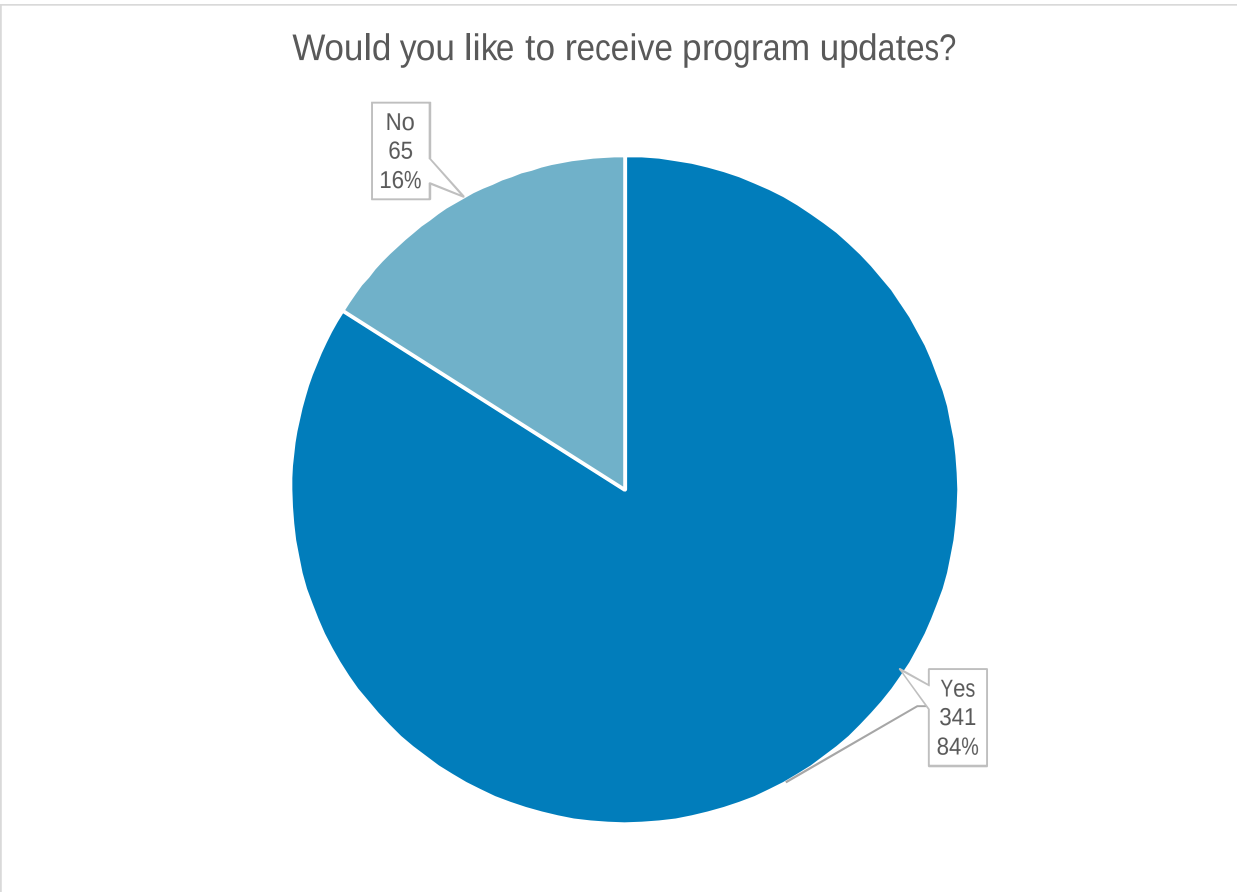
Additional respondent zip codes included:

Zip Code	Number of Respondents	Percentage of Total Respondents
80231	8	2%
80221	7	2%
80203	6	1.5%
80120	4	1%
80216	4	1%
80246	4	1%
80123	3	<1%
80219	3	<1%
80333	3	<1%
80111	2	<1%
80121	2	<1%
80222	2	<1%
80229	2	<1%
80236	2	<1%
80237	2	<1%
80238	2	<1%
01027	1	<1%
20009	1	<1%
22937	1	<1%
80004	1	<1%
80014	1	<1%
80016	1	<1%
80022	1	<1%
80035	1	<1%
80110	1	<1%
80214	1	<1%
80215	1	<1%
80224	1	<1%
80228	1	<1%
80232	1	<1%
80235	1	<1%
80241	1	<1%

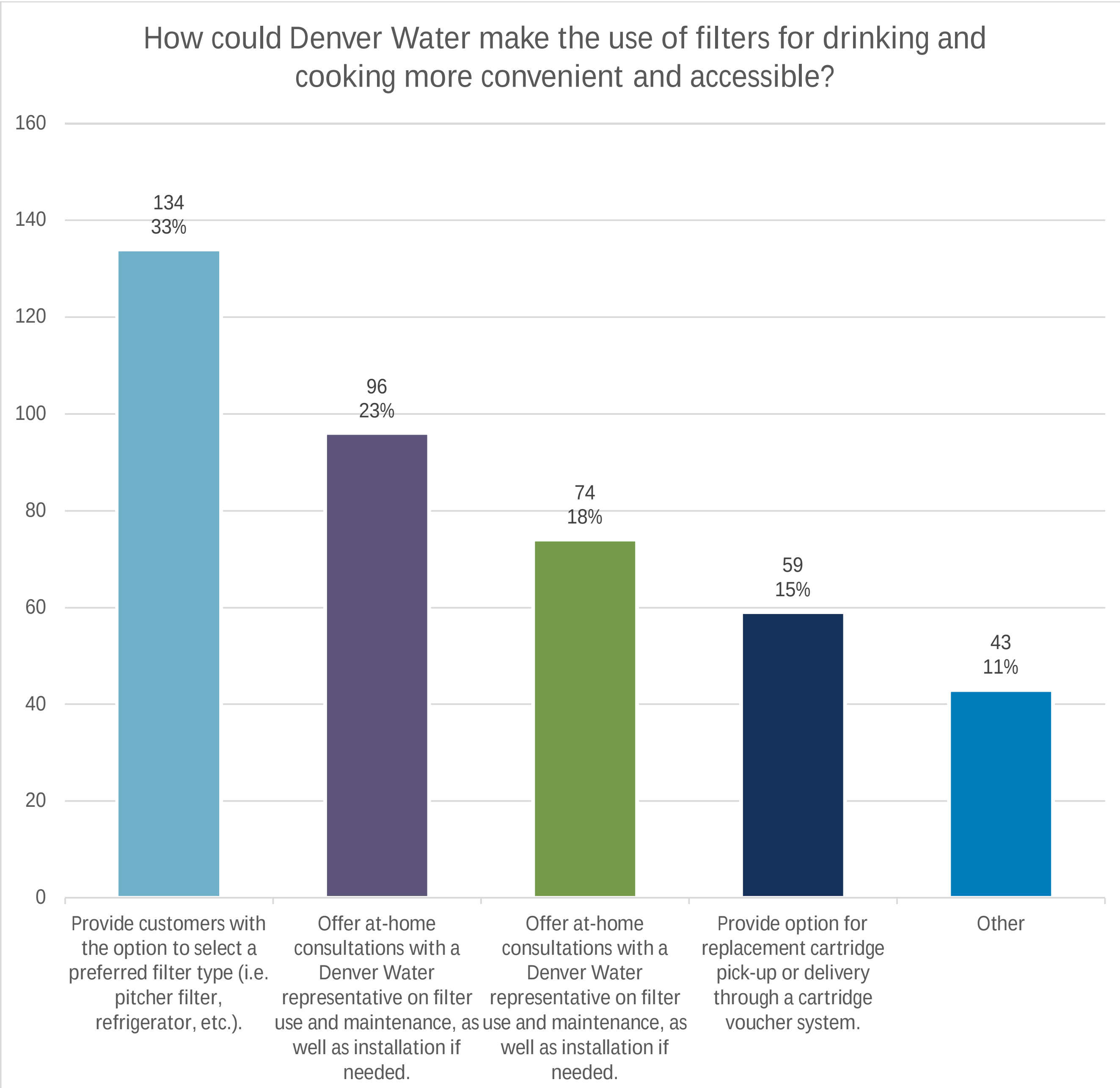
80247	1	<1%
80250	1	<1%
80401	1	<1%
80504	1	<1%
81623	1	<1%
89231	1	<1%
803204*	1	<1%

**Zip codes are presented as entered by respondents.*

Question Answer Results

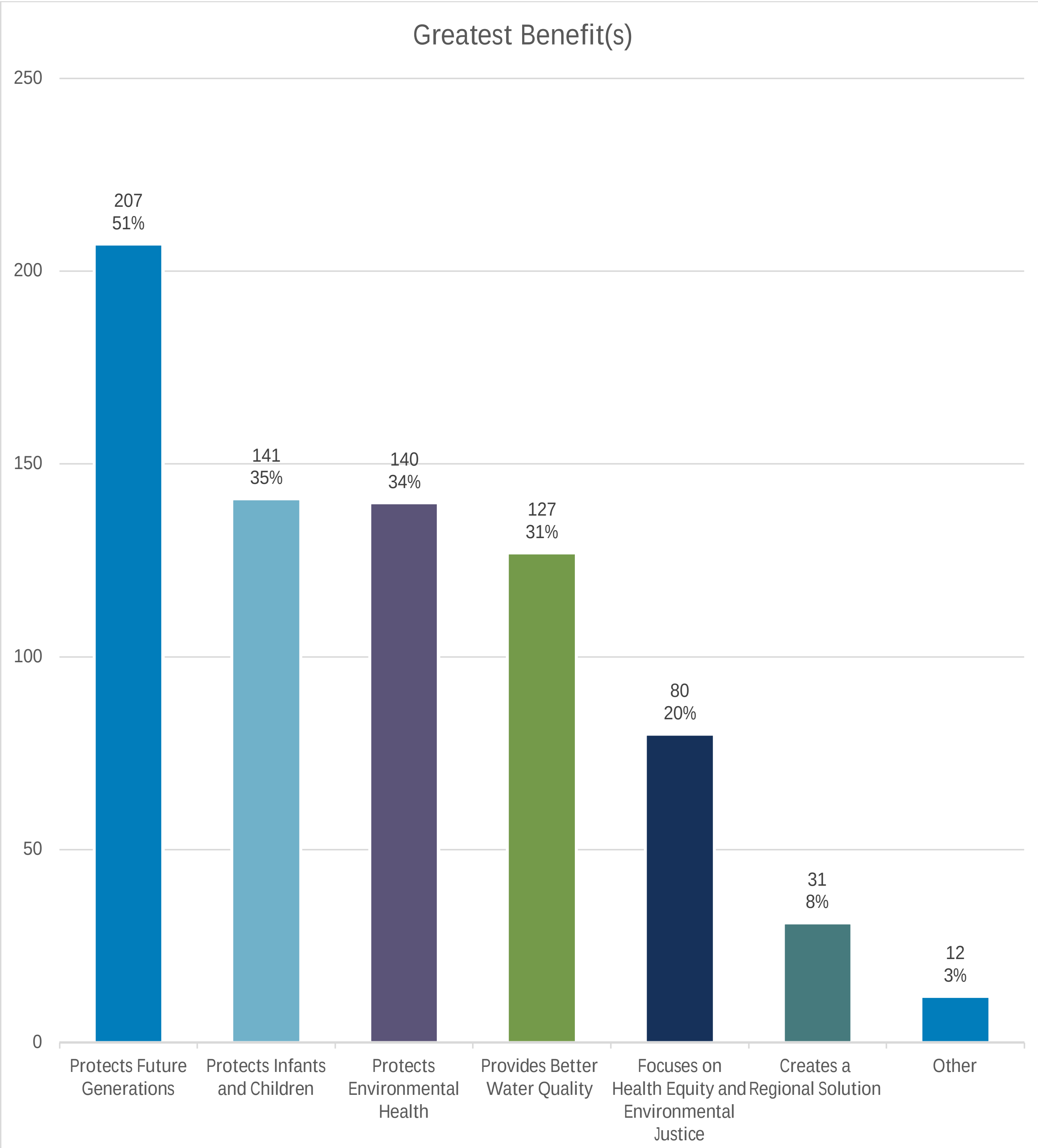


1. As part of the proposed Lead Reduction Program, Denver Water would provide at-home filters to customers with a suspected lead service line, free of charge. How could Denver Water make the use of filters for drinking and cooking more convenient and accessible? (Select one)



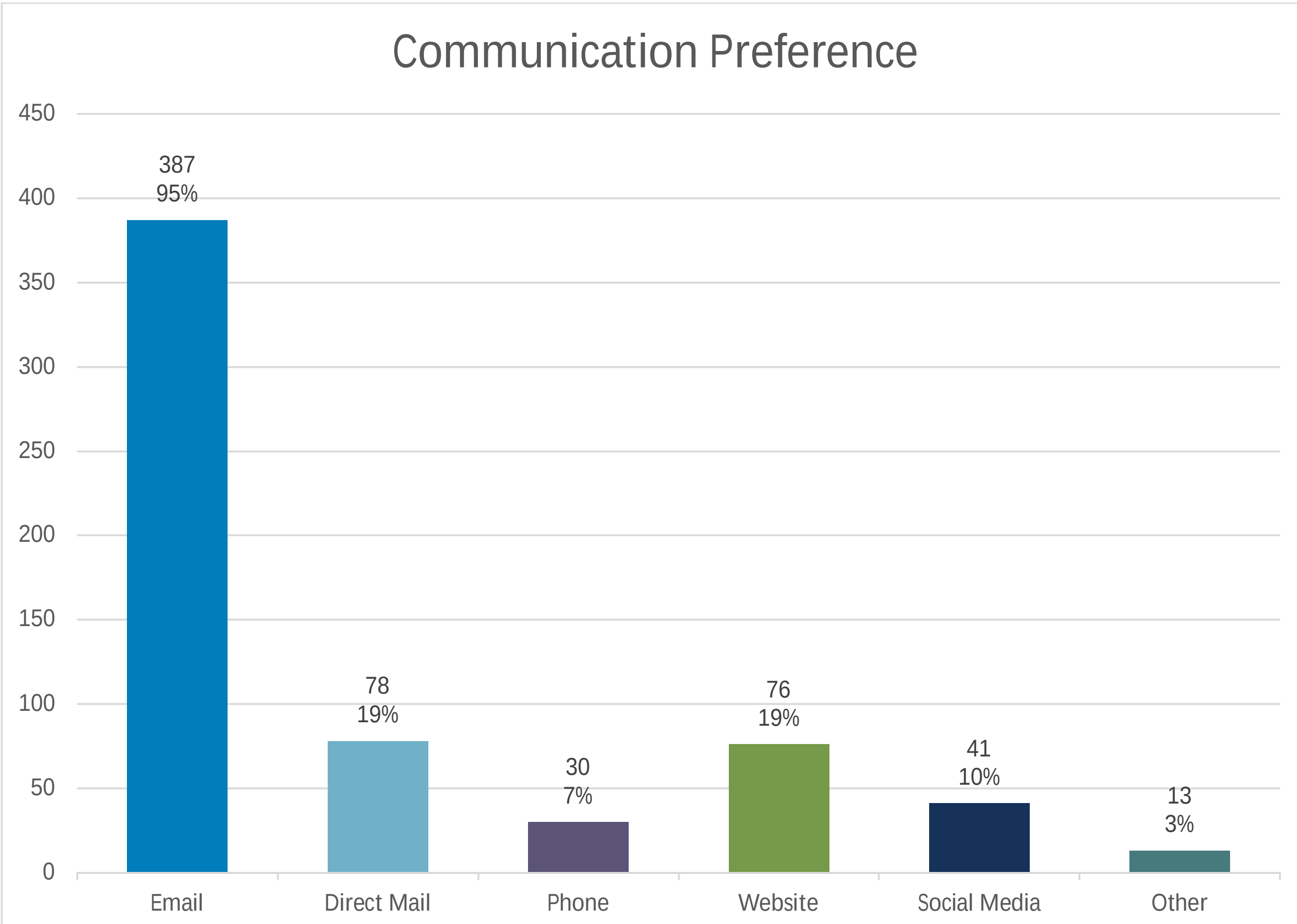
"Other" responses available following response result graphs.

2. What do you see as the greatest benefit of the proposed Lead Reduction Program? (Select up to two)



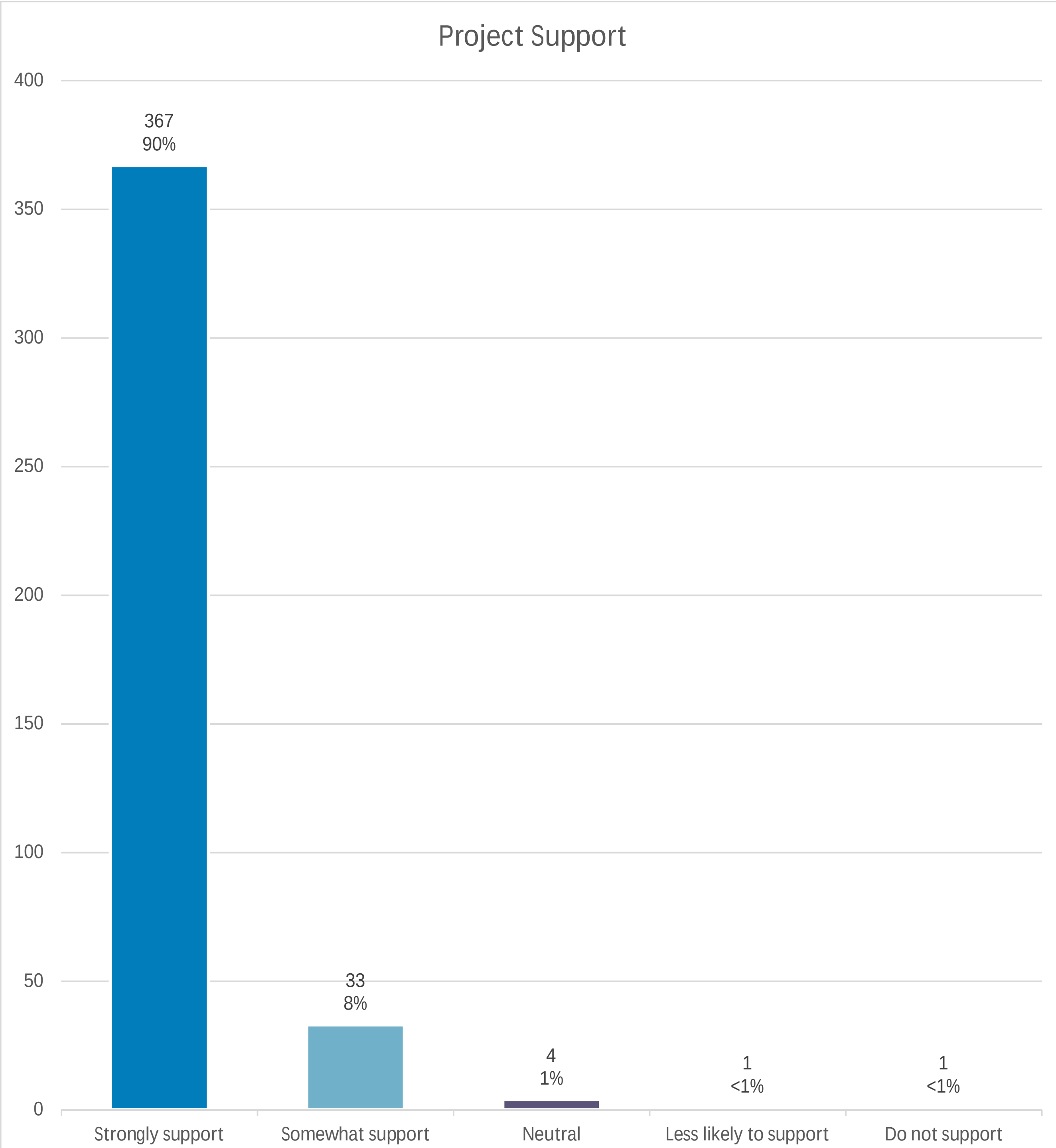
**"Other" responses available following response result graphs.*

3. What is your preference for how we communicate information and updates on the proposed Lead Reduction Program Plan? (Select all that apply)

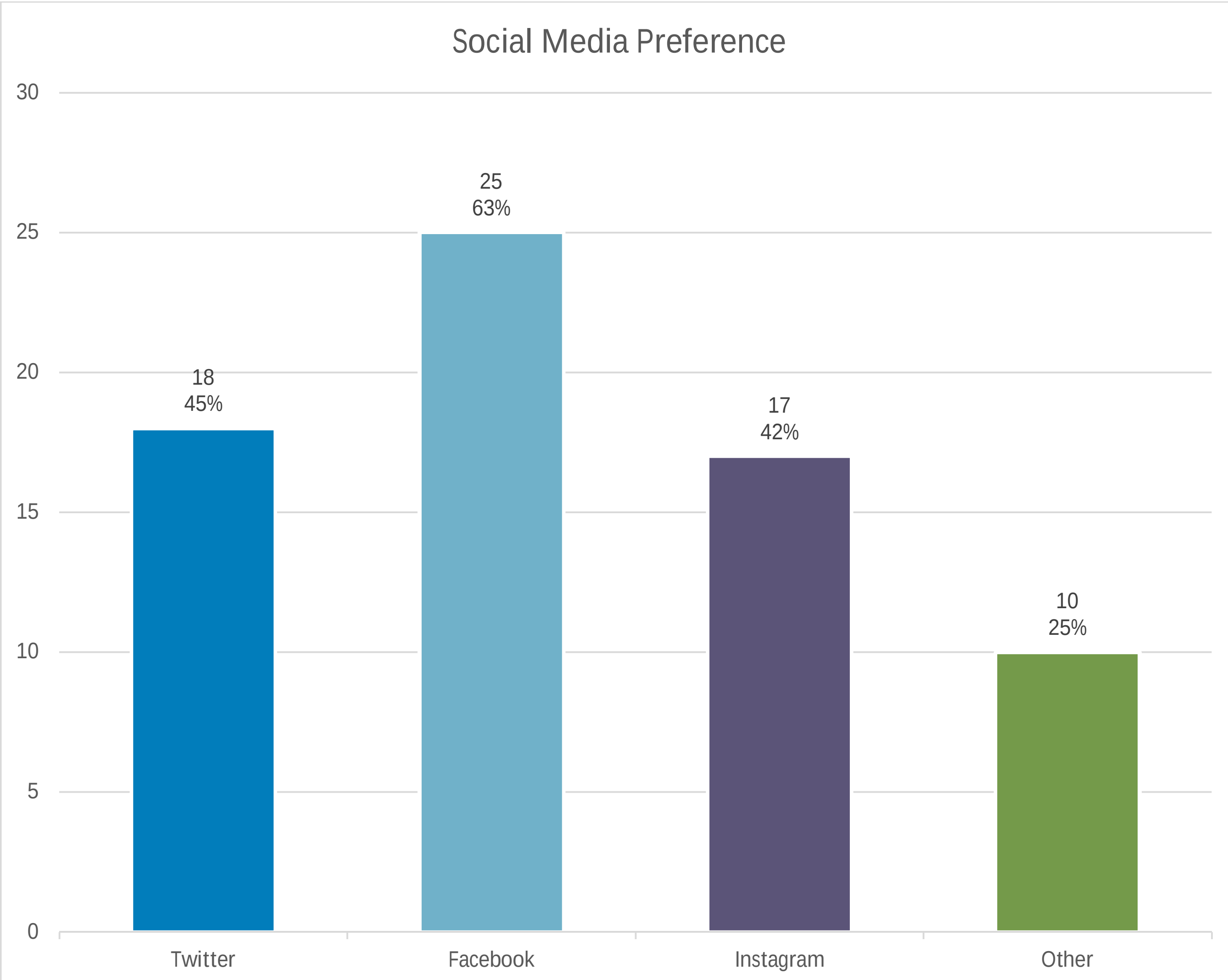


**"Other" responses available following response result graphs.*

4. How would you characterize your overall support for the proposed Lead Reduction Program?



5. Which social media option is your preference for how we communicate information and updates on the proposed Lead Reduction Program Plan? (Select all that apply)



Raw Comments

The following comments are included as they were received. No edits have been made to spelling, grammar or punctuation.

"Other" responses to How could Denver Water make the use of filters for drinking and cooking more convenient and accessible?"
all of the above
All of these options are important for helping residents use filters correctly and consistently
The basic thrust of this aspect of the lead remediation program is good. We don't have any preferences as to the four proposed methods for distributing filters.
...
Deliver filters to every home and offer consultation at the time of the delivery or scheduled at a later date, if requested.
Provide a list of allowable filters and then provide a statement credit when homeowner submits a receipt - similar to efficient toilet program. Add in a cartridge pick-up delivery program for ongoing maintenance..
I can't answer this one as I don't know the different types of filter types, or the difference between filters vs cartridges. Don't know where I'd have to go to pick up filter or voucher. If installation on the faucet is an option, I'd prefer that over a pitcher. But I need more information to be able to answer this, Maybe i need to re-read the
I think all of the above are important - customer needs to know what will work best for them and then have the opportunity to get that filter or cartridge in the easiest way possible (home delivery seems better)
All of the above
Would like to see filter attached to the main facet (in Kitchen)
I have been using an EverPure filter for 20 years - if denver will provide filter replacements - that would be terrific. My lines are lead - 1910 - I have submitted this response a cople weeks ago -it took a lot of read - read everything - resonded - call the water dept to expressmy interest in the possiblityi of a line replacement program in 2020 - I was told I would be contacted by that department (handling the lead issue once the decisions have been made - - have heard nothing.
Free, free filter replacements, delivered to homes,
Faucet filter
Faucet filter with delivery cartridge replacement
All of the above.
My choice is whatever would most increase access and participation for households most affected, especially in high-poverty areas. Otherwise I'd say being able to choose type of filter is would be helpful to make sure it's relevant to usage.
Provide water filters for ice makers
Provide the option of a whole house filter. This would make any water in the house safe to drink and use for cooking.
Provide water service and delivery like deep rock 5 gallon bottles and dispensers
Free filtration system
I have had a filter (Everpure)on my kitchen sink and ice maker since I moved into my house in 1996
Provide preferred filter type AND offer consultation. Be clear about why the filters are necessary and how and when they should be used
I want lead lines removed!
Test water at home, recommend type of filter and provide filter of choice

X
It would be great if Denver water could supply an easy at home test kit to help determine if your pipes introduce lead into your drinking water
Install whole home filtration system
Replace lines quickly. Already filling water filters to keep up with family drinking water use is cumbersome. In time, I can see folks getting lazy with dealing with it.
all of the above.
Offer undersink units
A combination of these needs to be offered rather than just one. For example combining the option of a preferred filter type, at home consultation and filter pick-up and delivery.
I understand you are requesting I select only one option, but I believe all of these options would equally make the use of filters more convenient and accessible, and I hope you decide to employ all of these options
Provide whole house water filters to be installed on the actual water line, or replace the lead pipes entirely.
Provide maintenance support for existing filters that customers have already installed
Filters need to also be installed in the showers and bathroom sinks where we brush our teeth. It will only really help if it's a whole-house filter, and my vote is for having all of the above available. Especially with the high prices we pay for water and wastewater.
I'm worried that the pitcher filter will be too slow for families to use for their needs. But the alternatives are not cost effective. Kitchen sink filter for those without fridge filter option?
Offer filtration for whole house/water main
Familiarize customers with kitchen water faucets that connect to filters under-the-counter.
Tell me where I can pick up my free (ideally) filter.
Replace service lines ASAP and/or provide subsidies to contract third party vendors to do so.
Provide under sink or whole house option as well rather then single source such as Refrigerator or single Pitcher.
Different customers may have different needs. We already have an in-refrigerator filter, and I'd appreciate replacement filters, but that probably isn't the most helpful for other households.

“Other” responses to “What do you see as the greatest benefit of the proposed Lead Reduction Program? (Select up to two)”
The DWD's proposed mixture of remedies is markedly better than simply adding a potential pollutant to wastewater and/or landscaping run-off.
...
This program benefits and protects consumers who have the means to replace their inside lead water pipes. When the city replaces water lines into people's homes and businesses, those of us with interior lead lines will continue to be exposed to lead.
silly question. Is it better to drink lead free water? of course. For all reasons above and more
I responded as described above - I will have a lot of expense to relocate my" in house" plumbing lines to a new location to hook up to new lines pulled from the street
All of the above.
I believe the root cause of the issue must be addressed, instead of a bandaid, for current residents and future generations.
repairing outdated infrastructure
Offers a more complete solution to the lead problem than any alternative
This program addresses a minority of all Denver Water customers.
all of the above.
Protects not just infants and children but also young adults, and animals in the home as well.

“Other” responses to “What is your preference for how we communicate information and updates on the proposed Lead Reduction Program Plan? (Select all that apply)”
…
Denver Water should use as many different means of communication that are feasible in order to reach the most people.
I would like to get on the list if the replacement program is the final solution that the Water deepartment decides to take!! I've tried to do what I can to make my interst known. I tested my water in April (your program - followed instruction explicitly!!)- it's not good
text/SMS with a short update and link to details
Text
Bill inserts
text message
Denver Water TAP Headlines
text message. a number of residents in our community do not have email but do use text. It is critical that everyone has access to the information that could affect their, and their children's, health.
outreach tables at community events and flyers through schools, community centers, etc.
Nextdoor
Nextdoor.com
Some neighbors might only be reachable via direct mail

“Other” responses to “Which social media option is your preference for how we communicate information and updates on the proposed Lead Reduction Program Plan? (Select all that apply)”
Via email: jeff.shoemaker@greenwayfoundation.org
There are options for automatic cross-posting on multiple social media platforms. No need to restrict sharing.
None used
email, us mail
Use all available social media tools.
I don't follow Denver Water currently on any social media
x
Neighborhood Email Exchanges
Hold a press conference(s). Get the Mayor to talk about it in his regular Friday broadcasts
Nextdoor

What would make you more likely to support the Lead Reduction Program? ***(For those who selected “neutral”, “less likely to support” or “do not support” in response to “How would you characterize your overall support for the proposed Lead Reduction Program?”)***
...
The report states on page 7 that the biggest issue is "customer owned service lines". I'd like to know why the 2012 exceedance of the lead action level took 5 years to result in the Optimal Corrosion Report. If Denver Water did not complete the lead service line pipe rack study during that time, then what new data was used to cause the Colorado Department of Public Health and Environment to designate the use of orthophosphate? I assume that this department knew that orthophosphates "could negatively affect rivers, streams and lakes in our region". Why, then, did they suggest that solution? What are the figures regarding the cost of treating orthophosphate corrosion at waste water treatment plants? Would the addition

of orthophosphates provide lead protection for the pipes in people's homes? My concern is that people without the means to replace their inside pipes and fixtures will be less protected from lead poisoning than Denver residents who have the means to incur these costs. Are we choosing between privately run water treatment facilities' budgets and Denver residents' budgets? I don't know enough about the Denver Water Dept and it's stakeholders but if this about saving corporate dollars at consumers' expense then this is a Health Equity and Environmental Justice issue.
For DENVER to REALLY do something about this problem!!
.
I would support it if the cost was not passed on to unaffected customers. Those with lead pipes should bear the cost of mitigation.
If it didn’t involve adding chemicals to my water. If you haven’t already, please watch documentary “The Devil You Know” about DuPont and 3M dumping toxic chemicals from Teflon. This also involves a water company, the EPA and a chemical in the water. I hope this is nothing like this. Water is a precious resource we all use and it would be unwise to add harmful additives without knowing the long term effects

APPENDIX I.B – LETTERS OF SUPPORT

September 2019

DENVER WATER

Bear Creek Water and Sanitation District
2517 South Flower Street, Lakewood, CO 80227-2912

August 1, 2019

RECEIVED

AUG 05 2019

Manager's Office
Board of Water Commissioners

Jim Lochhead
CEO/Manager
Denver Water
1600 West 12th Avenue
Denver, Colorado 80204
jim.lochhead@denverwater.org

RE: Comments on Denver Water's Lead Reduction Program Plan

Dear Mr. Lochhead,

On behalf of the Board of Directors of the Bear Creek Water and Sanitation District, I submit the following comments on Denver Water's draft Lead Reduction Program Plan (dated July 11, 2019).

The District recognizes that public health experts encourage the removal of lead service lines to provide public health protection from lead exposure in drinking water. We understand that Denver Water will prove to the USEPA that the proposed Lead Reduction Program provides a higher level of public health protection than the currently planned approach involving the addition of orthophosphate. If this is confirmed by the USEPA and CDPHE, the District will support Denver Water's Variance Request if the following changes are made to the final LRP Plan that is expected to be submitted to the USEPA in August of this year:

Increased collaboration with distributors regarding the development and execution of the communications and outreach plans associated with the Lead Reduction Program Plan (LRP) – The distributors were excluded from most of the pre-variance phase communication efforts mentioned on page 42 of the document. Details released to the public were typically provided to us on the same day press releases were issued with little advance warning. Moving forward, this needs to change and can be accomplished by specifically incorporating distributors into the communications for each of the action sections of the plan.

Collaboration with distributors is specifically mentioned several places with respect to the Lead Service Line (LSL) inventory actions, which is necessary given the distributors typically have most knowledge, whether field or historical records, regarding the existence of LSLs in their distribution networks. Upon a detailed review of the LRP Plan and associated appendices, the District noted that there is no mention of distributor collaboration in Section III.C (Filter Program) or III.D (Accelerated Lead Service Line Replacement Plan). This is a significant oversight on behalf of Denver Water given that customer communication is a shared responsibility for Read & Bill distributors and the sole responsibility of Master Meter distributors.

PHONE: (303) 986-3442 EMAIL: BearCreekWater@BearCreekWater.org WEBSITE: http://BearCreekWater.org FAX: (303) 986-8213

Bear Creek Water and Sanitation District does not have any homes with lead service lines within the District boundaries. However, Bear Creek Water and Sanitation District must be prepared to answer questions from our customers regarding Denver Water's Lead Reduction Program Plan including any impact to the District and our shared customers.

The District has worked hard to build a trusted relationship with our customers, similar to what Denver Water has done so well with its own inside City customers. To ensure that trusted relationship continues through the LRP, the District should be involved in any communications directed to them as part of the execution of the LRP Plan and Communications, Outreach & Education Plan (COE Plan).

We do acknowledge Denver Water is ultimately responsible for execution of the LRP Plan as they are the regulated entity. However, for this effort to be successful, Denver Water needs to revise the LRP Plan and the COE Plan to specifically commit to involving the distributors in communications efforts on the Filter Program and the Accelerated LSL Replacement Plan. The District requests Denver Water revise the LRP Plan and the COE Plan to include specific actions:

- Each distributor will be given the option to determine how they want to participate in the customer communications process. Some may prefer to be involved as a co-lead, others may only want advance notice, and a few may defer fully to Denver Water. All should be acceptable options offered by Denver Water and each district's preference should be respected.

- With respect to the Filter Program, include the following actions:
  - Develop communication materials that can be co-branded by distributors,
  - Include distributors in any planning efforts for door-to-door campaigns and neighborhood meetings (noted on page 54),
  - Provide training and/or talking points for distributor staff to use when engaging with customers on this topic. While the District understands that Denver Water prefers to be the primary POC for detailed information on the LRP, sufficient information needs to be provided to District staff to allow for informal conversations when we encounter questions from our customers, either in the field or during our own community events.

- With respect to the Accelerated LSL Replacement Plan, Denver Water should update the summary section located on page 57 to include a reference to coordinate construction activities with distributors. There is a specific reference to "coordinating with the City and County of Denver Public Works and other area municipal, utility, and public sector agencies"; however, coordination with distributors should be called out explicitly, especially for Read & Bill and Master Meter distributors.

In addition to the requested actions above regarding communication, we request two actions detailed below regarding the process of how the distributors should be included in COE Plan, which we understand will be more fully developed if the variance request is approved. Before submitting the LRP Plan and COE Plan to the USEPA, we would request the documents be revised to both increase the number of and provide more details for meaningful opportunities for engagement on customer communication for Read & Bill and Master Meter distributors.

Commit to the addition of a distributor representative on the LRP Leadership Committee – In the LRP Plan, Section III.F (Learning by Doing) outlines the approach to the formation and operation of an LRP Leadership Committee. The district supports the formation of this committee as an oversight entity that will guide the LRP through execution. However, we are significantly concerned that the distributors are not represented on that committee, especially given that 50% of the 1.4 million people who rely on Denver Water do so through a distributor. Although current indications are that only 5% of those people have a lead service line, many more may be impacted by the LSL inventory process, the Filter Program, or even ongoing communications about the LRP. Therefore, the District requests that, as the LRP Leadership Committee "invites other stakeholders to be members, such as representatives from watershed groups, wastewater dischargers, and public health agencies" (as stated on page 72), the Distributor Forum is allocated one representative to that Committee. In addition to participating in the Committee and working collaboratively towards the LRP Plan goals, this representative would also liaise between Denver Water and the distributors, ensuring continued support from that group and working to resolve any issues that may arise during the execution of the LRP. It may be that the Forum representative serves for the first few years of the LRP Plan execution process, working through the initial communication efforts, inventory tasks, filter distribution, and coordination efforts. Participation of the Forum representative can be evaluated every few years to ensure meaningful engagement opportunities still exist. If there are none, that representative could be sunset from the Committee.

Commit to an equitable distribution of the costs associated with the LRP Plan – The District understands there will be an extensive public input process over the next year to determine the appropriate allocation of costs associated with execution of the LRP Plan. However, the District requests an immediate commitment by Denver Water to an equitable distribution of those costs. We define equitable distribution to be an allocation of costs based upon the confirmed percentage of LSLs in the entire distributor network without the traditional multiplier applied to those costs. The distributor customers should not be required to subsidize the cost of replacing LSLs located within the City and County of Denver, which is where the vast majority of the LSLs are located (according to the current LSL inventory). We believe our customers would raise significant concerns to Denver Water if the cost of LSL replacement was distributed in any other way but as stated above. As Denver Water does not share in the cost of maintaining our customer's private systems, neither should the distributor customers be required to do that for inside City customers.

In conclusion, the District reiterates the need for Denver Water to revise the LRP Plan, including the appendix containing the COE Plan, to incorporate the requests outlined in this letter. The District will support the variance request and work collaboratively with Denver Water if those requests are incorporated into the final version of the LRP Plan. Successful execution of the LRP Plan depends on support from the distributor community as well as many other stakeholders located in the Denver metro area. Together we can achieve the goal of removing LSLs in our communities and significantly impacting public health protection through reduced exposure to lead in drinking water.

PHONE: (303) 986-3442 EMAIL: BearCreekWater@BearCreekWater.org WEBSITE: http://BearCreekWater.org FAX: (303) 986-8213

Should you have any questions or concerns about this letter, I can be reached by telephone at 303-986-3442 or e-mail at janwalker@bearcreekwater.org

Sincerely,

Jan C. Walker

Jan C. Walker
District Manager
Bear Creek Water and Sanitation District

cc: Dale L. Miller, Chairman, Bear Creek Water and Sanitation District
Denver Water Lead Reduction Program (lead@denverwater.org)
Julie Seagren, Denver Water Distributor Relations Manager
(julie.seagren@denverwater.org)

Citizens Advisory Committee

August 7, 2019

To: Lead Reduction Program, lead@denverwater.org

RE: Comments on Denver Water's Lead Reduction Program Plan

Dear Lead Reduction Program Staff,

On behalf of the Denver Water Citizen's Advisory Committee (CAC), I submit the following comments on Denver Water's draft Lead Reduction Program Plan (dated July 11, 2019).

The CAC recognizes that drinking water and public health experts encourage the removal of lead service lines to provide public health protection from lead exposure in drinking water. We are aware that Denver Water has substantial evidence and rationale to support a Variance Request from the USEPA to employ the proposed Lead Reduction Program (LRP), as it provides a higher level of public health protection than the currently planned approach involving the addition of orthophosphate. The CAC supports Denver Water's Variance Request.

On this matter, the CAC further advises that Denver Water:

- Commit to an equitable distribution of LRP costs and an early adoption of guiding principles to be applied in determining how costs will be distributed. Such guiding principles could include having property owners primarily responsible, not applying the cost adder for LRP costs for outside of City rate setting, seeking other sources of funding/financing, etc.
- Expand the LRP Leadership Committee to include representation from Water Distributors and outside of City Total Service Customers.
- Continue to coordinate an extensive communication plan with all customer classes.

Successful execution of the LRP Plan depends on support from many stakeholders located in the Denver metro area. Together we can achieve the goal of public health protection through reduced exposure to lead in drinking water.

Respectfully submitted on behalf of CAC,

Loretta Pineda
Chair, Denver Water CAC

CLEAN WATER ACTION | CLEAN WATER FUND

August 7, 2019

Jim Lochhead, Chief Executive Officer
Denver Water
1600 W. 12th Ave
Denver, CO 80204

RE: LEAD REDUCTION PROGRAM PLAN — July 11, 2019 Draft for Public Comment

Dear Mr. Lochhead:

Clean Water Action appreciates the opportunity to comment on Denver Water's Lead Reduction Program Plan. For over forty years, Clean Water Action's national water programs have focused on addressing threats to drinking water and water quality by winning strong water pollution controls, including through Safe Drinking Water Act (SDWA) and Clean Water Act implementation. We also pioneer innovative collaborations to support fundamental changes in how water pollution and drinking water challenges are approached.

Clean Water Action strongly supports Denver Water's commitment to seek an alternative to orthophosphate that will achieve the same or greater reduction in lead exposure risk for its customers. Denver Water's proposal is an innovative approach to address unintended consequences of orthophosphate treatment, and if approved as proposed and carried out successfully, will provide a greater benefit to public health and the environment.

Our comments below highlight what we consider the greatest strengths of Denver Water's plan and we also offer some recommendations for the utility to consider as it continues to revise and refine its plan.

Plan Strengths

Goes after the source of lead instead of just treating the symptoms: Fully replacing all known lead service lines in Denver Water's service area within 15 years will permanently eliminate the largest source of lead in drinking water from its service area. The most effective and sustainable way to limit exposure to lead in drinking water is to remove lead at the source, which, for lead in drinking water, means fully replacing all lead service lines.

Provides health protection while customers wait to have service lines replaced: To address concerns that some residents may have to wait up to 15 years to have their lead service lines replaced, Denver Water will provide filters that reduce lead by 97 percent for all customers with lead service lines until six months after their lead service line is replaced.

Focuses on health equity and environmental justice: By replacing lead service lines at no-cost to the property owner, all Denver Water customers with lead service lines will have equal access to the health benefits of full lead service line replacement, regardless of their ability—or their landlord's ability— to pay.

Prioritizes protecting the most vulnerable: Infants and children are among the most vulnerable to lead exposure and Denver Water will work to identify daycare centers, schools, and areas with young families in order to prioritize these vulnerable populations for filter distribution and lead service line replacement.

Protects water quality and the environment: An unintended consequence of orthophosphate treatment is that its use can threaten water quality in nearby surface waters by increasing phosphorus levels that can harm fish, wildlife, recreational users, and downstream water systems. The Lead Reduction Program avoids this unintended consequence by preventing the introduction of an additional source of phosphorus into rivers, streams, and reservoirs.

<u>Recommendations</u>

Ensure an effective filter program for all participants: Denver Water's Filter Lead out of Water (FLOW) pilot outreach project was limited to owner-occupied single family homes. As Denver Water refines its FLOW program based on the results of that pilot, it will be important to consider how renters, especially renters in large, multi-family dwelling units, could have lower filter adoption rates due to occupancy turnover and other factors. Denver Water should also consider how to ensure daycare centers, schools, and other places serving populations most vulnerable to lead exposure are using filters properly.

Enhance school outreach programs: A robust education and outreach program to reach all customers impacted by lead in drinking water is critical to the success of the proposed Lead Reduction Program. Denver Water should expand on its existing lead reduction education outreach program in schools, including both public and private schools.

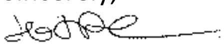
Address concerns over potential rate increase: Though as currently proposed there will be no cost to individual property owners whose lead service lines are replaced, there is the potential for a customer rate increase. As Denver Water completes its cost analysis for this program, it should consider how any potential rate increase could impact low-income customers and consider options for those who may be unable to absorb even a modest rate increase. Denver Water should communicate to its customers about any potential rate increases early on in the Lead Reduction Program.

Include messaging on regional water quality benefits in enhanced communications, outreach, and education plan: High rates of customer participation, especially in the FLOW program, are critical to the success of the Lead Reduction Program. Educating customers on the environmental benefits of keeping new sources of phosphorus out of regional streams, rivers, and reservoirs could increase willingness of some customers to participate in the program.

Include impacted community member(s) on Leadership Committee: It is critical that those most impacted by lead service lines have a voice at the table along with Denver Water, CDPHE, EPA, and other stakeholders. Community buy-in is vital to the success of this program, and we are concerned the program may not be successful without meaningful inclusion of community members in decision making.

Clean Water Action is committed to working with Denver Water and other stakeholders to ensure the success of a Lead Reduction Program that protects public health and the environment. Protecting all of our communities from lead must be a top priority, and it is also critical to continue making progress toward reducing nutrient pollution in our rivers, streams, and reservoirs.

Sincerely,



Jennifer Peters
National Water Programs Director
Clean Water Action/Clean Water Fund
jpeters@cleanwater.org

August 7, 2019

Sent by email only

Jim Lochhead, Chief Executive Officer
Denver Water
1600 W. 12th Ave.
Denver, CO 80204

Re: Lead Reduction Program

Dear Mr. Lochhead:

Environmental Defense Fund (EDF) supports Denver Water's proposed "Lead Reduction Program Plan" as an innovative solution to a challenging problem. If approved as proposed, Denver Water's plan would fund full replacement of the estimated 75,000 lead service lines (LSLs) in their system within 15 years – thus removing the primary source of lead within Denver Water's system, while avoiding the use of orthophosphate that can further exacerbate nutrient pollution problems in the South Platte River and other downstream reservoirs, rivers, and streams. And Denver Water will go the extra step by providing filters certified to remove lead to residents with LSLs until the lines are replaced.

EDF's mission is to preserve the natural systems on which all life depends. We have more than two million members and a staff of 700 scientists, economists, policy experts, and other professionals around the world. Guided by science and economics, we find practical and lasting solutions to the most serious environmental problems. This has drawn us to areas that span the biosphere: climate, oceans, ecosystems and health. Our Health Program seeks to safeguard human health by reducing exposure to toxic chemicals and pollution, including accelerating lead service line replacement to reduce lead in drinking water. Our Ecosystems Program works to increase the resilience of natural systems, including reducing harmful nutrient pollution.

Moving forward, EDF recommends that Denver Water broaden the proposed Leadership Committee to include representatives of the communities with LSLs. Their engagement and guidance is crucial to the success of the Program. Their absence may undermine the Committee's credibility and effectiveness.

Ultimately, EDF hopes that this type of resilient solution can be adopted and replicated elsewhere both to protect public health and prevent degradation of our natural systems.

Sincerely,

Tom Neltner, JD
Chemicals Policy Director

Brian Jackson, MA
Senior Manager, Western Water

CITY OF GLENDALE COLORADO

Glendale, Colorado

"The Urban Village"

Michael Dunafon
Mayor

Doris Rigoni
Mayor Pro-Tem

Jerry Peters
City Manager

Council Members:

Storm Gloor
Dario Katardzic
Lindsey Mintz

July 25, 2019

Jim Lochhead
CEO/Manager
Denver Water
1600 West 12th Avenue
Denver, Colorado 80204
jim.lochhead@denverwater.org

RE: Comments on Denver Water's Lead Reduction Program Plan

Dear Mr. Lochhead,

On behalf of the City of Glendale, I submit the following comments on Denver Water's draft Lead Reduction Program Plan (dated July 11, 2019).

The City of Glendale recognizes that drinking water and public health experts encourage the removal of lead service lines to provide public health protection from lead exposure in drinking water. We understand that Denver Water maintains that the proposed Lead Reduction Program provides a higher level of public health protection than the currently planned approach involving the addition of orthophosphate. If this is confirmed by the USEPA and CDPHE, the City of Glendale will support Denver Water's Variance Request if the following changes are made to the final LRP Plan that is expected to be submitted to the USEPA in August of this year:

First and Foremost, commit to an equitable distribution of the costs associated with the LRP Plan – The City of Glendale understands there will be an extensive public input process over the next year to determine the appropriate allocation of costs associated with execution of the LRP Plan. However, the City of Glendale requests an immediate commitment by Denver Water to an equitable distribution of those costs. We define equitable distribution to be an allocation of costs based upon the confirmed percentage of LSLs in the entire distributor network without the traditional multiplier applied to those costs. The City of Glendale customers should not be required to subsidize the cost of replacing LSLs located within the City and County of Denver, which is where the vast majority of the LSLs are located (according to the current LSL inventory). We believe our customers would raise significant concerns to Denver Water if the cost of LSL replacement was distributed in any other way but as stated above. As Denver Water does not share in the cost of maintaining our customer's private systems, neither should the distributor customers be required to do that for City and County of Denver customers.

Next, increased collaboration with distributors regarding the development and execution of the communications and outreach plans associated with the LRP – The distributors were excluded from most of the pre-variance phase communication efforts mentioned on page 42 of the document. Details released to the public were typically provided to us on the same day press releases were issued with little advance warning. Moving forward, this needs to change and may be accomplished by specifically incorporating distributors into the communications for each of the action sections of the plan.

950 South Birch Street Glendale, Colorado 80246-2599 Phone (303) 759-1513 Fax(303) 639-4707
http//www.glendale.co.us

Collaboration with distributors is specifically mentioned several places with respect to the LSL inventory actions, which is necessary given the distributors typically have most knowledge, whether field or historical records, regarding the existence of LSLs in their distribution network. Upon a detailed review of the LRP Plan and associated appendices, the City of Glendale noted that there is no mention of distributor collaboration in Section III.C (Filter Program) or III.D (Accelerated Lead Service Line Replacement Plan). This is a significant oversight on behalf of Denver Water given that customer communication is a shared responsibility for Read & Bill distributors and the sole responsibility of Master Meter distributors.

The City of Glendale has worked hard to build a trusted relationship with our customers, similar to what Denver Water has done so well with its own inside City customers. To ensure that trusted relationship continues through the LRP, the City of Glendale should be involved in any communications directed to them as part of the execution of the LRP Plan and Communications, Outreach & Education Plan (COE Plan). We do acknowledge Denver Water is ultimately responsible for execution of the LRP Plan as they are the regulated entity. However, for this effort to be successful, Denver Water needs to revise the LRP Plan and the COE Plan to specifically commit to involving the distributors in communications efforts on the Filter Program and the Accelerated LSL Replacement Plan.

The City of Glendale requests Denver Water revise the LRP Plan and the COE Plan to include specific action: Each distributor will be given the option to determine how they want to participate in the customer communications process. Some may prefer to be involved as a co-lead, others may only want advance notice, and a few may defer fully to Denver Water. All should be acceptable options offered by Denver Water and each City of Glendale's preference should be respected. This one specific example of how the distributors should be included in COE Plan, which we understand will be more fully developed if the variance request is approved. Before submitting the LRP Plan and COE Plan to the USEPA, we would request the documents be revised to both increase the number of and provide more details for meaningful opportunities for engagement on customer communication for Read & Bill and Master Meter distributors.

Also, commit to the addition of a distributor representative on the LRP Leadership Committee – In the LRP Plan, Section III.F (Learning by Doing) outlines the approach to the formation and operation of an LRP Leadership Committee. The City of Glendale supports the formation of this committee as an oversight entity that will guide the LRP through execution. However, we are significantly concerned that the distributors are not represented on that committee, especially given that 50% of the 1.4 million people who rely on Denver Water do so through a distributor. Although current indications are that only 5% of those people have a lead service line, many more may be impacted by the LSL inventory process, the Filter Program, or even ongoing communications about the LRP. Therefore, the City of Glendale requests that, as the LRP Leadership Committee "invites other stakeholders to be members, such as representatives from watershed groups, wastewater dischargers, and public health agencies" (as stated on page 72), the Distributor Forum is allocated one representative to that Committee. In addition to participating in the Committee and working collaboratively towards the LRP Plan goals, this representative would also liaise between Denver Water and the distributors, ensuring continued support from that group and working to resolve any issues that may arise during the execution of the LRP.

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http//www.glendale.co.us

It may be that the Distributor Forum representative serves for the first few years of the LRP Plan execution process, working through the initial communication efforts, inventory tasks, filter distribution, and coordination efforts. Participation of the Forum representative may be evaluated every few years to ensure meaningful engagement opportunities still exist. If there are none, that representative may sunset from the Committee.

In conclusion, the City of Glendale reiterates the need for Denver Water to revise the LRP Plan, including the appendix containing the COE Plan, to incorporate the requests outlined in this letter. The City of Glendale will support the variance request and work collaboratively with Denver Water if those requests are incorporated into the final version of the LRP Plan. Successful execution of the LRP Plan depends on support from the distributor community as well as many other stakeholders located in the Denver metro area. Together we can achieve the goal of removing LSLs in our communities and significantly impacting public health protection through reduced exposure to lead in drinking water.

Should you have any questions or concerns about this letter, I can be reached at 303-639-4501 or jbertrand@glendale.co.us.

Sincerely,

Joshua Bertrand
Director of Public Works
City of Glendale

cc: Jerry Peters, City Manager
Chuck Line, Deputy City Manager
Linda Cassaday, Deputy City Manager
Denver Water Lead Reduction Program (lead@denverwater.org)
Julie Seagren, Denver Water Distributor Relations Manager (julie.seagren@denverwater.org)

950 South Birch Street Glendale, Colorado 80246-2599 Phone (303) 759-1513 Fax(303) 639-4707
http//www.glendale.co.us

November 15, 2018

The Honorable Jared S. Polis
Governor-Elect of Colorado
136 State Capitol Building
Denver, CO 80203

Dear Governor-Elect Polis,

I am writing you today as a student from Denver North High School Engagement Center, and as a citizen who resides in Denver. I am concerned about the amount of orthophosphates being added to our water supply by the Colorado Department of Health. We, the citizens of Colorado, should really take this problem into consideration seeing as this is the water we drink, bathe, and play in. As you are now to be the governor of Colorado, you are now the voice of the people. Now is the time to talk about this because the Colorado Department of Health is deciding to add more orthophosphates to our water supply to prevent lead corrosion. What they don't know is it will cost the state of Colorado our excellent water quality.

In my Earth Science class, we have been researching how orthophosphates can damage our bodies of water, and can create toxic algae which can lead to many health problems for humans and animals. During our field work, we found that the phosphates in the South Platte River were completely maxed out at 4 ppm (parts per million). Orthophosphates, in excess, cause nutrient pollution. Orthophosphates are a type of nutrient phosphorus, which acts as a fertilizer for algae. This is very important because if we add orthophosphates to our drinking water supply, eventually our rivers would fill up with algae, creating toxins dangerous for both animals and humans alike.

There are intended and unintended consequences to adding orthophosphates in our water supply. The intended consequence is that orthophosphates create a barrier in our lead pipes and keeps the amount of lead in our water to below 15 ppb. This is important because we don't want another incident like what happened in Flint, where the lead was nearly 300 ppb.

But the unintended consequences of adding orthophosphates are far more disastrous to our ecosystem. As stated previously, orthophosphate acts as a fertilizer, which creates more algae (since algae uses phosphorus as a nutrient). Algae is dangerous for many reasons: it steals oxygen from the water, de-oxygenating it, and eventually suffocating the fish and other aquatic animals; also, some algae contains toxins that, if they come into contact with humans or animals, cause illnesses like rashes, vomiting, and liver damage.

Mr. Polis, there is a better alternative than using orthophosphates in our water supply: change the lead pipes to CPVC pipes. These pipes do not degrade with hot water exposure (as compared to lead pipes, which corrode when exposed to hot water), and they do not contain any dangerous chemicals (like lead). Compared to draining out the de-oxygenated water from our lakes and rivers (which costs $500-$1500 every time the body of water is drained) or charcoal filters (which cost $500-$1500 per house and must be replaced every 4-6 years), simply just replacing the pipes once (for a cost of **$6,000**-$22,000 per pipe depending on location) will last a lifetime. While the upfront cost of CPVC pipes seems high, we need to think about the long-term solution for our lead problem in Colorado. Replacing the pipe lines to our homes is the best option for a long-term solution.

If we do not act now, our water pipelines will continue to corrode. So we need to take action now or we may become the next Flint Michigan. Because I know you are a former teacher, I'm hoping a students' opinions will matter to you. Also, as a citizen of Colorado, that you, the Governor Elect, will make a difference and make Colorado's drinking water safer in an eco-friendly way. Remember, the CDH is, as of right now, is making the decision to add more orthophosphates to our water. We have a time limit, not only because of our pipes, but also because of our bodies of water.

Please contact me so we may discuss this in person.

Thank you for your time,

Itati Carson

METRO WASTEWATER RECLAMATION DISTRICT

William J. "Mickey" Conway, District Manager

August 7, 2019

Mr. Jim Lochhead, Chief Executive Officer/Manager
Mr. Tom Roode, Chief of Operations and Maintenance
Ms. Nicole Poncelet-Johnson, Water Treatment and Quality Manager
Denver Water
1600 West 12th Avenue
Denver, CO 80204

Submitted Via Electronic Mail:
jim.lochhead@denverwater.org; tom.roode@denverwater.org; nicole.poncelet@denverwater.org

Re: Denver Water's Lead Reduction Program

Dear Mr. Lochhead, Mr. Roode, and Ms. Poncelet-Johnson:

Thank you for the opportunity to comment on Denver Water's Lead Reduction Program. The Metro Wastewater Reclamation District (Metro District or District) strongly supports this Lead Reduction Program. As you know, the Metro District provides wastewater treatment and resource recovery services to more than two million people in the Denver metropolitan area. As a national model tailored to the unique needs of the arid west, this Program will permanently, holistically, and sustainably address lead in Denver Water's service area without adversely affecting downstream communities and the South Platte River watershed. This collaborative and innovative program provides protection to the District's 62 public and corporate connectors, and it has the full support of our Board of Directors representing 22 of the largest municipal entities in the metro area.

Central to this solution is the alignment of two important public health concerns—lead in drinking water and nutrients in watersheds. Since 2017, the Metro District, Denver Water, and several regional partners have worked collaboratively to develop and advocate for a solution that will protect Denver Water's customers at the tap from lead, while also protecting the public health of downstream communities and maintaining the health of the South Platte River watershed from the adverse effect of nutrients.

The Metro District supports the Lead Reduction Program presented by Denver Water because the Program:

- Is expected to **reduce lead at the tap within its service area to below 5 parts per billion (ppb) for all customers and for many customers to non-detect levels**[1]; and
- **Will eliminate the use of orthophosphate** as a corrosion control inhibitor, which will avoid adverse effects to downstream communities and the watershed.

[1] Figure 18 on page 39 of the Lead Reduction Program Plan demonstrates the Lead Reduction Program will reduce concentrations at the tap more effectively than the addition of orthophosphate.

The alternative to the Lead Reduction Program includes the use of a phosphorus-based chemical called orthophosphate as a corrosion control inhibitor. The alternative would adversely affect the public health of downstream communities and the health of the watershed by significantly increasing point and non-point phosphorus pollution in the South Platte River watershed. The following table shows the additional phosphorus loads that would result from the use of orthophosphate.

Orthophosphate Loadings

Total Loading		Year 2020	Year 2030	Year 2040	Year 2050
Average Daily Water Provided by Denver Water	MGD[1]	170	199	214	214
Percent Outdoor Use	Percent	40	40	40	40
Percent Indoor Use	Percent	60	60	60	60
Outdoor Average Daily Water Use	MGD	69	80	86	86
Indoor Average Daily Water Use	MGD	101	119	128	128
Total Annual Added Phosphorus Load from All Water Provided by Denver Water[2]	Pounds as Phosphorus	**505,603**	**591,555**	**637,060**	**637,060**

[1] Million gallons per day
[2] Based on Denver Water's Optimal Corrosion Control Technique (OCCT) result showing an orthophosphate dose of 3 milligrams per liter (mg/L)

This would be a significant new source of phosphorus pollution in the South Platte River watershed. Over the last 18 months, the region has been working with Denver Water to find an alternative solution that will avoid or minimize this new source of phosphorus pollution because the region recognizes that reducing nutrient pollution is also important for public health and the environment in the region. For decades, the U.S. Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE) have recognized that too much nitrogen or phosphorus in the environment produce more algae than the ecosystem can handle, resulting in environmental and human health issues.

National and State Frameworks to Reduce Nutrients

The EPA has conducted extensive research on nutrients, which is available on its website. The EPA website[2] explains the science concerning nutrient pollution and includes the following statements:

- **Nutrient pollution** is one of America's most widespread, costly and challenging environmental problems, and is caused by excess nitrogen and phosphorus in the air and water.
- **Too much nitrogen and phosphorus** in the water can have diverse and far-reaching impacts on public health, the environment, and the economy.
- **Excess nutrients can cause harmful algal blooms (HABs)** in freshwater systems, which not only disrupt wildlife but can also produce toxins harmful to humans.
- **Harmful algal blooms sometimes create toxins** that are detrimental to fish and other animals....Even if algal blooms are not toxic, they can negatively impact aquatic life by blocking out sunlight and clogging fish gills.

[2] https://www.epa.gov/nutrientpollution

- **Nutrient pollution has diverse and far-reaching effects** on the U.S. economy, impacting tourism, property values, commercial fishing, recreational businesses and many other sectors that depend on clean water.
- **Nitrates and algal blooms** in drinking water sources can drastically increase treatment costs.

To address these concerns, a 2011 EPA memorandum from Nancy K. Stoner to the Regional Administrators (*Working in Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions)* (page 2) explains that when creating a program to manage nitrogen and phosphorus pollution, it is "of most importance" to:

- Prioritize watersheds,
- Set load reduction goals for watersheds, and
- Reduce loadings.

The State of Colorado followed the programmatic approach recommended by the EPA, which included the adoption of new regulations that prioritized watersheds, set load reductions goals, and required point sources to reduce nutrient loads.

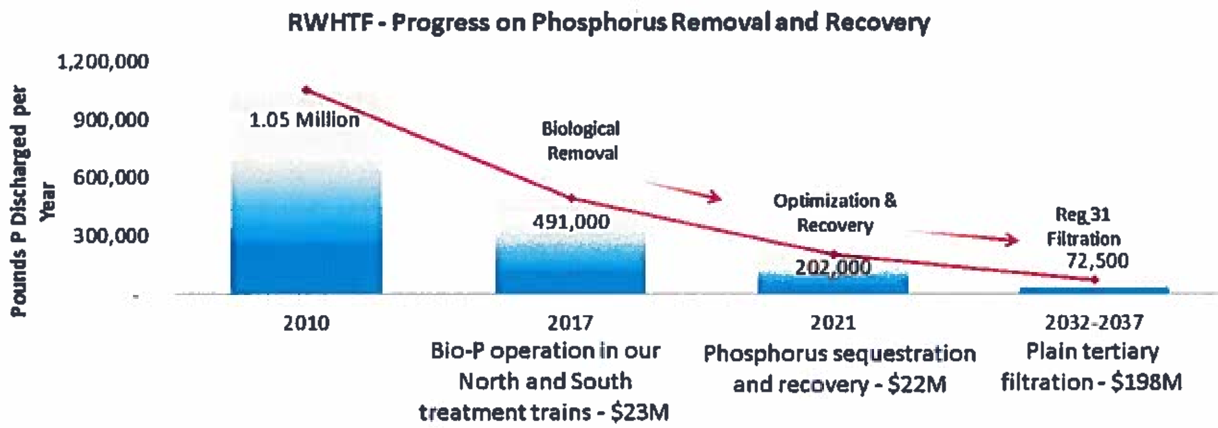
In 2012, the Colorado Water Quality Control Commission adopted parameter limitations for phosphorus and nitrogen in Regulation 85 (*Nutrients Management Control Regulation)* and numeric interim values for phosphorus, nitrogen, and chlorophyll *a* to protect domestic water supply use, recreation, and aquatic life uses in Regulation 31 (*The Basic Standards and Methodologies for Surface Water*). The CDPHE has been implementing the Regulation 85 parameter limitations in water quality discharge permits for the past several years.

In addition, in 2013 both the CDPHE and the EPA adopted Total Maximum Daily Loads (TMDL) for Barr Lake and Milton Reservoir that collectively required over 90 percent reduction in phosphorus loadings to each reservoir.

The Metro District's mission is to protect the region's health and environment by cleaning water and recovering resources. Consistent with its mission, over the last two decades, the District has partnered with the EPA and CDPHE to establish the Colorado nutrient framework and has invested in treatment technologies to reduce its phosphorus loadings.

Technological Investments and Improvements in the South Platte Watershed Water Quality

In furtherance of the national and state policy to reduce nutrients, without a current regulatory requirement to do so, the Metro District has already invested $50 million in treatment technologies to reduce phosphorus. These treatment technologies have significantly reduced the District's Robert W. Hite Treatment Facility's (RWHTF) phosphorus loads to the South Platte River watershed as demonstrated in the following graph. (Please note that the reductions presented in the graph do not include the additional load that would result from the use of orthophosphate).



The Metro District's reductions in phosphorus loads coupled with reductions achieved through the Colorado nutrient framework have resulted in measurable improvements to the water quality of the South Platte River watershed. In-stream total phosphorus (TP) concentrations downstream of the RWHTF have decreased significantly.

The nutrient reductions have also resulted in lower concentrations in the South Platte River and off-channel reservoirs, including Barr Lake and Milton Reservoir. For example:

- **Segment 15, South Platte River.** The average annual TP concentration was 0.78 mg/L in 2018, a 52 percent reduction from the 2013 average annual TP concentration of 1.5 mg/L.
- **Milton Reservoir.** The average spring TP concentration from 2014 to 2018 was 0.28 mg/L, a 60 percent reduction from the 2008–2012 average spring TP concentration of 0.72 mg/L.
- **Barr Lake:** The average spring TP concentration from 2014 to 2018 was 0.29 mg/L, a 48 percent reduction from the 2008–2012 average spring TP concentration of 0.55 mg/L and a 62 percent reduction from the 2003–2007 average spring TP concentration of 0.75 mg/L.

By avoiding the addition of a substantial amount of phosphorus into the South Platte River watershed, the Lead Reduction Program will allow the region to sustain and continue the progress already made to improve the water quality in the South Platte River watershed because of nutrient reductions.

Adding a large volume of orthophosphate to the South Platte River watershed would be a serious—and likely irreversible—setback to the progress accomplished in recent years to reduce phosphorous in the South Platte River watershed. In addition to the public health and environmental impacts, the use of orthophosphate would also result in significant financial impacts on the Metro District. To treat this significant new load of phosphorus the Metro District would install advance treatment at the RWHTF, which would increase the capital cost for advance treatment by $120 million (2017 dollars). The annual operational costs would also increase by $4.6 million due to the need for chemical addition to the treatment process. Not only would this approach conflict with the national and state frameworks to reduce nutrients, it would also put a significant financial burden on the two million ratepayers located within the service area of the District.

Maximizing Public Health through the Lead Reduction Program

The Metro District supports the Lead Reduction Program because it aligns two important public health frameworks. It achieves the greatest expected reductions of lead at the tap (short and long term) in a manner that avoids the negative impacts to the South Platte River watershed from the alternative approach, orthophosphate.

Decisions about water management in the arid west present unique challenges because of water scarcity. Throughout the arid west we are dependent upon water reuse for vibrant and healthy communities. The introduction of a large volume of chemicals, such as orthophosphate, within the water cycle will cause rippling adverse effects through the rest of the water cycle. This cannot be the right solution when there is an alternative that, on its own merits, is superior at protecting public health from exposure to lead in drinking water.

Recognizing this is a complex and interconnected issue, the Metro District and its partners have continued to advocate for the Lead Reduction Program, a one watershed and one ratepayer solution. Because of water scarcity in this region, a customized solution is more important than ever to ensure decisions today will not impair the ability of future generations to use and enjoy this valuable resource.

Sincerely,

William J. "Mickey" Conway
District Manager

July 29, 2019

Jim Lochhead
CEO/Manager
Denver Water
1600 West 12th Avenue
Denver, Colorado 80204
jim.lochhead@denverwater.org

RE: Comments on Denver Water's Lead Reduction Program Plan

Dear Mr. Lochhead,

On behalf of the Boards of Directors of the Platte Canyon Water & Sanitation District and the Southwest Metropolitan Water & Sanitation Districts (Districts), I submit the following comments on Denver Water's draft Lead Reduction Program Plan (dated July 11, 2019).

The Districts recognize that drinking water and public health experts encourage the removal of lead service lines to provide public health protection from lead exposure in drinking water. We understand that Denver Water will prove to the USEPA that the proposed Lead Reduction Program provides a higher level of public health protection than the currently planned approach involving the addition of orthophosphate. If this is confirmed by the USEPA and CDPHE, the Districts will support Denver Water's Variance Request if the following changes are made to the final LRP Plan that is expected to be submitted to the USEPA in August of this year:

Increased collaboration with distributors regarding the development and execution of the communications and outreach plans associated with the LRP – The distributors were excluded from most of the pre-variance phase communication efforts mentioned on page 42 of the document. Details released to the public were typically provided to us on the same day press releases were issued with little advance warning. Moving forward, this needs to change and can be accomplished by specifically incorporating distributors into the communications for each of the action sections of the plan.

Collaboration with distributors is specifically mentioned several places with respect to the LSL inventory actions, which is necessary given the distributors typically have most knowledge, whether field or historical records, regarding the existence of LSLs in their distribution network. Upon a detailed review of the LRP Plan and associated appendices, the District noted that there is no mention of distributor collaboration in Section III.C (Filter Program) or III.D (Accelerated Lead Service Line Replacement Plan).

This is a significant oversight on behalf of Denver Water given that customer communication is a shared responsibility for Read & Bill distributors and the sole responsibility of Master Meter distributors.
The Districts have worked hard to build a trusted relationship with our customers, similar to what Denver Water has done so well with its own inside City customers. To ensure that trusted relationship continues through the LRP, the Districts should be involved in any communications directed to them as part of the execution of the LRP Plan and Communications, Outreach & Education Plan (COE Plan).
We do acknowledge Denver Water is ultimately responsible for execution of the LRP Plan as they are the regulated entity. However, for this effort to be successful, Denver Water needs to revise the LRP Plan and the COE Plan to specifically commit to involving the distributors in communications efforts on the Filter Program and the Accelerated LSL Replacement Plan. The Districts requests Denver Water revise the LRP Plan and the COE Plan to include specific actions:

- Each distributor will be given the option to determine how they want to participate in the customer communications process. Some may prefer to be involved as a co-lead, others may only want advance notice, and a few may defer fully to Denver Water. All should be acceptable options offered by Denver Water and each district's preference should be respected.
- With respect to the Filter Program, include the following actions:
    - Develop communication materials that can be co-branded by distributors,
    - Include distributors in any planning efforts for door-to-door campaigns and neighborhood meetings (noted on page 54),
    - Provide training and/or talking points for distributor staff to use when engaging with customers on this topic. While the District understands Denver Water prefers to be the primary POC for detailed information on the LRP, sufficient information needs to be provided to District staff to allow for informal conversations when we encounter questions from our customers, either in the field or during our own community events.
- With respect to the Accelerated LSL Replacement Plan, Denver Water should update the summary section located on page 57 to include a reference to coordinate construction activities with distributors. There is a specific reference to "coordinating with the City and County of Denver Public Works and other area municipal, utility, and public sector agencies"; however, coordination with distributors should be called out explicitly, especially for Read & Bill and Master Meter distributors. Where there are identified LSLs to be replaced, the District would prefer a coordinated approach to identify any capital project construction synergies that could be realized during this process. Additionally, as the District already attempts to coordinate our capital projects with county paving plans, Denver Water would benefit from our existing planning efforts and relationships with those entities.

These are some specific examples of how the distributors should be included in COE Plan, which we understand will be more fully developed if the variance request is approved. Before submitting the LRP Plan and COE Plan to the USEPA, we would request the documents be revised to both increase the number of and provide more details for meaningful opportunities for engagement on customer communication for Read & Bill and Master Meter distributors.

Commit to the addition of a distributor representative on the LRP Leadership Committee – In the LRP Plan, Section III.F (Learning by Doing) outlines the approach to the formation and operation of an LRP Leadership Committee. The Districts support the formation of this committee as an oversight entity that will guide the LRP through execution. However, we are significantly concerned that the distributors are not represented on that committee, especially given that 50% of the 1.4 million people who rely on Denver Water do so through a distributor. Although current indications are that only 5% of those people have a lead service line, many more may be impacted by the LSL inventory process, the Filter Program, or even ongoing communications about the LRP. Therefore, the Districts requests that, as the LRP Leadership Committee "invites other stakeholders to be members, such as representatives from watershed groups, wastewater dischargers, and public health agencies" (as stated on page 72), the Distributor Forum is allocated one representative to that Committee. In addition to participating in the Committee and working collaboratively towards the LRP Plan goals, this representative would also liaise between Denver Water and the distributors, ensuring continued support from that group and working to resolve any issues that may arise during the execution of the LRP. It may be that the Forum representative serves for the first few years of the LRP Plan execution process, working through the initial communication efforts, inventory tasks, filter distribution, and coordination efforts. Participation of the Forum representative can be evaluated every few years to ensure meaningful engagement opportunities still exist. If there are none, that representative could be sunset from the Committee.

Commit to an equitable distribution of the costs associated with the LRP Plan – The Districts understands there will be an extensive public input process over the next year to determine the appropriate allocation of costs associated with execution of the LRP Plan. However, the Districts request an immediate commitment by Denver Water to an equitable distribution of those costs. We define equitable distribution to be an allocation of costs based upon the confirmed percentage of LSLs in the entire distributor network without the traditional multiplier applied to those costs. The distributor customers should not be required to subsidize the cost of replacing LSLs located within the City and County of Denver, which is where the vast majority of the LSLs are located (according to the current LSL inventory). We believe our customers would raise significant concerns to Denver Water if the cost of LSL replacement was distributed in any other way but as stated above. As Denver Water does not share in the cost of maintaining our customer's private systems, neither should the distributor customers be required to do that for inside City customers.

In conclusion, the Districts reiterate the need for Denver Water to revise the LRP Plan, including the appendix containing the COE Plan, to incorporate the requests outlined in this letter. The Districts will support the variance request and work collaboratively with Denver Water if those requests are incorporated into the final version of the LRP Plan. Successful execution of the LRP Plan depends on support from the distributor community as well as many other stakeholders located in the Denver metro area. Together we can achieve the goal of removing LSLs in our communities and significantly impacting public health protection through reduced exposure to lead in drinking water.

Should you have any questions or concerns about this letter, I can be reached at (303) 979-2333 or pjfitzgerald@plattecanyon.org.

Sincerely,

Pat Fitzgerald
District Manager
Platte Canyon Water & Sanitation District
Southwest Metropolitan Water & Sanitation District

cc: Richard Rock, Board of Directors, Platte Canyon Water & Sanitation District
Anthony Dursey, Board of Directors, Southwest Metropolitan Water & Sanitation District
Denver Water Lead Reduction Program (lead@denverwater.org)
Julie Seagren, Denver Water Distributor Relations Manager (julie.seagren@denverwater.org)

Comments on Denver Lead Reduction Plan

The Lead Reduction Program Plan proposed by Denver Water represents a comprehensive, proactive strategy for the nearly immediate reduction of lead exposure in drinking water at the highest risk homes by distributing filters at all lead service line homes, while beginning the longer term process of permanently removing lead service lines and optimizing corrosion control for addressing remaining sources of lead in Denver's drinking water infrastructure. The comprehensive approach also approaches the program from an equity perspective, ensuring that all high-risk customers have access to filters and lead service line replacements, regardless of ability to pay. This approach, which places public health protection and permanent removal of lead service lines as the highest priority, should be seen as a model for addressing lead in drinking water. The execution of the program as described in the program plan and the verification that all program components are executed as described will ultimately determine how successful the program is at reaching and reducing risk for all lead service line customers. The success of this program is dependent on each of these programs following through consistently. We know that any individual staff member can be the weakest link. Rigorous tracking protocols and regular program audits will be critical for verifying the program is working as intended.

The Proposed Lead Reduction Program Plan includes aggressive commitments to protect all customers in lead service line homes. However, on the whole the program evaluation criteria proposed present a low bar for identifying a system that failed to meet criteria and must proceed with a corrective action. When the program is built around the concept that all lead service lines homes have filters and the information they need to use them on a daily basis, then to meet expectations the annual filter adoption rate should be very close to 100% and the need for corrective action should be triggered when the number falls below 95%. The corrective actions should focus on providing the necessary resources to achieve the programmatic goals rather than changing course entirely as suggested in the corrective actions currently listed.

It should be noted that, contrary to the information on page 12 of the executive summary, actual "lead-free" plumbing components are not available. Plumbing components labeled "lead-free" contain up to 0.25% lead by weight. Materials that Denver Water distributes to its customers should not obscure the fact that installing new plumbing components still continues to add new lead to household plumbing systems.

Page 52 of the lead reduction program plan states that if the LSLR program is complete and a new LSL is identified, Denver Water has 6 months to replace the line. This seems far too long, given that at this point Denver will have finished the rest of the lead service line replacements and know how to replace the lead service line more efficiently than ever. After 15 years of unknown lead exposure, another 6 months if far too long for this home to race.

Page 61 of the lead reduction program plan describes a process for investigating homes with water quality above the action level. This answer implies that the inspection will identify lead in water risks in the home, but the programs described historically have not addressed drinking water sources of lead. This response should be updated to clarify the procedures of community organizations and grant programs for incorporating lead in drinking water into their lead reduction programs.

On Page 62, the service line material should be positively confirmed for any home that chooses to not participate in lead service line replacement so that it can be accurately captured in Denver Water's inventory.

On Page 71, last paragraph, please clarify the frequency with which corrosion control adjustments are made based on monthly data. Are Water Quality Parameters also adjusted from month to month to reflect this program?

Page 72, the concept of learning by doing as presented here appears to implement water treatment changes while distributing water to customers, implying that customers might be treated like guinea pigs and the water system will come back and continue to make adjustments until treatment is optimized. Updating protocols as new information becomes available is always appropriate, but it must be done in a way that does not put customers at greater risk.

Page 84, there are many limitations in using blood lead data to be able to correlate exposure to lead in drinking water to an elevated blood lead level. I recommend that this lead reduction plan does not imply that Denver is seeking evidence of elevated blood lead levels to establish causation from drinking water. The time to address lead in drinking water is when lead is detected in the water, not in children. http://graham.umich.edu/project/revised-lead-and-copper-rule/faq?faq=2

Elin Betanzo

SafeWaterEngineering.com

248-326-4339

August 6, 2019

Denver Water
Attn: Lead Reduction Program
1600 W. 12th Ave.
Denver, CO 80204

Dear Denver Water,

We are writing to commend Denver Water's Lead Reduction Program Plan. The plan's foundational statement, "When it comes to lead in drinking water, no levels are safe," its accelerated city-funded lead service line replacement plan, and its focus on protecting pregnant women, formula-fed infants and young children are exemplary science-driven actions.

The submitters of this comment are participants in Project TENDR (Targeting Environmental Neuro Developmental Risks). TENDR is a diverse group of experts in epidemiology, toxicology, exposure science, pediatrics, obstetrics and gynecology, nursing, public health, learning, intellectual and developmental disabilities, federal and state chemical policy and environmental justice, along with child and environmental advocacy organizations.

In July 2017, three Project TENDR leaders, David C. Bellinger, PhD, MSc, Aimin Chen, MD, PhD, and Bruce P. Lanphear, MD, MPH, published a Viewpoint article in *JAMA Pediatrics* titled "Establishing and Achieving National Goals for Preventing Lead Toxicity and Exposure in Children." In that article, Bellinger, Chen and Lanphear reviewed the science on the impacts of lead exposure including intellectual deficits, diminished academic abilities, attention deficits, and problem behaviors in children and affirmed the finding that there is no safe level of lead exposure.

The focus of the Denver Water Plan is on prevention, the best way to protect children and other vulnerable groups. The Plan seeks to reduce the sources of childhood lead exposures rather than solely identifying children who have already been unduly exposed or attempting to ameliorate the toxic effects after lead exposure has occurred. Thus, the Denver Water Plan is right on target to enhance public health.

We also applaud the plan's inclusion of "Focused and prioritized education and engagement to high risk community members (e.g., families with young children, including formula-fed infants, and pregnant women) with efforts to:

- Leverage existing stakeholder relationships/communication channels established by Denver Department of Public Health and Environment and Denver Water.
- Target messaging for various community organizations, doctor offices, etc.

- Partner with community health clinics, daycares/child care providers, social service programs for women and families.

Prioritizing the protection of the most vulnerable community members is sound public health policy. While the city is replacing lead service lines, the provision of effective water filters to women during their pregnanices as well as to families with formula fed infants and young children will lower the risk of neurodevelopmental harm for thousands of Denver's youngest residents. We hope the City will continue to monitor the water supply for lead levels after the new service lines are installed.

Thank you for developing a water plan grounded in science that puts children's health first; the Denver Water Plan provides a great model for others.

Sincerely,

David C. Bellinger, PhD, MSc
Research Director, Boston Children's Hospital
Professor, Harvard Medical School, Harvard T.H. Chan School of Public Health

Asa Bradman, PhD, MS
Associate Adjunct Professor, Department of Environmental Health Sciences
University of California, Berkeley

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Past President, The American College of Obstetricians and Gynecologists
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Katie Huffling, RN, MS, CNM
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COLORADO WASTEWATER UTILITY COUNCIL

Support Statement for Denver Water Optimal Corrosion Control Treatment (OCCT) Variance Request by the Colorado Wastewater Utility Council

The Colorado Wastewater Utility Council is in support of the Denver Water OCCT variance request to the U.S. Environmental Protection Agency. Provided the variance request is deemed to be as protective to public health as the approved OCCT option, we believe it is a better overall solution. The variance request avoids addition of chemicals to the water supply that is a less sustainable alternative. The variance request proposal addresses the root cause of the problem in the form of accelerated lead service line removal rather than providing a secondary fix, which could have unintended environmental consequences.

As wastewater treatment plants, our members' first concern is the health and safety of the public and the environment. The variance would eliminate many concerns of wastewater plants impacted by the OCCT determination. These issues include addition of phosphorus to watersheds that can degrade water quality in lakes and streams. Wastewater plants are currently working on treating phosphorus and other nutrients to comply with Regulation 85 nutrient limits, and even more stringent Regulation 31 limits in the future. The variance eliminates the need for plants to remove an additional phosphorus load on the road to this end.

The Colorado Wastewater Utility Council (CWWUC) is a nonprofit organization whose members include many of the wastewater treatment plants in Colorado. The Council has always strived to find common-sense approaches to protecting the environment and meeting regulatory requirements. We feel the Denver Water OCCT variance request is in alignment with this approach and we support it.

Please let me know if you have any questions or would like to discuss this further.

Thank you,

Julie Tinetti, CWWUC Chair

Conservation Colorado is writing in support of Denver Water's proposal to accelerate the removal of customer-owned lead service lines to address the utilities 2012 exceedance of the EPA's allowable levels of lead in drinking water.

We believe this approach is the best method to permanently reduce lead in drinking water within its service area. The Utility is currently using orthophosphates to comply following the 2012 test results. While the use of orthophosphates is an effective tool for lead reduction, it comes with with negative effects to streams, rivers, reservoirs, and wastewater treatment plants by increased rates of algae blooms and phosphorus loading at wastewater treatment facilities.

We are particularly supportive of the Utility's plan because it is comprehensive and designed to meet the needs of the diverse water users who rely on Denver Water. The plan includes the provision of free of charge water filters to all customers until their lines have been replaced. Denver Water also aims to first address pipe replacement in lower socioeconomic communities which aligns with our organizational focus on equity and community health.

Conservation Colorado's support is contingent upon Denver Water's commitment of not solely being dependent upon customer rates to pay for this effort. It is our understanding that a variety of methods will be utilized to pay for this effort. This aspect is crucial to our support as we do not want to see dispropriate effects on lower socio-economic households. Additionally, we also expect the Utility to ensure the free of charge water filters distributed to all customers are functioning as anticipated.

Conservation Colorado is the state's largest environmental advocacy non-profit with 60,000 members throughout the state. For over 50 years, we've worked with communities statewide to ensure that our quality of life and our environment are protected. We recognize that not all Coloradans have access to a clean and safe environment. Communities of color, indigenous communities, and families living on lower incomes are far more likely to live, work, and play near pollution. We are fostering equity, diversity, and inclusiveness to ensure all Coloradans are fully represented and engaged in our work to protect this state we love.

We are very appreciative of Denver Water's leadership to address the issue of lead in drinking water.

Sincerely,
Josh Kuhn
Water Advocate Conservation Colorado

APPENDIX II.A - COMPARING IMPACTS OF OPTIMAL CORROSION CONTROL TREATMENT AND VARIANCE IMPLEMENTATION

September 2019

DENVER WATER

Appendix II.A

Comparing Estimated Impacts of OCCT and Lead Reduction Plan Implementation on Lead Exposure at Denver Water Customers

Date:	Revised August 16, 2019 March 22, 2019
To:	Denver Water
From:	Corona Environmental Consulting, LLC

Executive Summary

The following analysis compares the estimated reductions of lead exposure to Denver Water customers from implementing either the designated optimal corrosion control treatment (OCCT) or the Denver Water proposed Lead Reduction Plan (LRP) conditions. The analysis demonstrates with supporting data that the requested LRP conditions of pH and alkalinity adjustment for CCT, accelerated lead service line replacement (LSLR), and distribution and validation of lead filters to customers served by lead service lines can achieve equivalent or greater lead reductions than the OCCT conditions of orthophosphate treatment and the current lead service line replacement rate. The analysis conservatively utilizes the best available data to inform the comparison through statistical analysis to compare impacts system-wide for all customers in the integrated service area.

The analysis outputs a predicted lead concentration at every tap in Denver Water's integrated system through time in one-year increments with only the number of lead service lines changing yearly due to replacements. This model analysis utilized an estimated number of lead service lines presently existing in Denver Water's integrated system of 74,138. The model was also exercised to analyze 55,000 lead service lines to test sensitivity to this parameter. The results are presented herein in multiple ways to fully represent and compare the impacts of implementing either OCCT or LRP conditions.

Implementing either OCCT or the LRP conditions achieves significant public health protection by limiting lead exposure at Denver Water customer's taps. Lead filters put customers in control to best limit lead exposure making it possible to provide the greatest protection to those at the highest risk (high lead concentrations, children, etc.). Replacing lead service lines removes the primary source of lead in drinking water. At 65% filter adoption, implementing the LRP conditions achieves greater lead reductions than OCCT implementation alone.

Objective

The objective of this analysis is to compare the estimated impacts of the designated optimal corrosion control treatment (OCCT) with the Denver Water proposed Lead Reduction Plan (LRP) conditions on lead exposure to Denver Water customers.

Approach

Corona has developed and exercised a statistical model to conservatively compare the impacts of orthophosphate addition as OCCT and LRP implementation of increased pH/alkalinity with accelerated lead service line replacement and lead filter deployment on lead exposure to Denver Water customers. The model estimates lead concentrations for all connections in the Denver Water service area every year using defined inputs under the scenarios detailed in Table 1. Because the model predicts a lead concentration at every tap and uses pilot rack data for lead concentrations from lead service lines, it will not be representative of current or future LCR compliance data.

Table 1 Description of conditions for OCCT and LRP scenarios.

Variables	**OCCT**	**LRP**
Total Service Connections	335,457	
Estimated existing lead service lines	74,138	
Implementation Start	March 20, 2020	
Corrosion Control Treatment (CCT)	Orthophosphate starting at 3 mg/L and reduced to 2 mg/L within first year of implementation	pH/alkalinity adjustment to pH 8.8
Lead Service Line Replacement (LSLR) Rate	1,200 annually Estimated to be completed in 62 years	7% annually of initial lead service line estimate (7% * 74,138= 5,190) Estimated to be completed by July 31, 2034.
Lead Filter Implementation	No	Yes Estimates of lead filter adoption rates of 50-100% considered

Data Sources

The model uses data from the following sources.

(1) Inventory Estimate: updated by Corona on 7/31/2019 using databases provided by Denver Water on 6/17/2019 and 7/12/2019. See Appendix III.B.2 - Preliminary Identification of Lead Service Lines for more detail. The estimate provides p-values for all taps in the service area. It also includes parcel year built for most taps.

(2) Source of Supply Shape File: provided by Denver Water on June 14, 2018 The shape file was paired with the inventory to determine water supply from Marston and Foothills (S. Platte R. supplies), Moffat (Fraser R. supply), and blend areas.

(3) LCR and Customer Requested Sampling Database: provided by Denver Water on 7/22/2019 from LIMS. The data were filtered to include only first draw lead samples. The database provides project year built for customer requested samples, addresses for all samples, and lead concentrations. These data were paired with the inventory using a list of tap numbers paired with addresses provided by Denver Water on 6/7/2019. Samples taken after this date may not have been paired with tap numbers. Samples for which a tap number was not assigned were not used in the model inputs.

(4) Pipe Rack Experimental Data: updated on 7/11/2019 from Denver Water LIMS. Data from the pre-treatment period and the control racks were used for pre-treatment lead release in the model. Data meeting the target operational conditions were used for post-treatment lead release in the model. See Appendix II.B - Lead Pilot Results for additional details.

(5) Immersion Study Experimental Data: updated on 7/31/2019 from Denver Water LIMS. Only data from the copper with lead solder coupons were used in the model. See Appendix III.E.2 additional for details.

Model Assumptions

The following assumptions were informed by the listed data sources.

(1) **Total Service Connections:** The total number of service connections in the integrated Denver Water system is used to define the extent of Denver Water customers in the integrated system. For this analysis, a total of 335,457 connections are considered. Services are distributed to the approximate sources of supply: Marston/Foothills 162,540, Moffat 59,369, Blend 108,472. 5,076 services were not assigned a source in mapping and were therefore excluded from the calculated ratios.

(2) **Estimated Number of Existing Lead Service Lines (LSLs):** The estimated number of existing lead service lines is used to define the expected lead concentrations experienced at those connections under current and potential future conditions. The estimated number of lead service lines in Denver Water's integrated system used at the time of this model analysis is 74,138. Lead service lines are distributed to the approximate sources of supply: Marston/Foothills 28%, Moffat 25%, Blend 47%. The model was also exercised to analyze 55,000 lead service lines to test sensitivity to this parameter.

(3) **Estimated Number of Existing Copper with Lead Solder (CuLSs):** The estimated number of existing CuLS is used to define the expected lead concentrations for homes with CuLS under current and potential future conditions. A conservative number of CuLSs was determined by selecting the taps with a parcel build year before 1988. The number of lead service lines mathematically assigned to the same subset of taps was subtracted from this total. The total number of CuLS taps is 152,630. CuLSs are distributed to the approximate sources of supply: Marston/Foothills 38%, Moffat 49%, Blend 13%. This estimate is conservative because many of these services would have CuLS premise plumbing replaced with non-lead bearing materials.

(4) **Source of Supply:** The source of supply for each tap is assigned based on the shape file, which represents only a certain time period when the data were collected. When lead release data for blended sources is not available, samples are drawn from either Marston or Moffat data. For example, when the service is a lead service line, the fraction of samples drawn from the Marston data are equal to the number of lead service lines in the Marston zone divided by the total lead service lines in the Marston and Moffat zones. Inversely, the fraction of samples drawn from the Moffat pipe rack is equal to the number of lead service lines in the Moffat zone divided by the total lead service lines in the Marston and Moffat zones. The same procedure is used for CuLS and other.

(5) **Lead Release from Lead Service Lines (LSLs):** The lead release from lead service lines is taken from the data from the pipe rack experiments for both pre- and post-CCT. These data are used instead of the LCR data because the pipe racks directly test the effectiveness of orthophosphate and pH adjustment. The lead concentrations coming off the pipe rack have high variability and can exhibit 2 to 3 times the peak concentrations observed from sequential sampling (profiling) studies undertaken by Denver Water.

(6) **Lead Release from Copper with Lead Solder (CuLS):** The lead release from CuLS is taken from the LCR database. These data consist of LCR compliance samples and first-draw customer requested samples. Samples are identified as CuLS when the inventory parcel year built is less than 1988 and the p-value assigned in the inventory is less than 0.8 (which are likely to be lead service lines).

For samples with no parcel year built, project year built from the LCR database is used. A lognormal distribution was fit to these data and used to determine lead release at each tap.

(7) **Lead Release from Other Materials:** The lead release from other lines is taken from the LCR database. These data consist of first-draw customer requested samples (no LCR compliance samples are taken at homes without lead service line or CuLS). Samples are identified as other when the inventory parcel year built is greater than 1987. For samples with no parcel year built, project year built from the LCR database is used. These data were also fit to a lognormal distribution.

(8) **Corrosion Control Treatment (CCT):** Either orthophosphate or pH/alkalinity adjustment is considered for corrosion control treatment. The effectiveness of these approaches on minimizing lead release for lead service lines come from results of the lead service line pipe rack experiments. The reductions achieved in CuLS and other lines come from the immersion study. The data from only copper with lead solder coupons are used. Bootstrapping is used to calculate the reduction from the pH or orthophosphate treated jars in comparison with the control jars. Since lead release is not expected to increase as a result of CCT, negative reductions were changed to zero.

The remaining assumptions are a function of the OCCT and LRP conditions.

(9) **Implementation Start Date:** Either the OCCT or LRP option will be implemented on March 20, 2020.

(10) **Lead Service Line Replacement (LSLR) Rate:** Denver Water currently estimates 1,200 lead service lines are replaced annually as a result of main replacement projects and parcel redevelopment which is assumed to continue at a constant rate in the OCCT scenario. As a part of the LRP, Denver Water will implement accelerated lead service line replacement rate of 7% annually (5,190 lead service lines/yr calculated as a 3-year running annual average). After replacement of a lead service line, the service is conservatively assumed to contain CuLS as premise plumbing. The model assumes the lead service lines will be randomly selected for replacement. The LRP will prioritize high lead concentration areas and sensitive sub-populations.

(11) **Lead Filter Implementation:** As a part of the LRP, Denver Water will distribute and verify use of NSF/ANSI 53 certified lead filters at homes with known or suspected lead service line until 3 months after the lead service line is confirmed to be removed. NSF/ANSI 53 certified lead filters achieve lead reduction to the detection limit of 1 ppb (Bosscher et al., 2019). This analysis considers estimates of filter adoption rates from 50 to 100% in increments of 10%.

Model Configuration

A flowchart of the model configuration is shown in Figure 1. The model starts by estimating current lead exposure conditions across the Denver Water service area for connections characterized by having a lead service line, CuLS, or other material. The model represents lead exposure at lead service line served connections as those experienced by the lead service line pipe rack experiments. The model represents lead exposure at CuLS and other using the historic LCR samples.

The model applies a variable reduced lead release due to CCT for lead service lines by randomly drawing from the treated pilot rack data for the appropriate CCT (orthophosphate or pH). The lead reduction for CuLS and other materials is determined by calculating percent reduction from random draws of immersion study data for CuLS coupons with the appropriate CCT (orthophosphate or pH). Negative reductions were changed to zero because CCT is not expected to increase lead release. This calculation is applied to both CuLS and other material lines even though only CuLSs are represented in the immersion study because no site-specific lead reduction data for other materials are available.

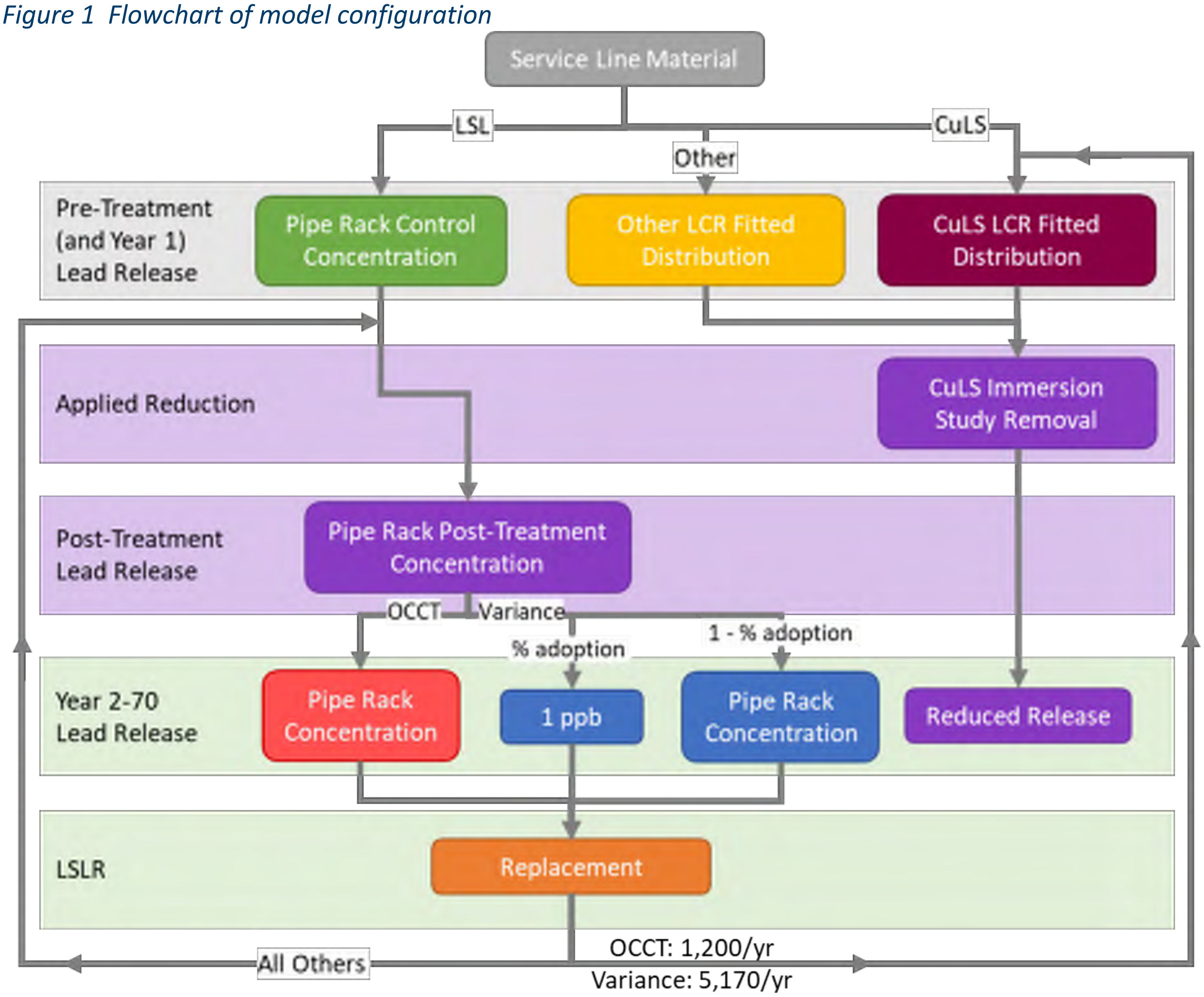
Lead filter exposure in the model is set to 1 ppb lead. Lead filters are only applied to remaining lead service lines; therefore, once a lead service line is removed, so is the filter. This service line will then be drawn from the CuLS distribution which can result in a lead concentration greater than 1 ppb.

Lead service line replacement is modeled by shifting the inventory of lead service lines in the integrated service area from lead service lines to CuLS by the number of lead service line replacements in each year.

All taps and distributions are divided by source: Marston, Moffat, or blend. The model simulates lead release from all individual taps every year for 70 years. The only parameter that changes through time is the number of lead service lines and CuLS due to replacement.

Further details describing the modeling approach, model inputs, choices, and assumptions are provided in Appendix B. Histograms of the underlying data can be found in Appendix C.

Figure 1 Flowchart of model configuration



Results

The model outputs a predicted lead concentration at every tap in Denver Water's integrated system through time in one-year increments (the only parameter to change through time is the number of lead service lines due to replacements). The results have then been summarized in multiple ways.

Lead concentration over time compares the effectiveness of the different chemical treatments and lead service line replacement rates. Figure 2 displays the 95th percentile lead concentration of the entire integrated service area over the time frame from the beginning of treatment to after the last lead service line is removed (figures showing other percentile outputs can be found in Appendix A).

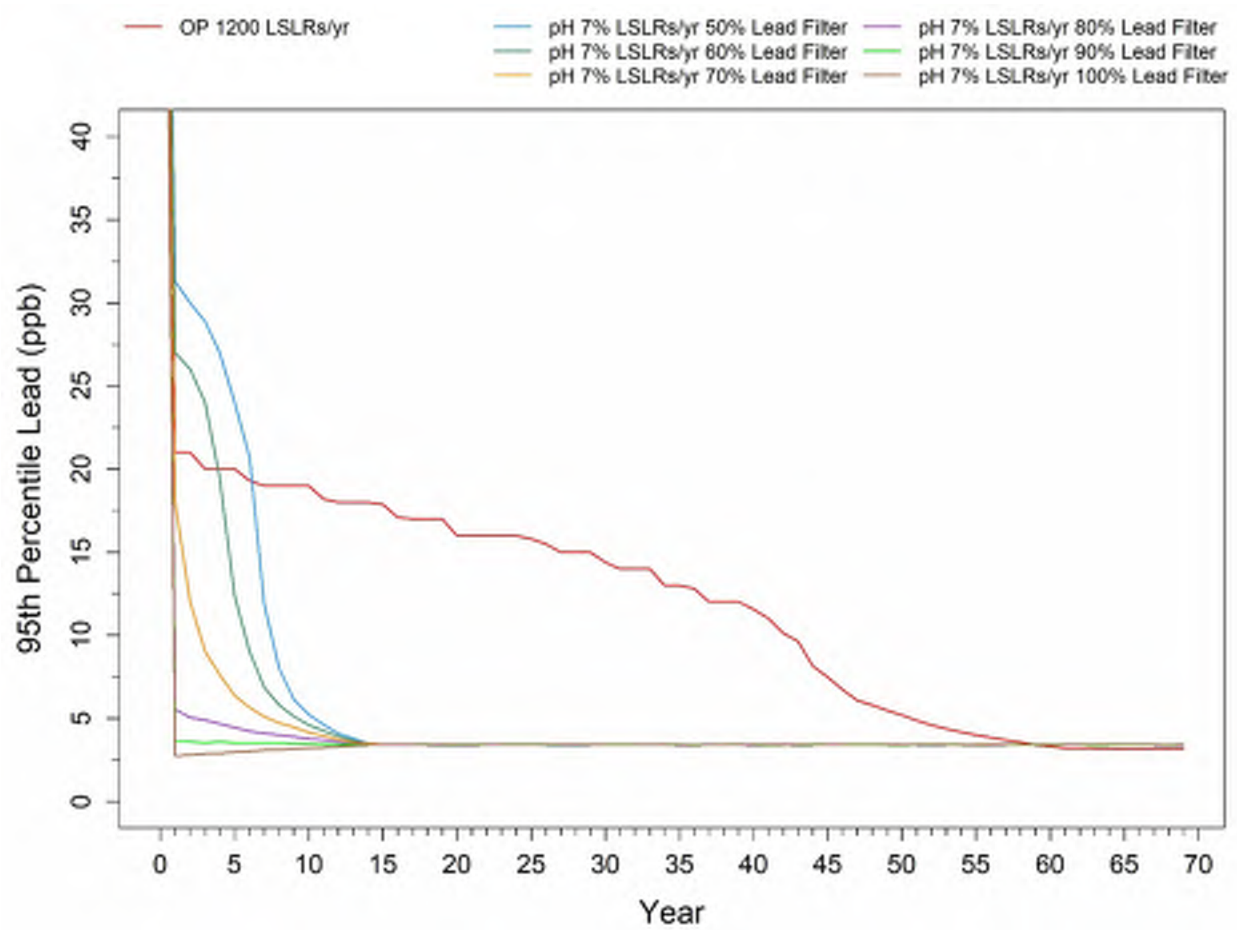
The OCCT condition of orthophosphate is shown in red, while the LRP conditions are shown in different color lines. Each LRP condition line represents a different lead filter adoption rate from 50 – 100%.

Figure 2 shows that the 70% lead filter adoption rate results in lower lead concentrations than the OCCT scenario under the conditions modeled. This is confirmed from outputs at other statistical descriptions as shown in Appendix A. The 60% lead filter adoption rate shows slightly higher concentrations than the OCCT scenario in years 1–4. Therefore, the lead filter adoption rate that demonstrates lower lead concentrations than the OCCT scenario for all tested statistical descriptions is between 60–70%. At the limits of the model, the OCCT scenario indicates lower concentrations than the LRP. This is a result of the lead reduction due to orthophosphate being higher than pH for CuLS.

Similar behavior at other statistical outputs is observed and shown in Appendix A. The 95th percentile outputs were chosen for reporting because it is the most conservative case. Model outputs indicate the LRP conditions result in lower lead concentrations at any lead filter adoption rate of at least 50% at 50th, 75th, and 90th percentiles. At the 99th percentile output, the LRP condition indicated lower lead level at all filter adoption rates 60% and above.

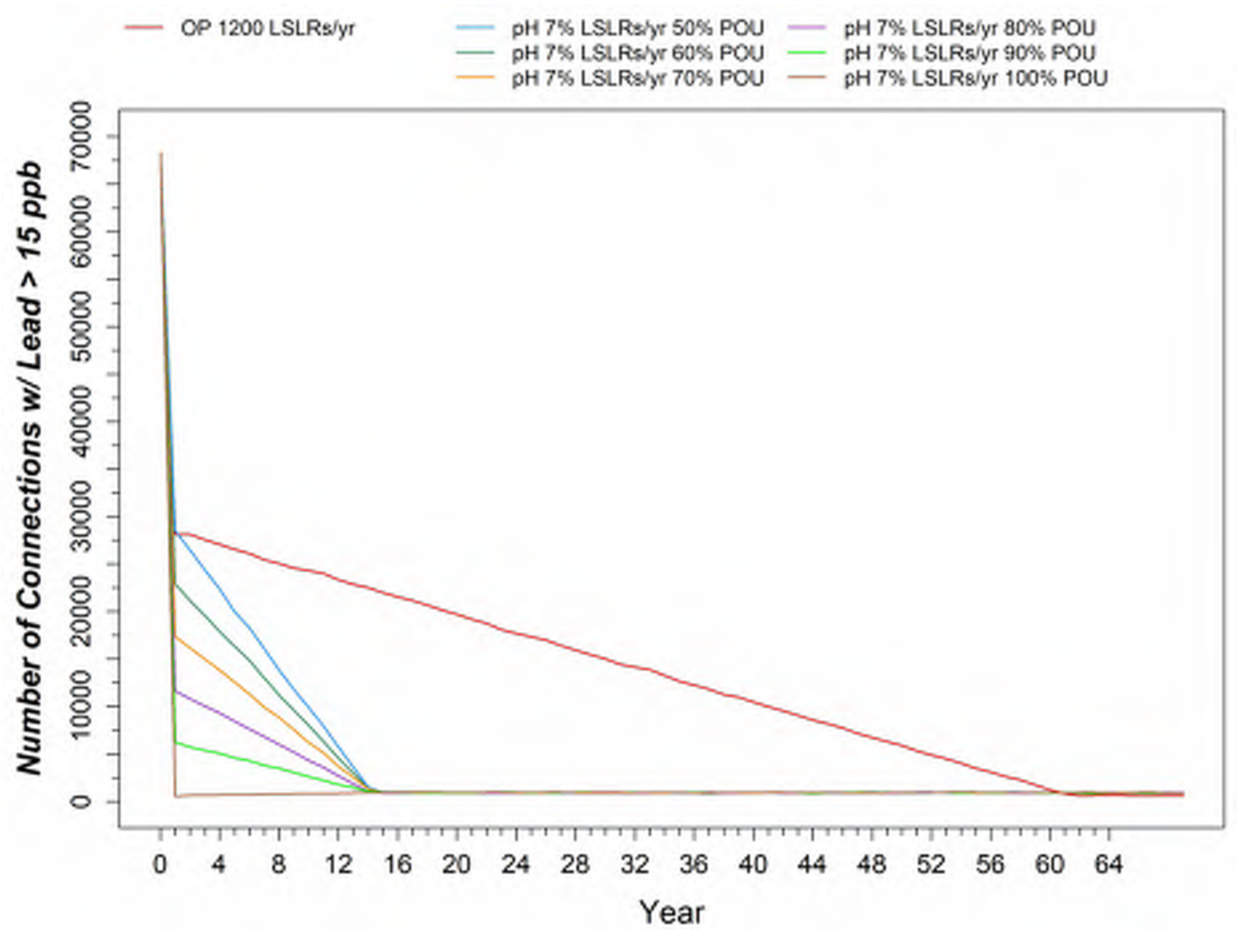
The OCCT condition shows a relatively gradual reduction in 95th percentile lead concentrations over time, while the LRP conditions show more dramatic reduction over the first 15 years. This result is due to the effective lead removal from the lead filters coupled with accelerated lead service line replacements that are included in the LRP. In the LRP condition with 100% lead filter adoption, there is a minimal increase in the 95th percentile lead concentration between years 1 and 15. The increase happens because when a lead service line is replaced, the customer will no longer get credit for use of a lead filter. The lead concentration at the tap will be drawn from the copper with lead solder distribution and therefore may have a higher concentration than with a lead filter.

Figure 2 95th percentile lead concentration over time



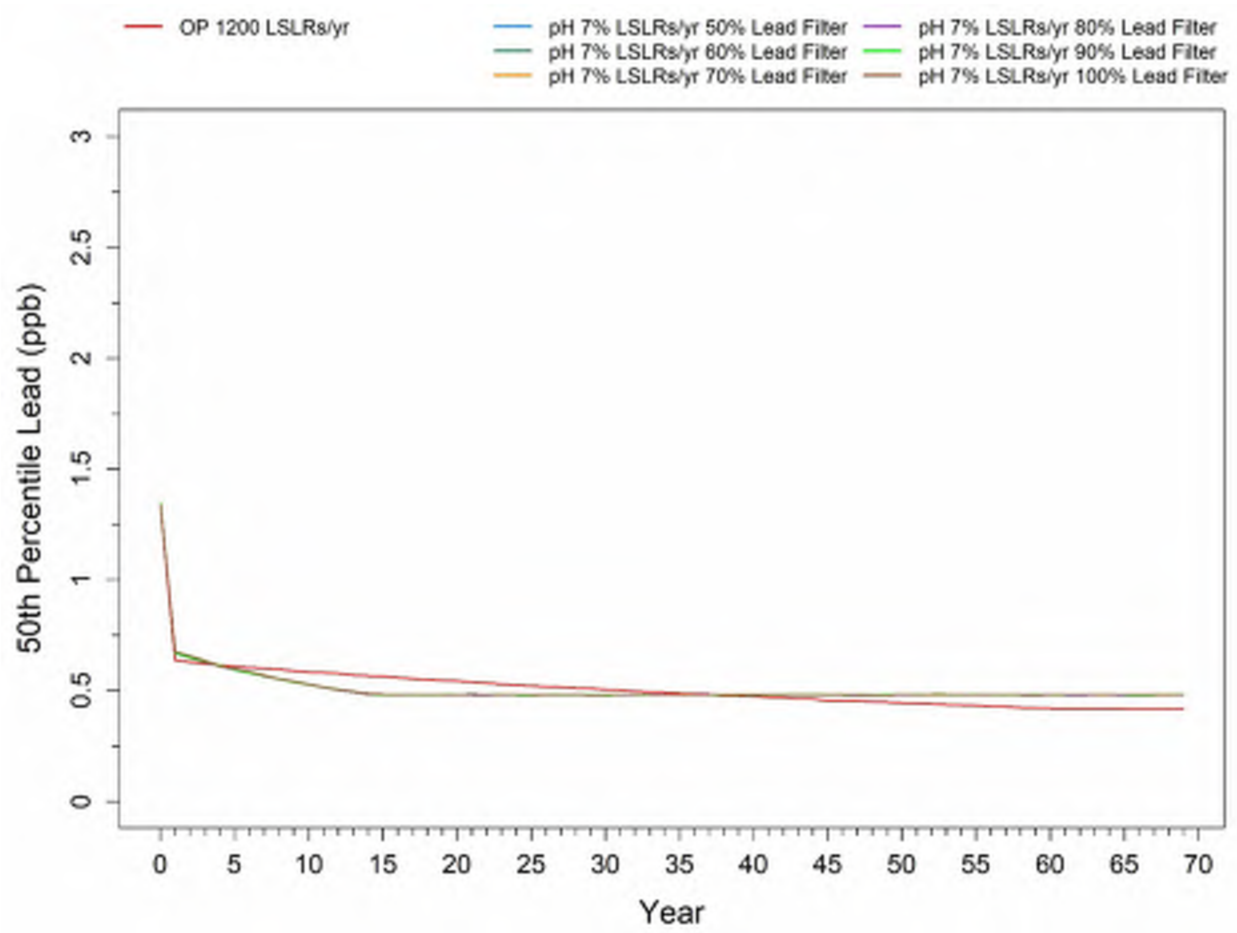
Another way to visualize the results is to compare the number of service connections above a threshold concentration. These results are presented in Figure 3 which indicates that the LRP results in a lower number of services with high lead concentrations under all filter adoption rate scenarios above 50%. Note again that this is not a prediction of the actual service connection lead concentrations but a tool to compare the conditions of the LRP to OCCT.

Figure 3 Number of connections above 15 ppb lead concentration over time



The model can also be used to look at the lead concentrations at lower statistical outputs. Figure 4 presents the median lead concentration (50th percentile), which is representative of copper with lead solder plumbing materials. In addition to the low lead concentration ranges, we see equivalent performance between the LRP and OCCT. This indicates that the LRP achieves its objectives of addressing the public health concern of the lead service lines while providing equivalent protection for the entire system.

Figure 4 Median lead concentration over time



Corona also exercised the model under two scenarios to test the senetivity of the model to major assumptions. First we tested the effect of the concentrations from lead service lines, then we tested the model for a lower inventory estimate of lead service lines.

In general, the lead concentrations from the pilot control racks range from 50 - 100 ppb. The peak lead concentrations from three rounds of profile sampling of seven in situ lead service lines generally ranges from 20 to 40 ppb. Therefore, the lead concentrations used in the model are about 2x higher than we might expect in the distribution system. The model was run with all lead service line concentrations halved; Figure 5 shows the 95th percentile results. As expected, concentrations decrease; however, the equivalence point between the OCCT and the LRP does not change substantially.

The estimated number of lead service lines is calculated based on conservative p-values and may; therefore, be high. The model was also run with 55,000 lead service lines; 95th percentile results are shown in Figure 6. The equivalence point shifts to lower filter adoption rates. In addition, the OCCT condition reaches its minimum sooner, since the rate of lead service line replacement is not dependent on the total number of lead service lines.

Figure 5 95th percentile lead concentration over time with lead concentrations from pilot racks halved to be more representative of actual lead concentrations observed in the distribution system

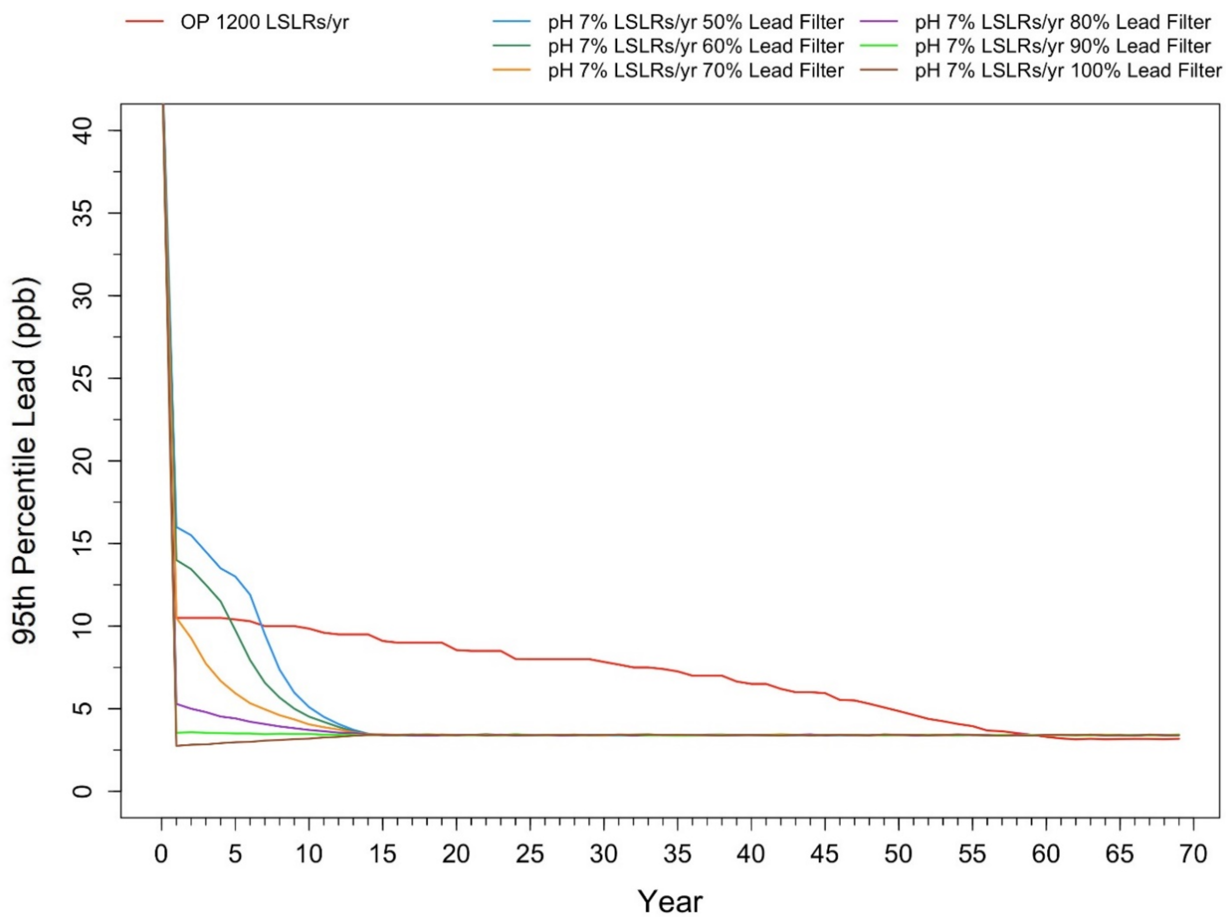
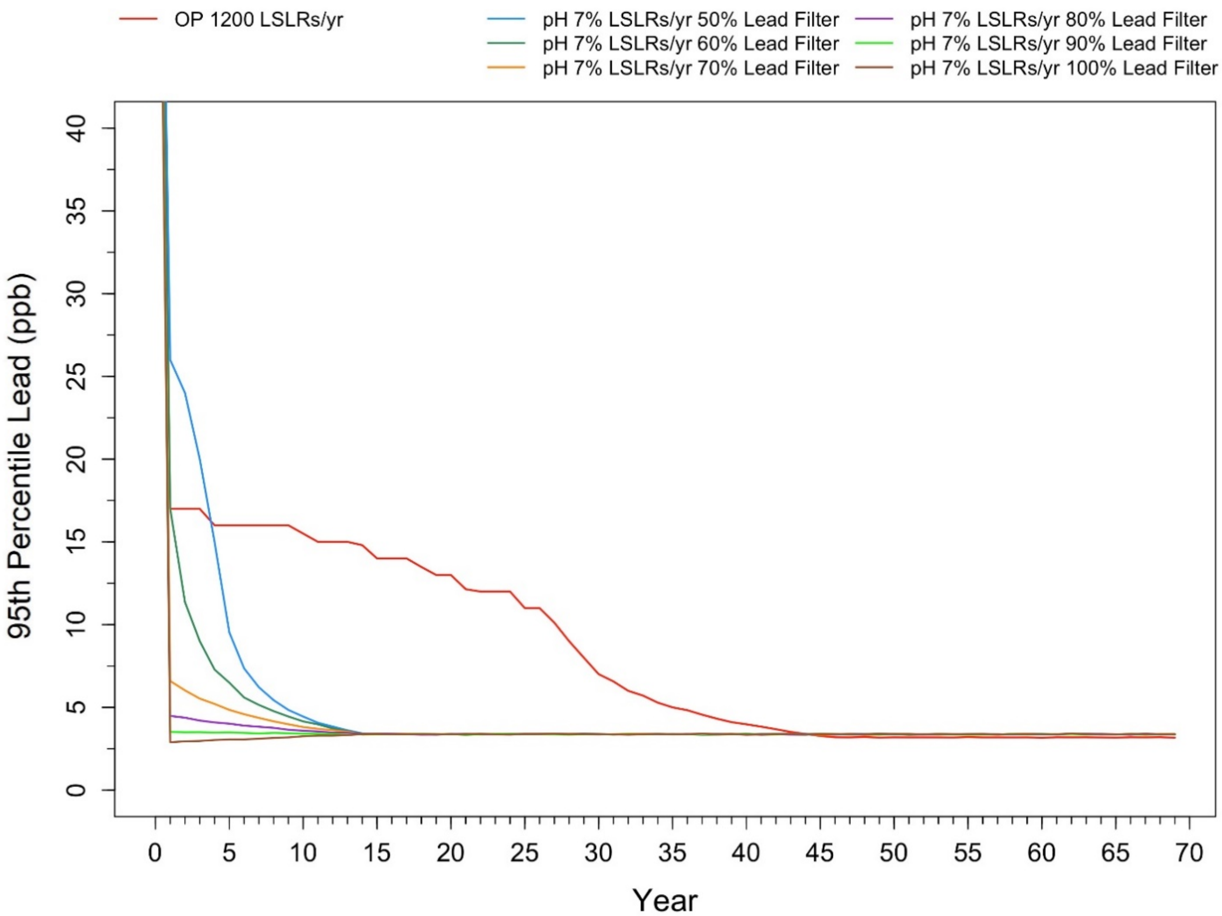


Figure 6 95th percentile lead concentration over time with number of lead service lines changed to 55,000



Each of the previous plots is a statistical summary of the data for every year. For a better understanding of the actual lead concentrations, the distribution of lead release for select years is shown in Figure 7 with each service line material in a different color. The y-axis is cropped at a count of 10,000 due to the high number of services with lead levels below the detection limit. Year 1 shows the lead concentrations without a lead reduction strategy. Year 2 shows the immediate impacts of each lead reduction strategy. For OCCT, the shift to 5–25 ppb in lead service line concentrations is due to the implementation of orthophosphate treatment. For the LRP scenario, the lead service line distribution shifts to a higher range of 10–50 ppb. However, the counts in this distribution are lower because 60% are served by lead filters, which result in a release of 1 ppb. In addition, both scenarios have fewer lead service lines due to replacement. In Year 16, all lead service lines have been replaced in the LRP scenario. Therefore, the high lead concentrations are eliminated. For the OCCT scenario, there are still an estimated 56,000 lead service lines remaining, which leaves a distribution of lead service lines lead release from 5–25 ppb. However, higher lead release is also observed. In Year 63, all lead service lines have been replaced in the OCCT scenario. High lead release has been eliminated in both scenarios. The difference between the two CCT techniques is visible in the remaining bars, with the OCCT distribution shifted slightly left of the LRP distribution. More years are shown in the Appendix.

Figure 7 Lead concentration distribution for select years at 60% filter adoption

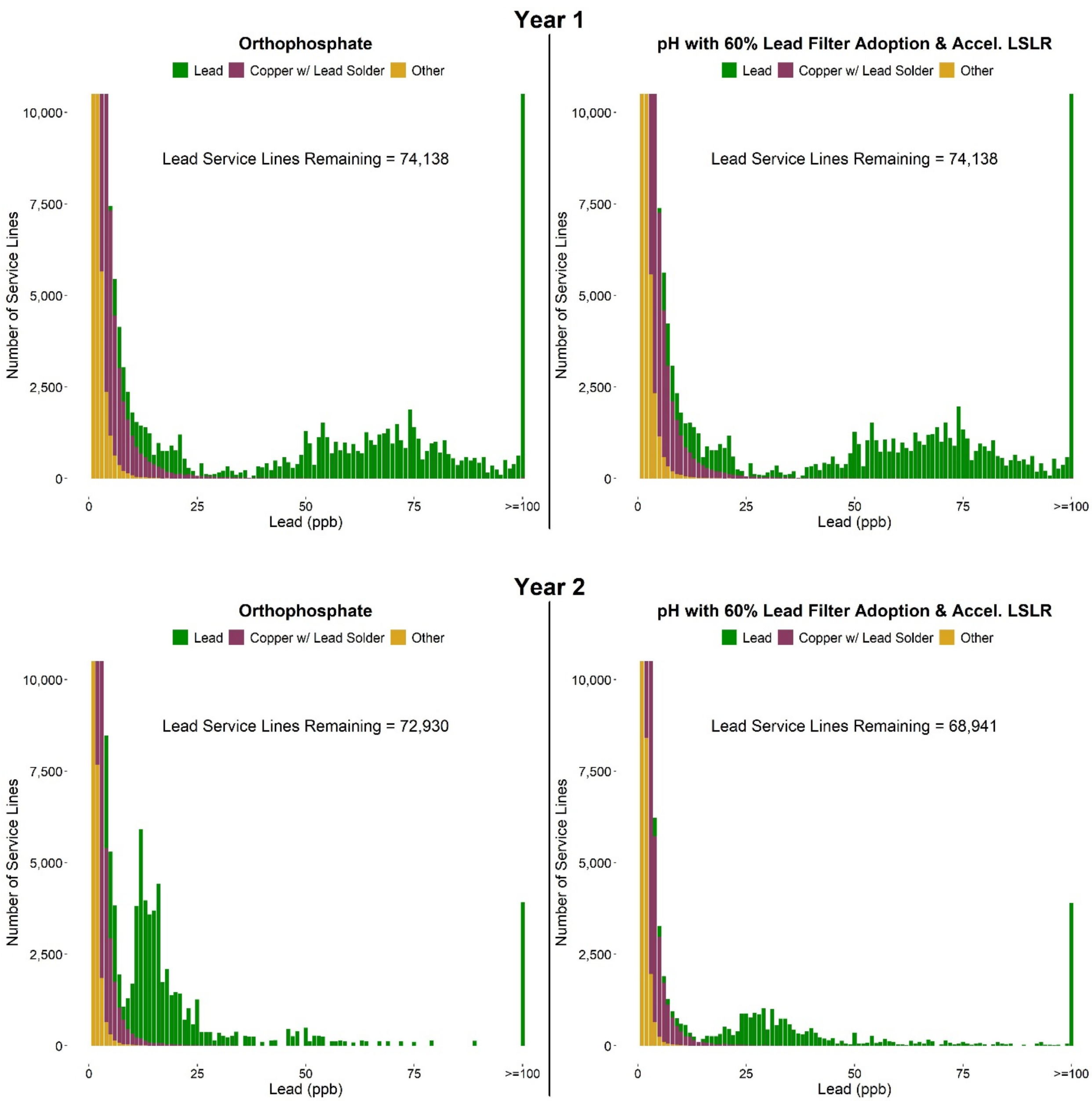
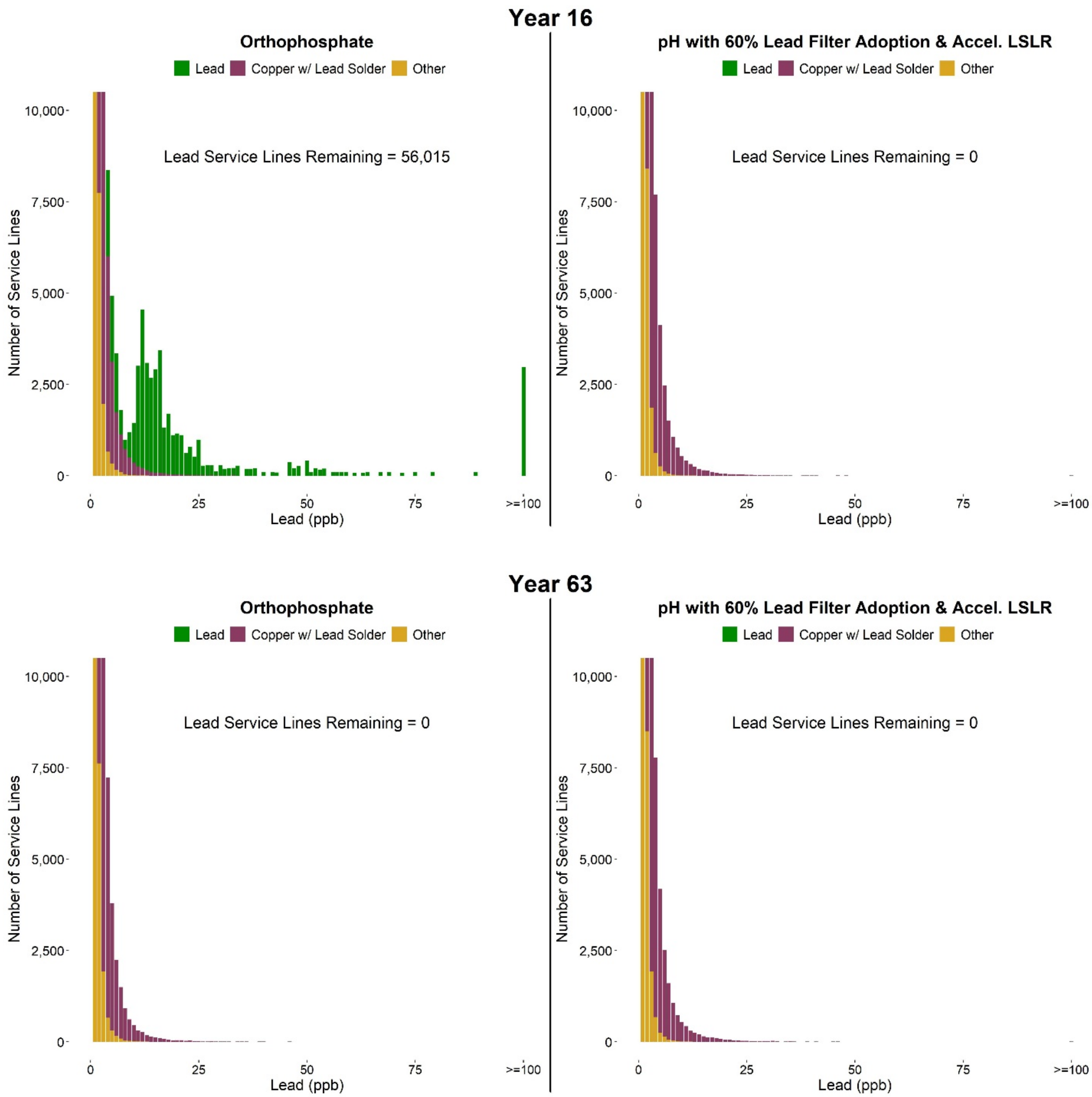


Figure 7 Lead concentration distribution for select years at 60% filter adoption



Conclusions

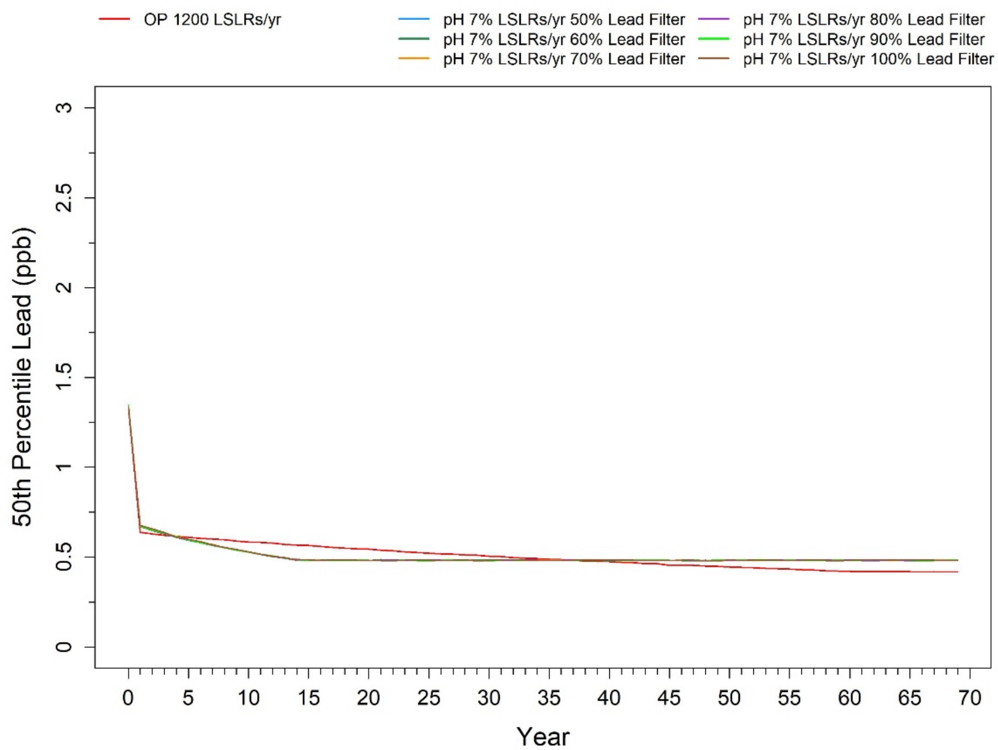
Implementing either OCCT or the proposed LRP conditions achieves significant public health protection by limiting lead exposure at Denver Water connections. At lead filter adoption of 65% and greater, implementing the LRP conditions achieves equivalent or greater lead reductions than OCCT implementation alone.

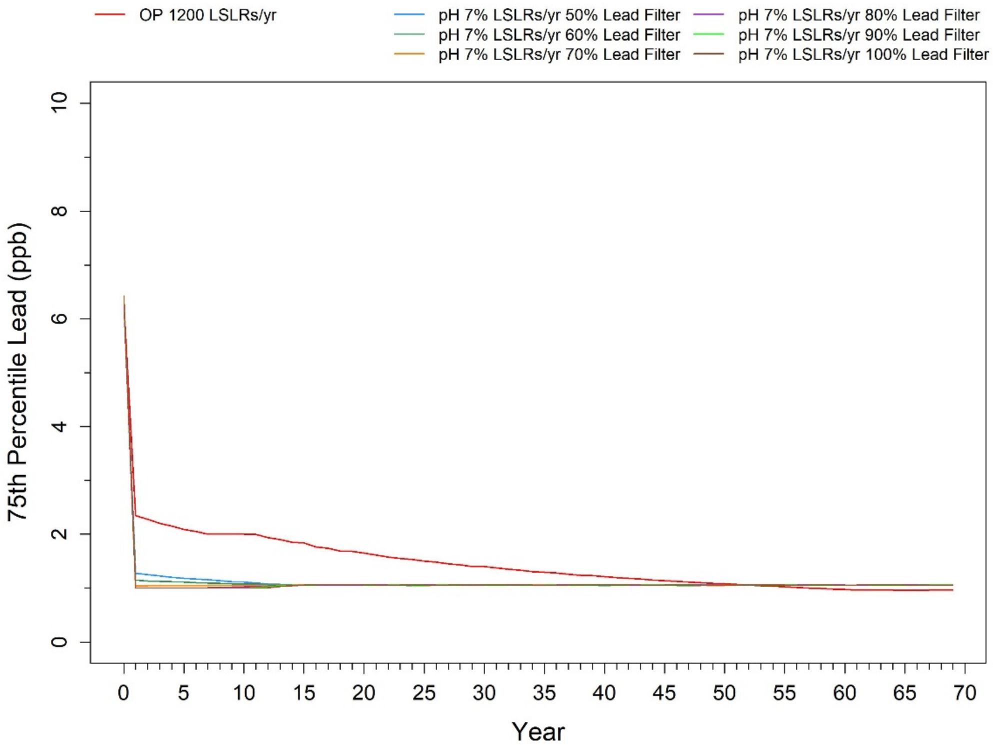
References

Bosscher, V., Lytle, D. A., Schock, M. R., Porter, A., Del Toral, M. (2019). POU water filters effectively reduce lead in drinking water: a demonstration field study in Flint, Michigan. *Journal of Environmental Science and Health* 54(5) 484 – 493.

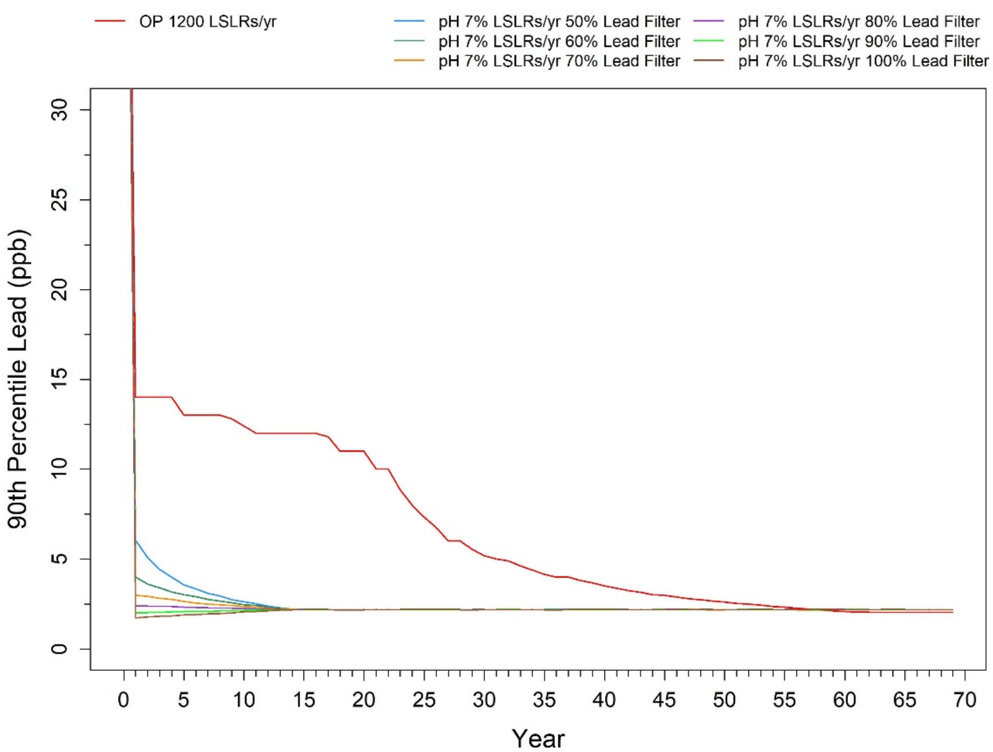
Appendix A: Additional Model Outputs

50th, 75th, 90th, 95th, and 99th percentile lead concentration over time

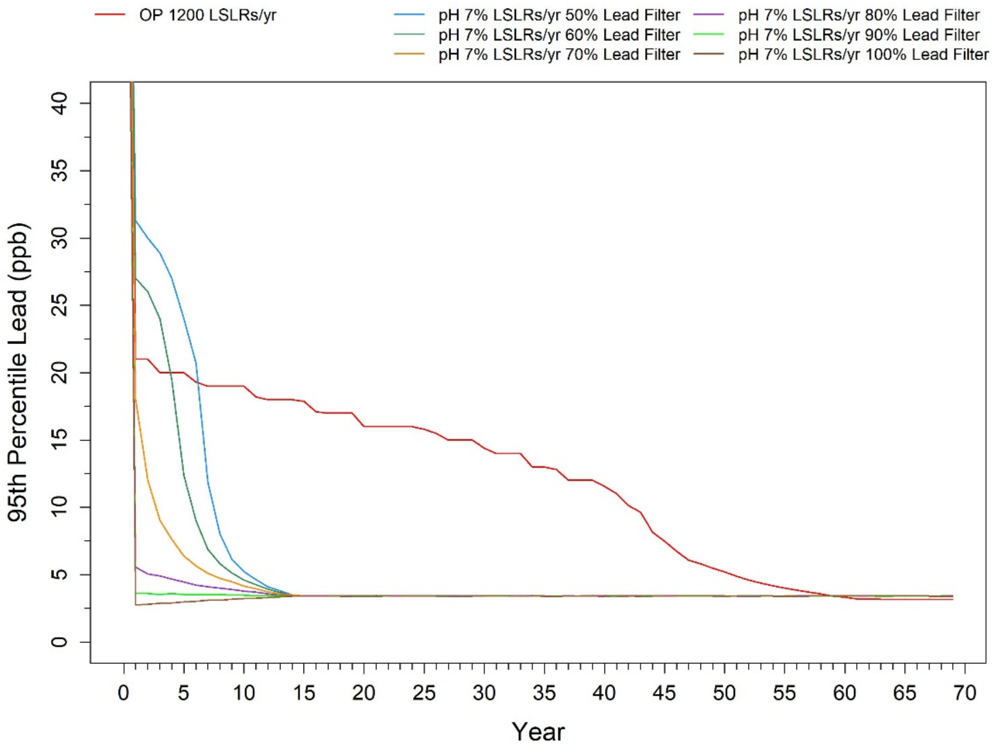


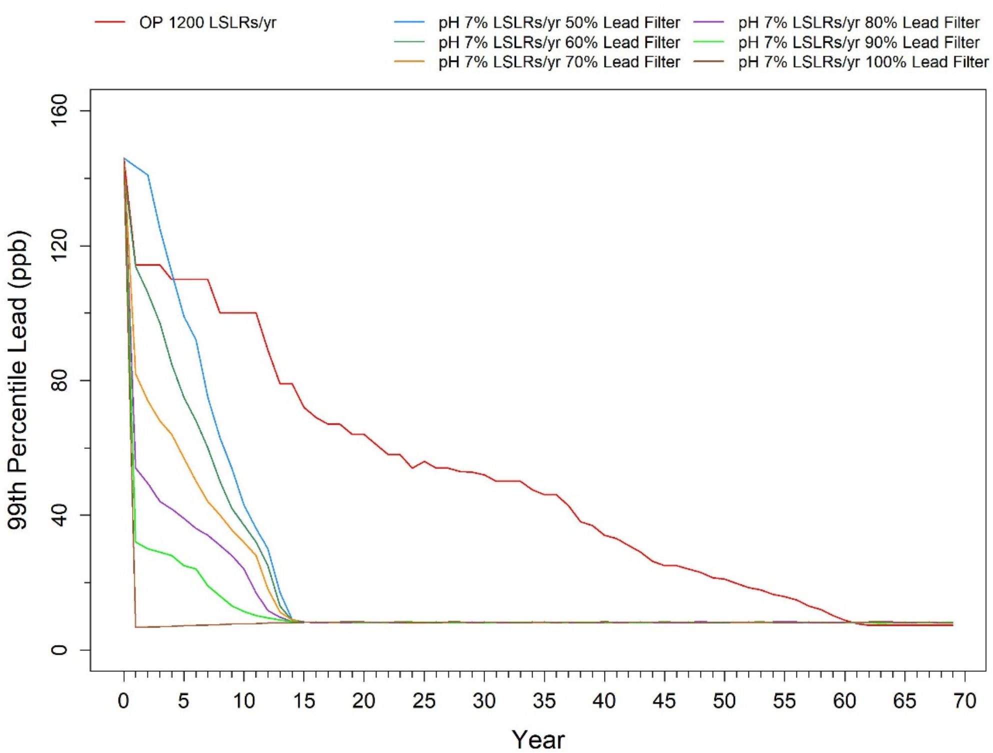


OP 1200 LSLRs/yr
pH 7% LSLRs/yr 50% Lead Filter
pH 7% LSLRs/yr 60% Lead Filter
pH 7% LSLRs/yr 70% Lead Filter
pH 7% LSLRs/yr 80% Lead Filter
pH 7% LSLRs/yr 90% Lead Filter
pH 7% LSLRs/yr 100% Lead Filter
75th Percentile Lead (ppb)
0
2
4
6
8
10
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Year

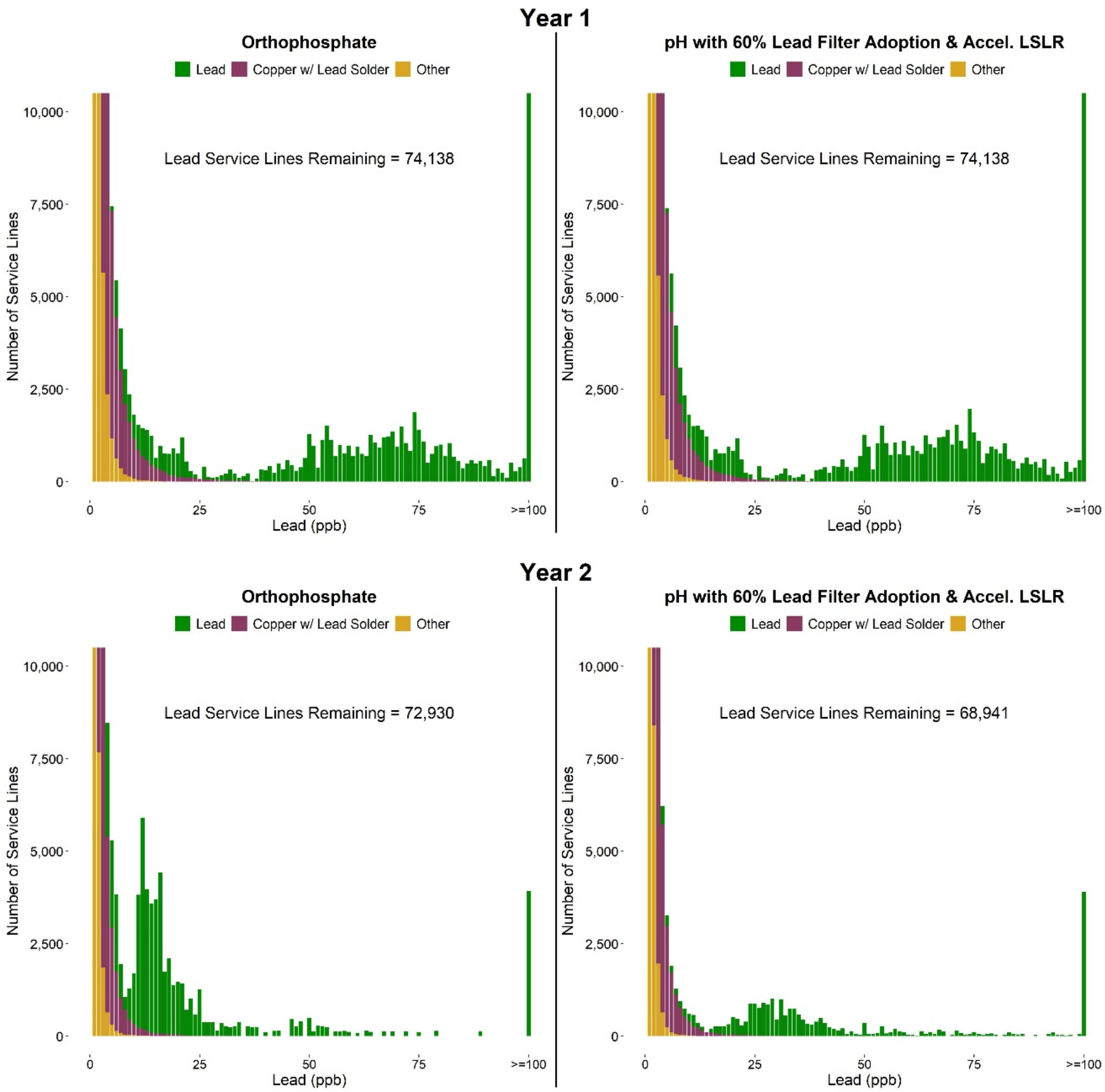


OP 1200 LSLRs/yr
pH 7% LSLRs/yr 50% Lead Filter
pH 7% LSLRs/yr 60% Lead Filter
pH 7% LSLRs/yr 70% Lead Filter
pH 7% LSLRs/yr 80% Lead Filter
pH 7% LSLRs/yr 90% Lead Filter
pH 7% LSLRs/yr 100% Lead Filter
90th Percentile Lead (ppb)
0
5
10
15
20
25
30
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Year

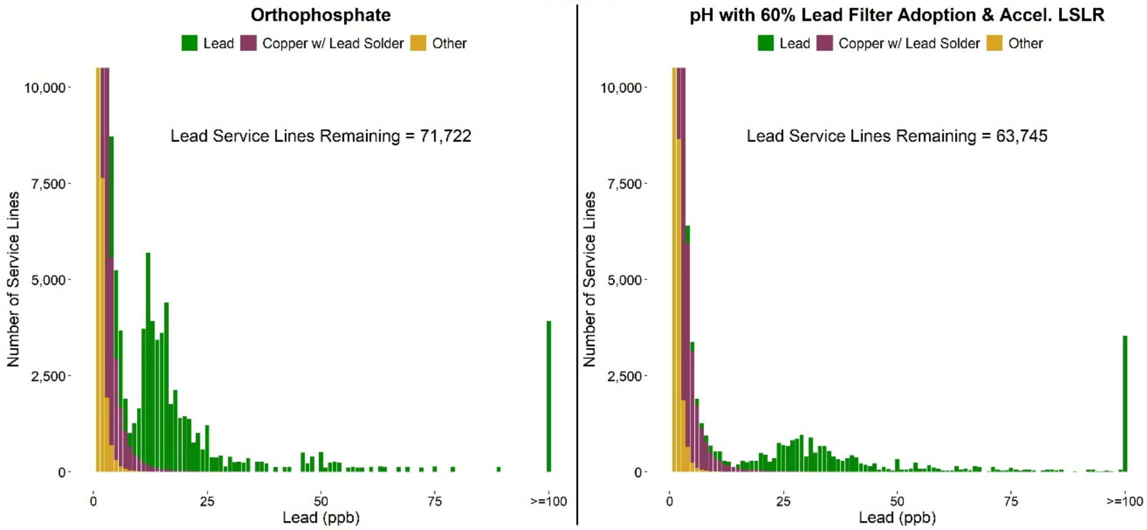

OP 1200 LSLRs/yr
pH 7% LSLRs/yr 50% Lead Filter
pH 7% LSLRs/yr 60% Lead Filter
pH 7% LSLRs/yr 70% Lead Filter
pH 7% LSLRs/yr 80% Lead Filter
pH 7% LSLRs/yr 90% Lead Filter
pH 7% LSLRs/yr 100% Lead Filter
95th Percentile Lead (ppb)
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Year


OP 1200 LSLRs/yr
pH 7% LSLRs/yr 50% Lead Filter
pH 7% LSLRs/yr 60% Lead Filter
pH 7% LSLRs/yr 70% Lead Filter
pH 7% LSLRs/yr 80% Lead Filter
pH 7% LSLRs/yr 90% Lead Filter
pH 7% LSLRs/yr 100% Lead Filter
99th Percentile Lead (ppb)
0
40
80
120
160
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Year

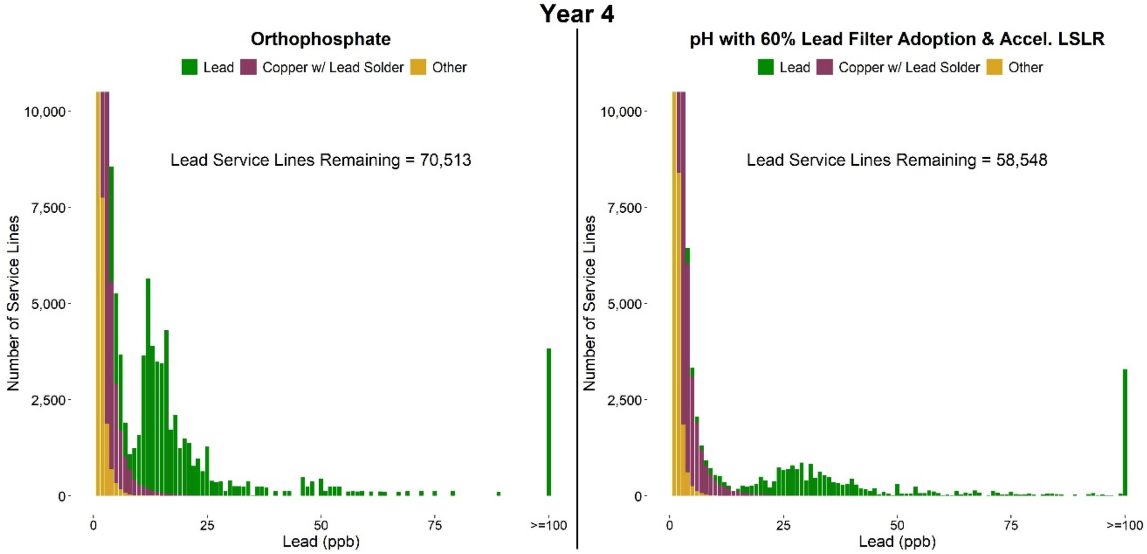
Distribution of lead concentrations by year



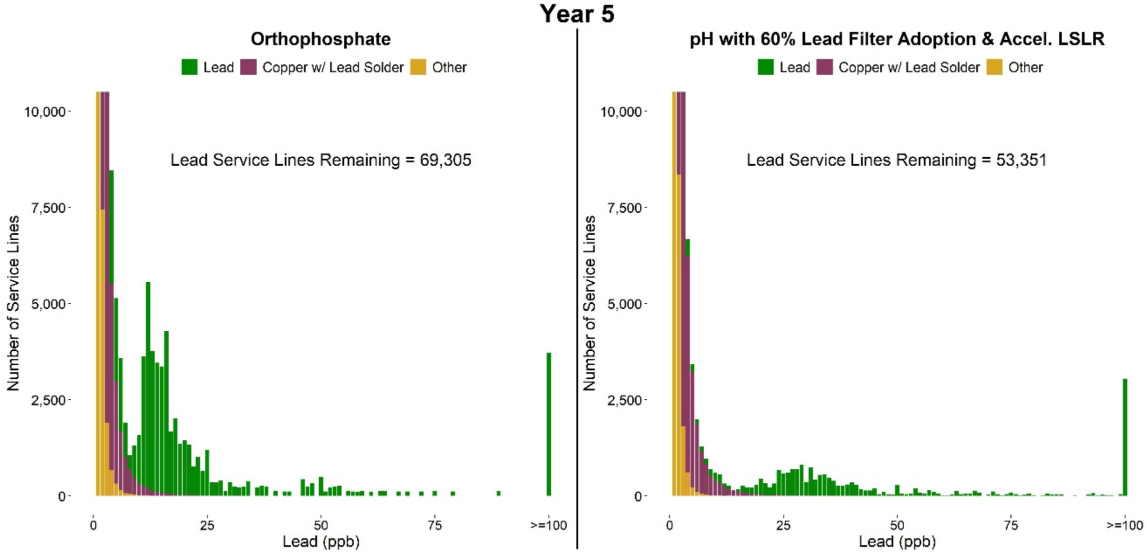
Year 3



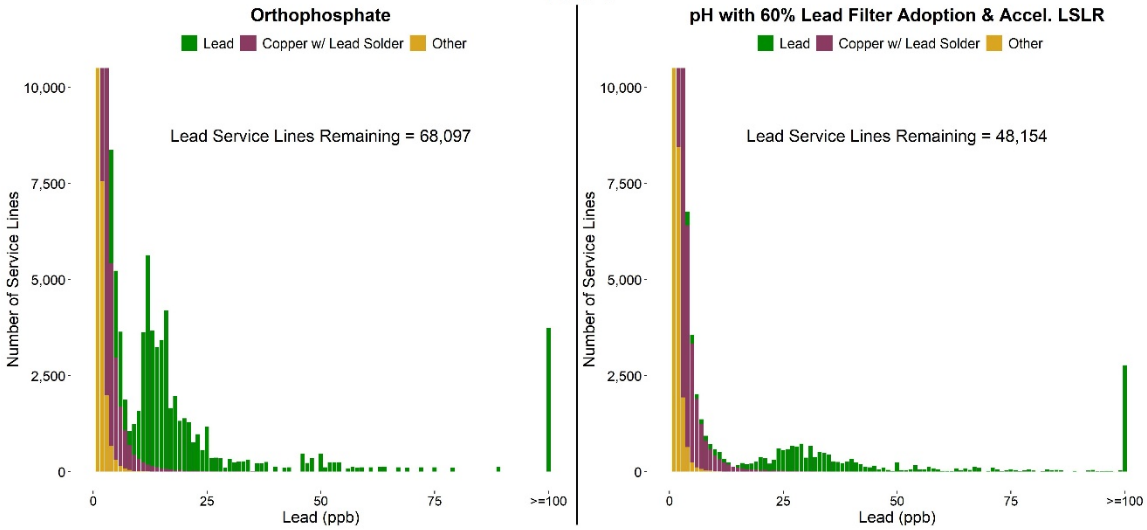
Year 4



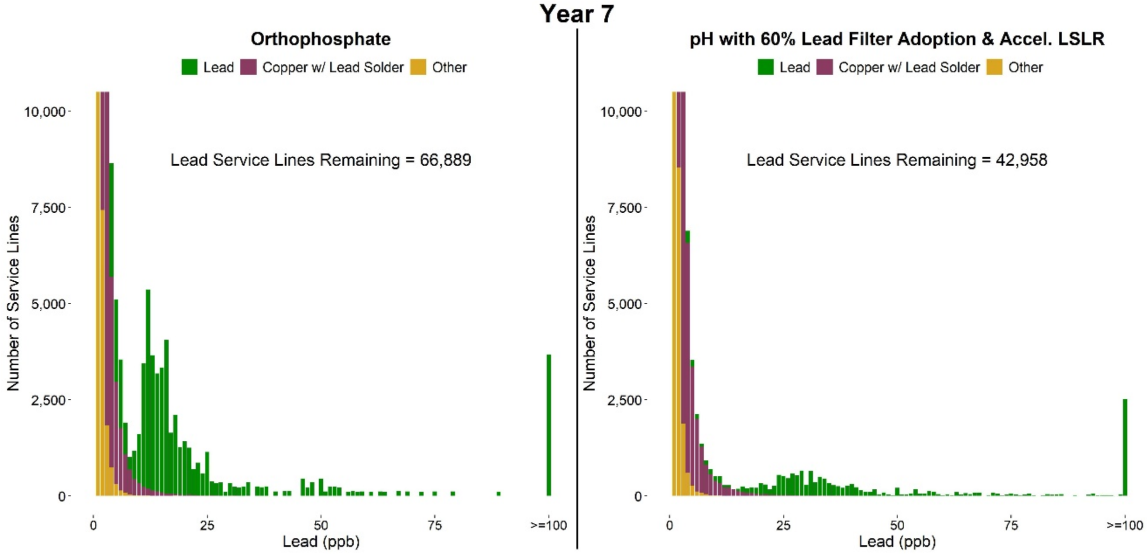
Year 5



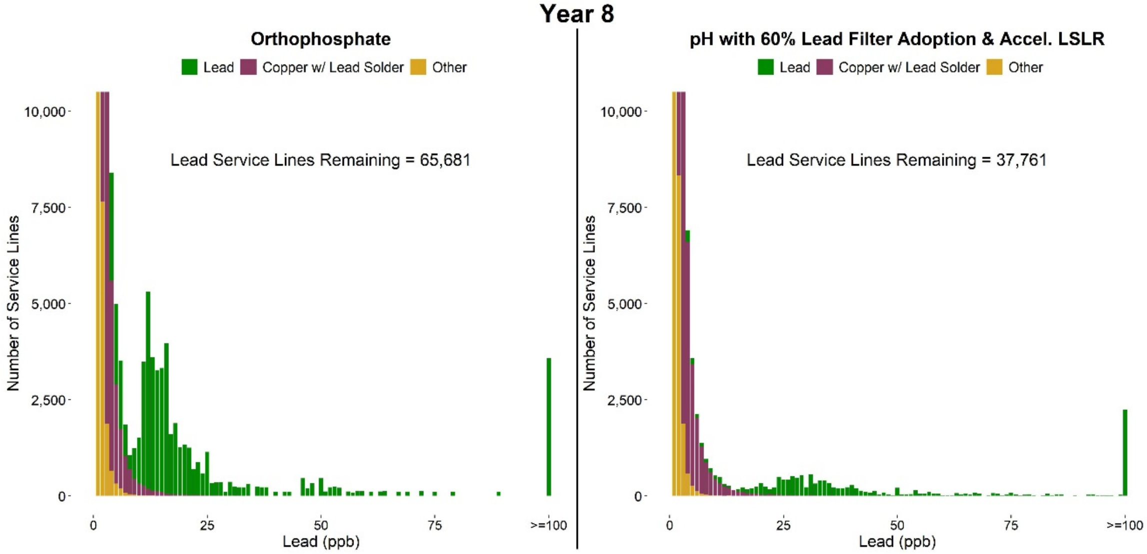
Year 6



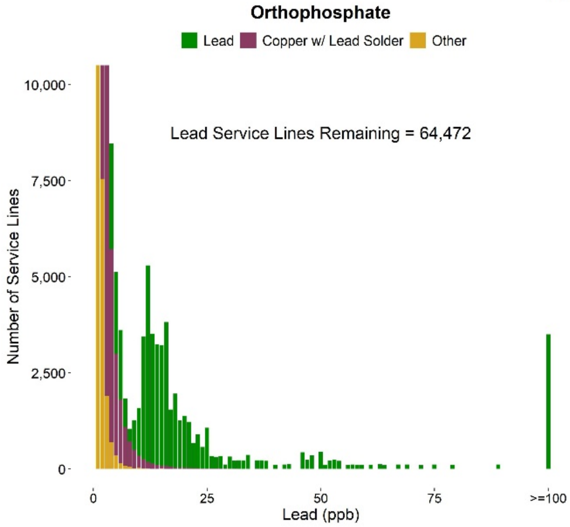
Year 7

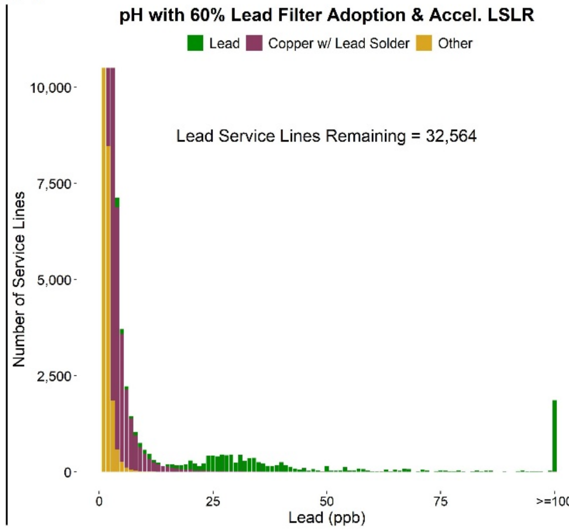


Year 8

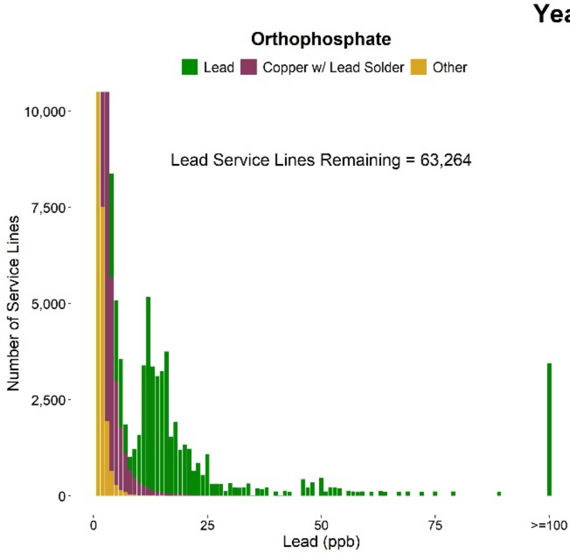


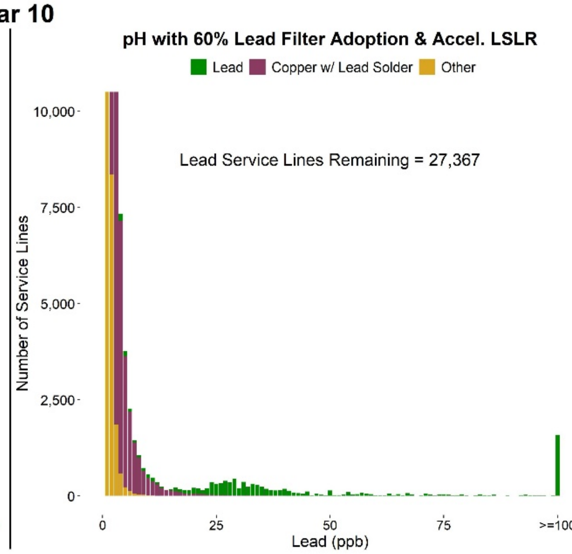
Year 9



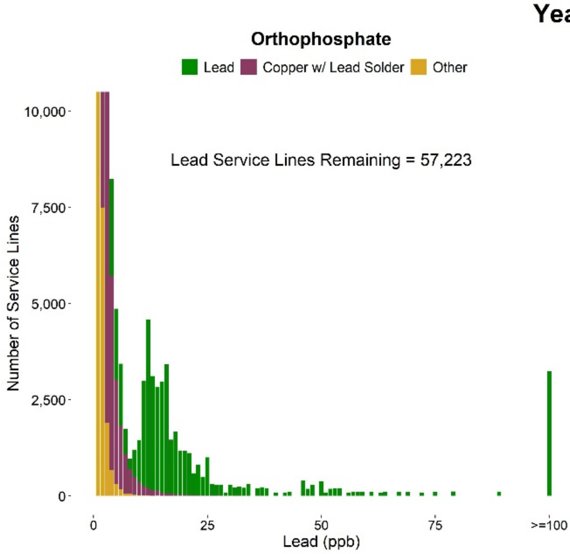


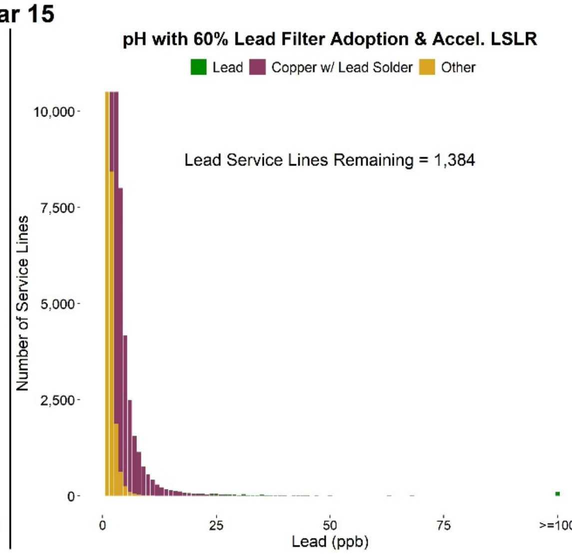
Year 10

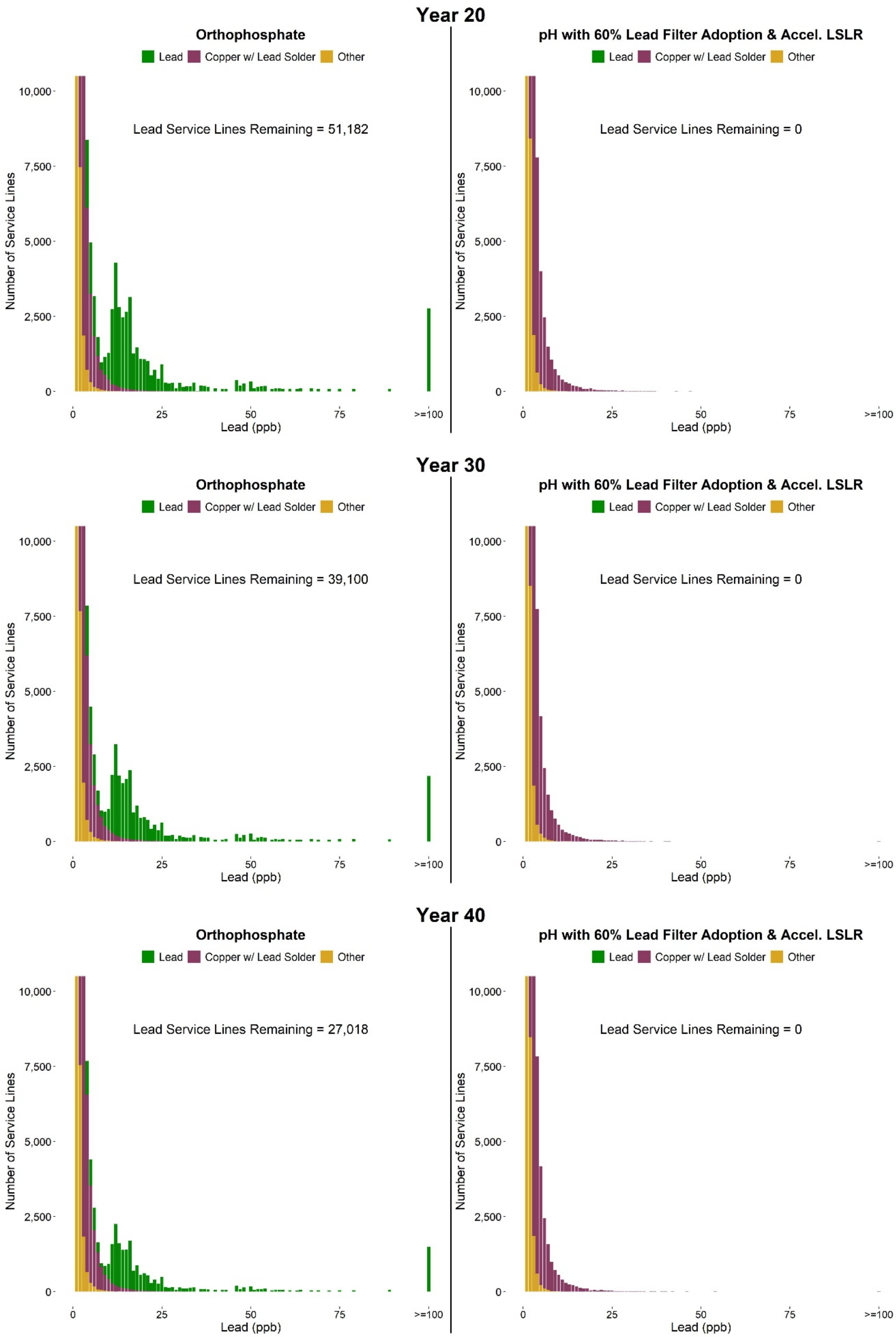


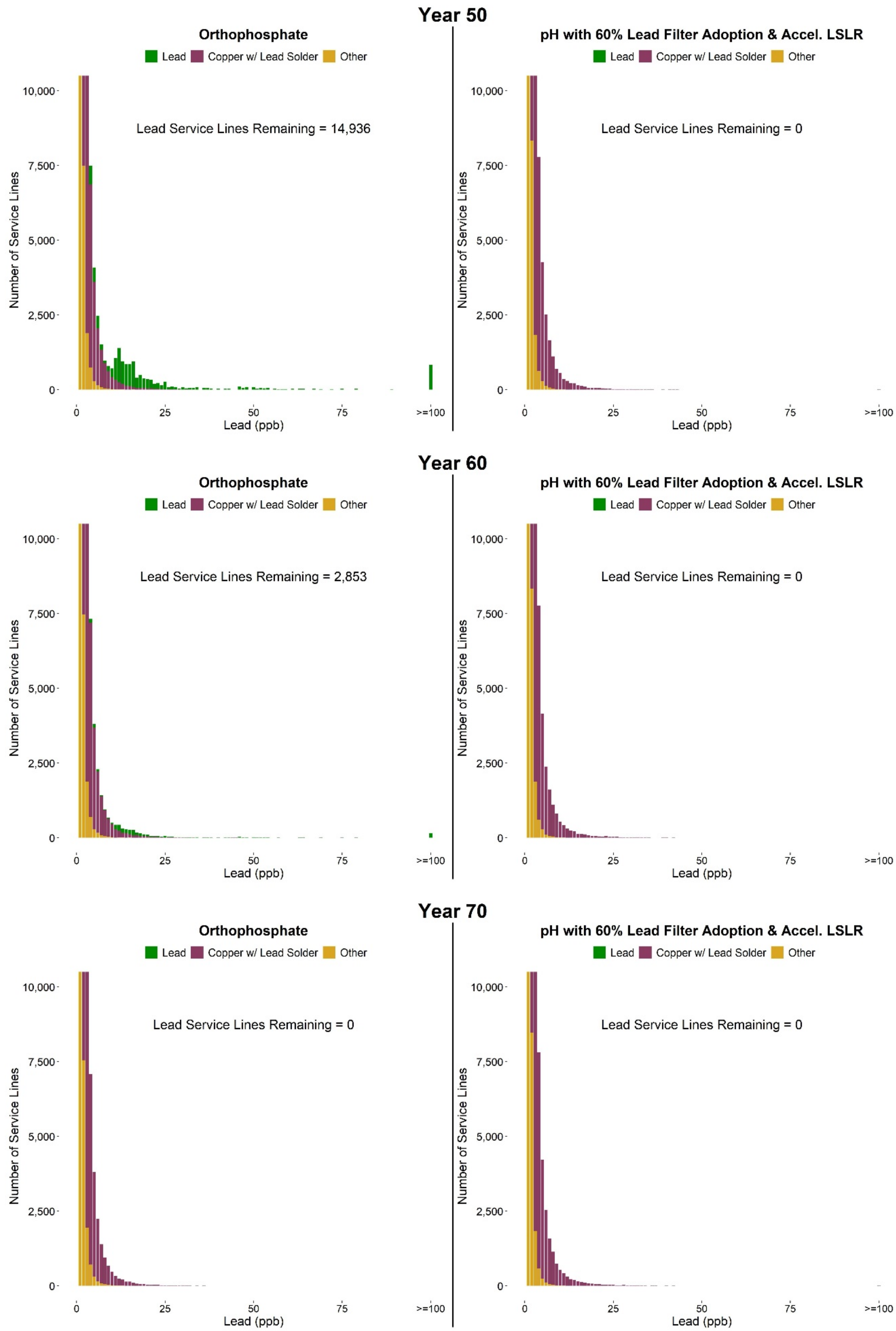


Year 15






Year 20
Orthophosphate
Lead Copper w/ Lead Solder Other
Lead Service Lines Remaining = 51,182
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Year 30
Orthophosphate
Lead Service Lines Remaining = 39,100
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Year 40
Orthophosphate
Lead Service Lines Remaining = 27,018
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Number of Service Lines
Lead (ppb)



Year 50
Orthophosphate
Lead
Copper w/ Lead Solder
Other
Lead Service Lines Remaining = 14,936
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Year 60
Orthophosphate
Lead Service Lines Remaining = 2,853
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Year 70
Orthophosphate
Lead Service Lines Remaining = 0
pH with 60% Lead Filter Adoption & Accel. LSLR
Lead Service Lines Remaining = 0
Number of Service Lines
10,000
7,500
5,000
2,500
0
Lead (ppb)
0
25
50
75
>=100

Appendix B: Modeling Approach, Choices, and Assumptions

Introduction

This appendix describes the approach, choices, and assumptions used in Corona's simulations of corrosion control and lead service line (LSL) replacement for Denver Water's (DW's) service area.

Modeling is divided into two major components:

- Immersion study data analysis (bootstrap) conducted to better characterize variability in treatment technique performance, and
- Simulations (Monte Carlo) for lead risk reduction strategies (combinations of treatment strategies and lead service line reduction scenarios).

Models were programmed in the open source R environment.

Simulation Description

Pre-treatment Data Inputs (First Year)

- **Lead Service Lines:**
  - **Marston Source:** For each Denver Water service connection identified as having a lead service line and served by Marston, a random sample is drawn from the Marston pre-treatment pipe rack lead concentration data.
  - **Moffat Source:** For each connection identified as having a lead service line and served by Moffat, a random sample is drawn from the Moffat pre-treatment pipe rack lead concentration data.
  - **Blended Source:** For service connections in the blended region (receiving water from Marston and Moffat), samples are drawn from either Marston or Moffat untreated pipe rack lead concentration data. The fraction of samples drawn from the Marston pipe rack is equal to the number of lead service lines in the Marston zone divided by the total lead service lines in the Marston and Moffat zones. Inversely, the fraction of samples drawn from the Moffat pipe rack is equal to the number of lead service lines in the Moffat zone divided by the total lead service lines in the Marston and Moffat zones.
- **Copper with Lead Solder**:
  - **Marston Source**: For each service connection identified as having copper with lead solder and served by Marston, a random sample is drawn from the lognormal distribution fit to the LCR lead concentration data for taps identified as copper with lead solder served by Marston.
  - **Moffat Source**: For each connection identified as having copper with lead solder and served by Moffat, a random sample is drawn from a lognormal distribution fit to LCR lead concentration data for taps identified as copper with lead solder served by Moffat.
  - **Blended Source**: For each service connection identified as having copper with lead solder in the blended region, a random sample is drawn from a lognormal distribution fit to LCR lead concentration data for taps identified as copper with lead solder in the blended region.
- **Other Material**:
  - For each service connection identified as having other material, a random sample is drawn from the lognormal distribution fit to the LCR data for taps identified as other. A single distribution is used for "other materials" because the number of samples is too low to stratify amongst the Marston and Moffat service areas.

Post Treatment Data Inputs for OCCT (After First Year)

- **Lead Service Lines:**
  - **Marston Source:** For each service connection identified as having a lead service line and served by Marston, a random sample is drawn from the Marston orthophosphate pipe rack lead concentration data during the post-treatment period. During this period, orthophosphate was being dosed at either 3 mg/L or 2 mg/L.
  - **Moffat Source:** For each service connection identified as having a lead service line and served by Moffat, a random sample is drawn from the Moffat orthophosphate pipe rack lead concentration data during the post-treatment period. During this period, orthophosphate was being dosed at either 3 mg/L or 2 mg/L.
  - **Blended Source:** For each service connection identified as having a lead service line in the blended region, a random sample is drawn from either the Marston or Moffat orthophosphate pipe rack lead concentration data during the post-treatment period. The percentages of samples drawn from the Marston pipe rack data and from the Moffat pipe rack data for the post-treatment period are consistent with those for the pre-treatment period, as described above.
- **Copper with Lead Solder:**
  - **Marston Source:** For each service connection identified as having copper with lead solder and served by Marston, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Marston orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Moffat Source:** For each service connection identified as having copper with lead solder and served by Moffat, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Moffat orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Blended Source:** For each service connection identified as having copper with lead solder in the blended region, a random sample is drawn from the CuLS blended orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
- **Other Material:**
  - **Marston Source:** For each service connection identified as having other material and served by Marston, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Marston orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Moffat Source:** For each service connection identified as having other material and served by Moffat, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Moffat orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
- **Blended Source:** For each service connection identified as having other material in the blended region, a random sample is drawn from the CuLS blended orthophosphate immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.

- **Lead Service Line Replacement:** Each year, 1,200 lead service line connections are randomly selected for lead service line replacement. For each of these connections, the lead concentration is replaced by a random sample from the pre-treatment copper with lead solder distribution. The line is then categorized as copper with lead solder and follows the post-treatment rules for copper with lead solder described below.

Post Treatment Data Inputs for LRP (After First Year)

- **Lead Service Lines:**
  - **Marston Source:** For each service connection identified as having a lead service line and served by Marston, a random sample is drawn from the Marston pH pipe rack lead concentration data during the post-treatment period. During this period, the target pH was 8.8.
  - **Moffat Source:** For each service connection identified as having a lead service line and served by Moffat, a random sample is drawn from the Moffat pH pipe rack lead concentration data during the post-treatment period. During this period, the target pH was 8.8.
  - **Blended Source:** For each service connection identified as having a non-lead service line in the blended region, a random sample is drawn from either the Marston or Moffat pH pipe rack lead concentration data during the post-treatment period. The percentages of samples drawn from the Marston pipe rack data and from the Moffat pipe rack data for the post-treatment period are consistent with those for the pre-treatment period, as described above.
- **Copper with Lead Solder:**
  - **Marston Source:** For each service connection identified as having copper with lead solder and served by Marston, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Marston pH immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Moffat Source:** For each service connection identified as having copper with lead solder and served by Moffat, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Moffat pH immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Blended Source:** For each service connection identified as having copper with lead solder in the blended region, a random sample is drawn from a distribution of percent lead reduction data for the CuLS blended pH immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
- **Other Material:**
  - **Marston Source:** For each service connection identified other and served by Marston, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Marston pH immersion study. The selected reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.
  - **Moffat Source:** For each service connection identified as other and served by Moffat, a random sample is drawn from a distribution of percent lead reduction data for the CuLS Moffat pH immersion study. The selected percent reduction is then multiplied by the

connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.

  - **Blended Source:** For each service connection identified as other in the blended region, a random sample is drawn from a distribution of percent lead reduction data for the CuLS blended pH immersion study. The selected percent reduction is then multiplied by the connection's assigned pre-treatment lead concentration to determine the post-treatment lead concentration.

- **All Sources (Lead Filter):** Denver Water will provide each household with a lead service line with a lead filter. The model is run with lead filter adoption rates, *p*, of 50%, 60%, 70%, 80%, 90% and 100%. For each adoption rate scenario, *p*% of the lead service line connections are randomly sampled and the assigned lead concentration is replaced with 1 ppb to account for the lead reduction achieved by the lead filter.
- **Lead Service Line Replacement:** Each year, 7% of the total lead service lines (7% of 74,138 lead service lines = 5,190 replacements per year) are randomly selected for lead service line replacement. For each of these connections, the post-treatment lead concentration is replaced by a random sample from the pre-treatment copper with lead solder distribution. The line is then categorized as copper with lead solder and follows the post-treatment rules for copper with lead solder described below.

Estimating the Reduction in Lead Release (Immersion Study Data Analyses)

Approach

1. Data used in the bootstrap analysis are immersion study data for periods of stable operation. All immersion study data for CuLS coupons from these periods are retained.
   1.1. The immersion study included CuLS coupons for the Marston plant and for the Moffat plant. For both Marston and Moffat CuLS coupons, data from June 7, 2019 through July 5, 2019 were used. The CuLS coupons included control coupons, coupons with orthophosphate treatment, and coupons with pH treatment.
2. For each plant, draw a sample from the control coupon lead concentration data and a sample from the treatment, either orthophosphate treatment or pH treatment, coupon lead concentration data. The size of the control sample is equal to the number of control data and the size of the treatment sample is equal to the number of treatment data.
3. Calculate the reduction in lead concentration for the control and treatment samples for the coupon. Reduction calculated as the difference in the expected values for a lognormal distribution of the control and treatment samples as a percent of the expected value of the lognormal distribution of control samples.
4. In some case, negative reductions were observed. Because increases in lead concentrations observed in the pilot rack and immersion study were assumed to due to other factors and not as a result of CCT, these values were changed to zero.
5. Steps 2 - 4 were repeated 1,000 times for each treatment.
6. The distribution of reductions for a given treatment is given by the combination of reductions for the 1,000 reduction estimates for a given plant and a given treatment. This resulted in 4 output files, each with 1,000 potential reduction and all used in the Monte Carlo analysis:
   6.1. Moffat plant, OP treatment
   6.2. Moffat plant, pH adjustment
   6.3. Marston plant, OP treatment
   6.4. Marston plant, pH adjustment

Choices and Underlying Assumptions

1. Assume coupons and operating conditions for coupons are representative of pipes and operating conditions for a given service area (Moffat or Marston).
2. Assume that sufficient data were collected from immersion study to account for seasonal differences in corrosion control performance.
3. Assume data are lognormally distributed and calculate reduction based on the difference in the expected value for lognormal distribution for control and treatment data.
4. 1,000 samples per plant and treatment is sufficient for establishing the range of reductions that might have been observed for a pipe carrying water from that plant with the specified treatment.

Lead Risk Reduction Strategy Simulations

Approach

1. Create virtual customers/connections
   1.1. 74,138 lead service lines, distributed following source of supply ratios throughout the service area. (Marston only, Moffat only and Blend).
2. Lead concentration for a given service connection is sampled randomly from the appropriate distribution every year.
   2.1. For lead service line connections, lead concentration is sampled from pipe rack data.
      2.1.1. For connections served exclusively by the Marston or Foothills plant, lead service line lead concentration is sampled from the Marston plant pipe rack data. The following data are sampled:
         2.1.1.1. All post-stabilization control pipe data (both the pre-treatment and post-treatment period)
         2.1.1.2. All post-stabilization, pre-treatment data (all pipes)
      2.1.2. For connections served exclusively by the Moffat plant, lead service line lead concentration is sampled from the Moffat pipe rack data. The following data are sampled.
         2.1.2.1. All post-stabilization control pipe data (both the pre-treatment and post-treatment period)
         2.1.2.2. All post-stabilization, pre-treatment data (all pipes)
      2.1.3. For connections in blended areas, the connection is randomly assigned a “dominant” plant based on the proportion of connections serving each service area in the compliance and customer requested sample data. Lead concentration is drawn from pipe rack data for the assigned plant as described above.
   2.2. For CuLS and other connections, lead concentration is drawn from a random distribution corresponding to the distribution that fit the compliance data for the corresponding service area (Marston, Moffat or Blend) and material. Best fit distributions were developed separately from the Monte Carlo simulation and via maximum likelihood estimation (mle). The median lead concentration was used for addresses with more than one lead concentration in the compliance and customer requested data set.
3. In each simulation year, lead service lines can be removed, lead filters can be adopted, and treatment can be applied. There are two treatment options: orthophosphate addition and pH adjustment.
   3.1. Orthophosphate treatment is assumed to be fully implemented by March 20, 2020, which is the start of year 1 of the simulation. Under the orthophosphate treatment option, the annual lead service line replacement rate is N=1,200 and no lead filters are provided by Denver Water.
   3.2. pH addition is assumed fully implemented by the start of year 1 of the simulation. Under pH treatment option, the annual lead service line replacement rate is 7% of the total 74,138 lead service lines at the start of the simulation, N=5,190. Lead filters are provided to all addresses

with a lead service line. The lead filter adoption rate is equal to *p*%, which is varied from 50% to 100%.

3.3. Lead service line replacement is assumed to begin in year 1 of the simulation.

4. Lead concentrations are assigned or calculated for each virtual service connection for each simulation year.
    4.1. Before initiation of treatment, there is no reduction in lead concentration (i.e., the lead concentration is the same as the concentration assigned in step 2) for any connection.
    4.2. After treatment:
        4.2.1. Lead concentrations for lead service lines are sampled from the post-treatment, post-stabilization pipe rack data for the chosen treatment strategy and for the plant serving the address.
        4.2.2. Lead concentrations for non- lead service line connections are estimated as the pre-treatment lead concentration (from 2.2) minus a percent reduction drawn from the distribution of reductions from immersion study data for the plant serving the address and treatment type (i.e., from the results of the bootstrap analysis described above).
5. Lead service lines are removed at a specified rate at the beginning of each simulation year. In the simulation, lead service line addresses are reassigned as CuLS addresses.
    5.1. Addresses are converted from lead service lines to CuLS at random. At the beginning of each simulation year, a random value from a uniform distribution between 0 and 1 is assigned to each lead service line, and the N addresses with the highest random values are converted from a lead service line to a CuLS, where N is the annual replacement rate.
    5.2. Pre-treatment lead concentration for lead service line addresses converted to CuLS are drawn from the appropriate distribution (as described in 2.2). Post-treatment lead concentration for lead service line addresses converted to CuLS are assigned in the same way as for other CuLS addresses (as described in 4.2.2).
6. Lead filter adoption is randomly assigned, based on the lead filter adoption rate (*p*%), to addresses with lead service lines. A random value from a uniform distribution between 0 and 1 is assigned to each address with a lead service line and the *p*% of the addresses with the highest random values are assumed to have an adopted lead filter. The lead concentration for these addresses are reassigned as 1 ppb.
7. The simulation continues for 70 years. Statistics are output for each simulation. Those statistics include median, 75th, 90th, 95th and 99th percentile lead concentrations, the number of addresses with lead concentration exceeding some threshold (typically 15 ppb) and the proportion of addresses exceeding the threshold.

Choices and Assumptions

1. Assume that lead concentrations observed in pipe racks are indicative of worst-case concentrations that could be observed (and ingested) for connections with lead service lines.
2. Assume that distributions fit to first-draw compliance sample data adequately characterize the distribution of lead concentrations for CuLS and other connections and provide a realistic indication of lead concentrations in water that could be ingested (brass fittings and lead solder are closer to taps and lead releases from them are more likely to be caught in a first-draw sample).
    2.1. For addresses with multiple observations, assume that median lead concentration for that address is representative.
3. Assume that reductions in lead observed in immersion studies for CuLS also apply to other materials and real service connections and plumbing.
4. Lead filters are provided to all Denver Water customers with lead service lines and if adopted, the lead filter removes the customers' lead exposure (i.e. lead concentration = 1 ppb at addresses with

lead service lines and adopted lead filters). Lead filters distributed to non- lead service line customers will occur but are not considered in the analysis.

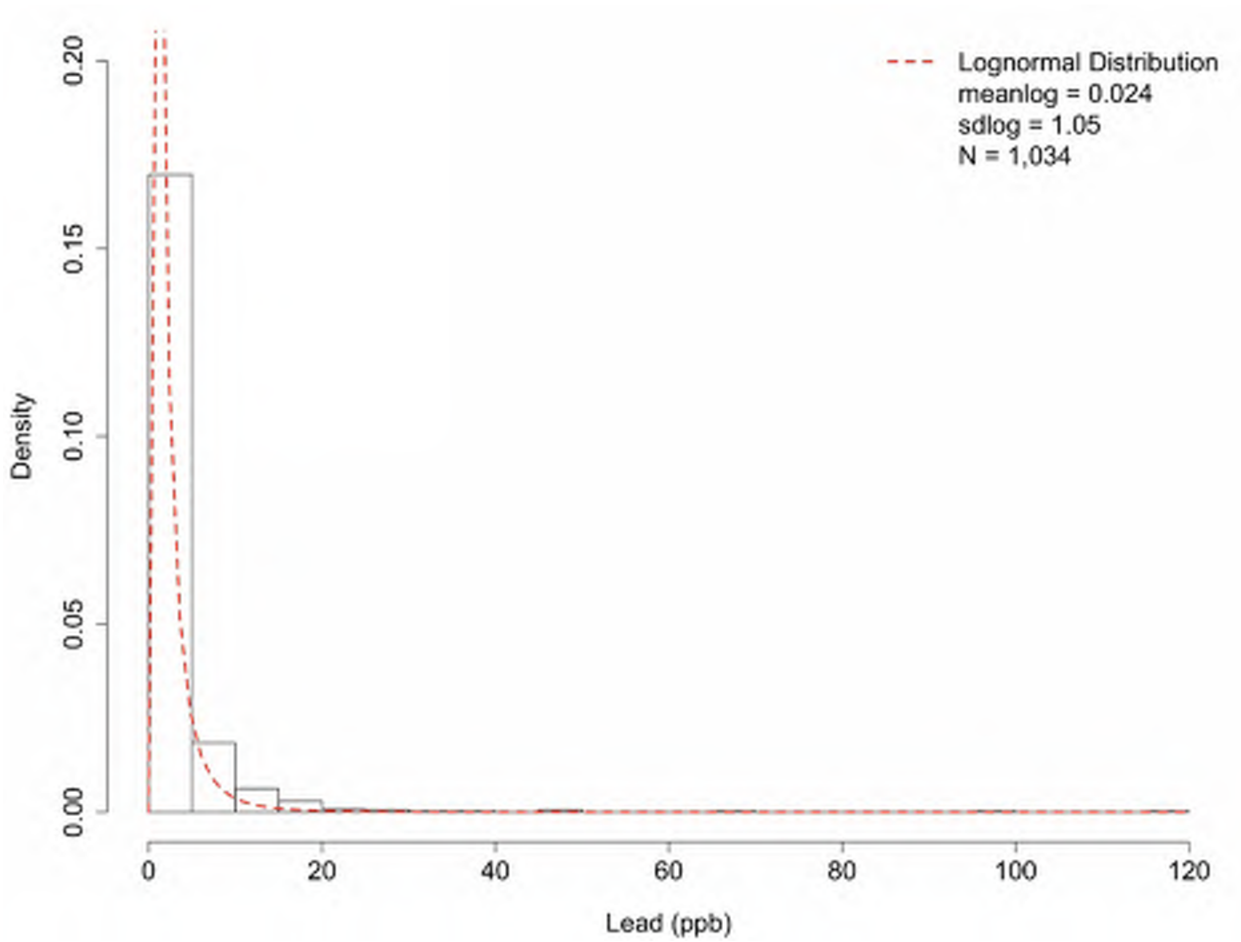
5. Choices:
    5.1. Treatment strategy (none, OP addition, pH adjustment)
    5.2. Lead service line replacement rate (# pipe/year)
    5.3. Lead filter adoption rate (% of addresses where customers adopt lead filter)

Appendix C: Model Input Data Distributions

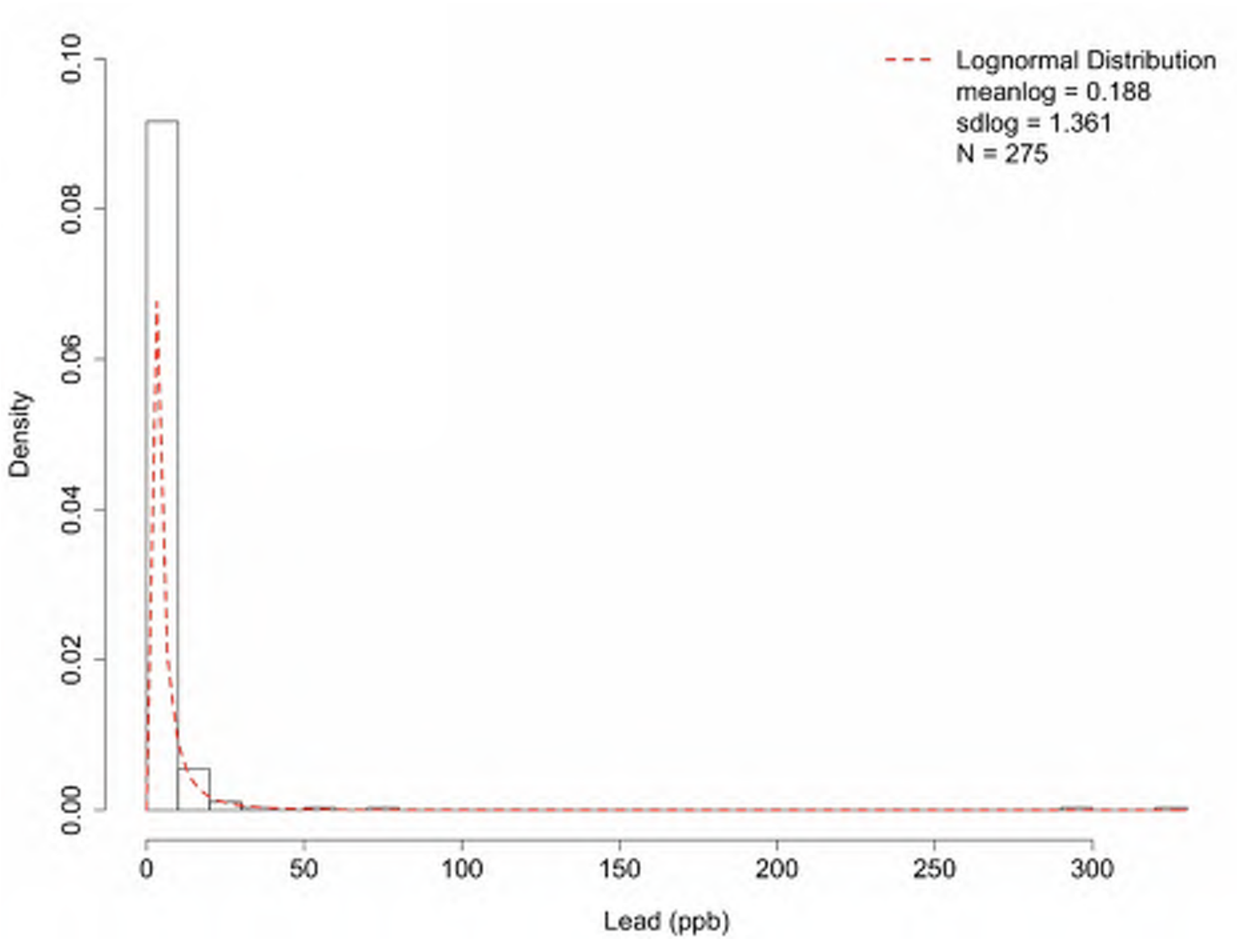
Input Data for CuLS

For CuLS, the model uses lead concentrations drawn from a distribution fitted to the lead concentrations sampled in the distribution system from CuLS. In the LCR data set, there are a total of 2,403 lead concentrations data records for 1,243 addresses over a period from June 2000 through July 2019. A subset of these data was created by taking the median lead concentration for each address. Distributions were fit to the subset of median lead concentrations for each service area (Marston, Moffat or Blend). The following figures show histograms of the median lead concentration data for each address with the best-fit distribution.

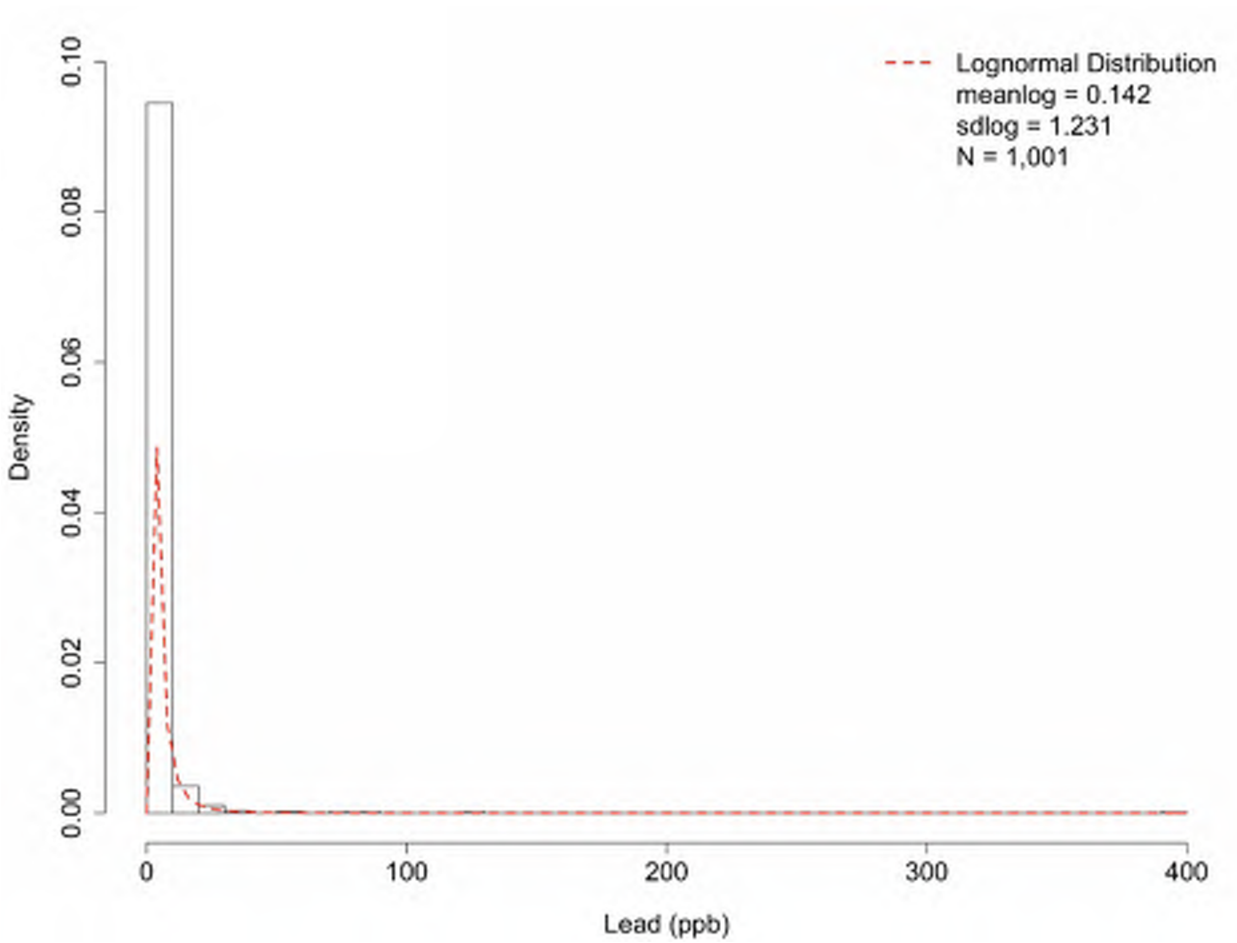
Marston Service Area



Moffat Service Area



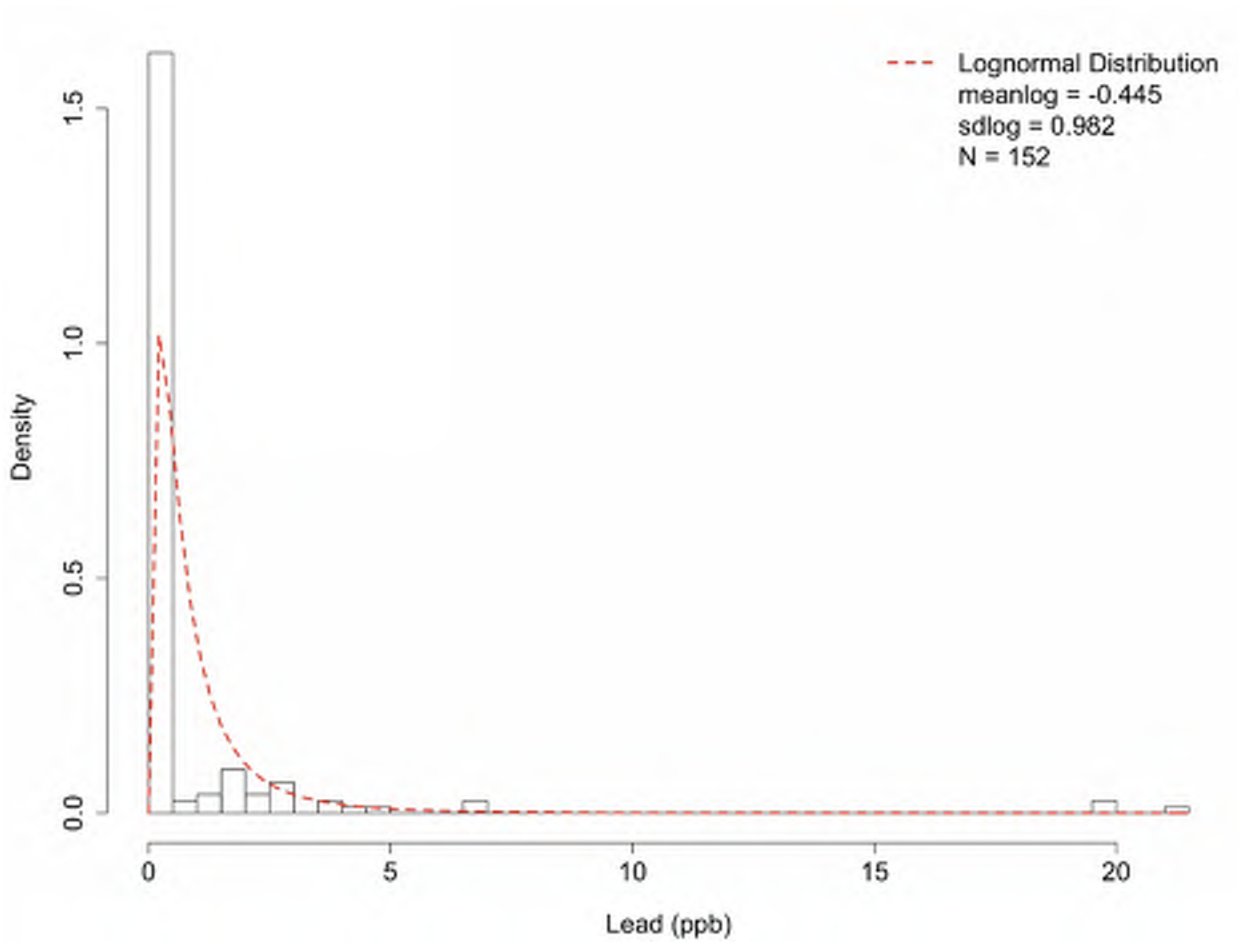
Blend Service Area



Input Data for Other Service Lines

For other service lines, the model uses lead concentrations drawn from a distribution fitted to the lead concentrations sampled in the distribution system from other service lines. In the LCR data set, there are a total of 152 lead concentrations data records for 133 addresses over a period from August 2010 through July 2019. A subset of these data was created by taking the median lead concentration for each address. Distributions were fit to the median lead concentrations for the entire distribution system. Distributions were not fit separately for different service zones (Marston, Moffat, Blend) due to limited data availability. The following figure shows a histogram of the median lead concentration data for each address with the best-fit distribution.

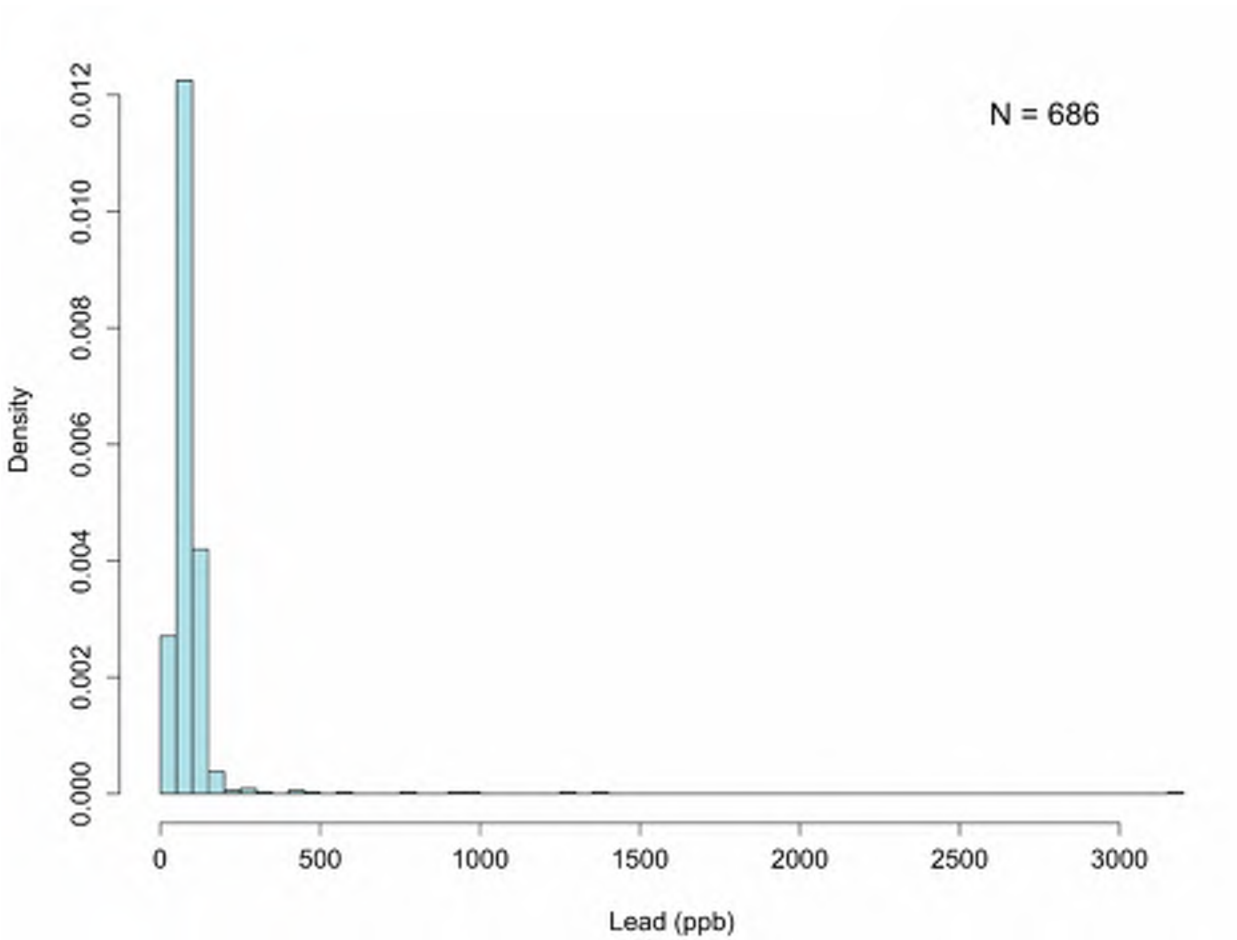
Entire Distribution System



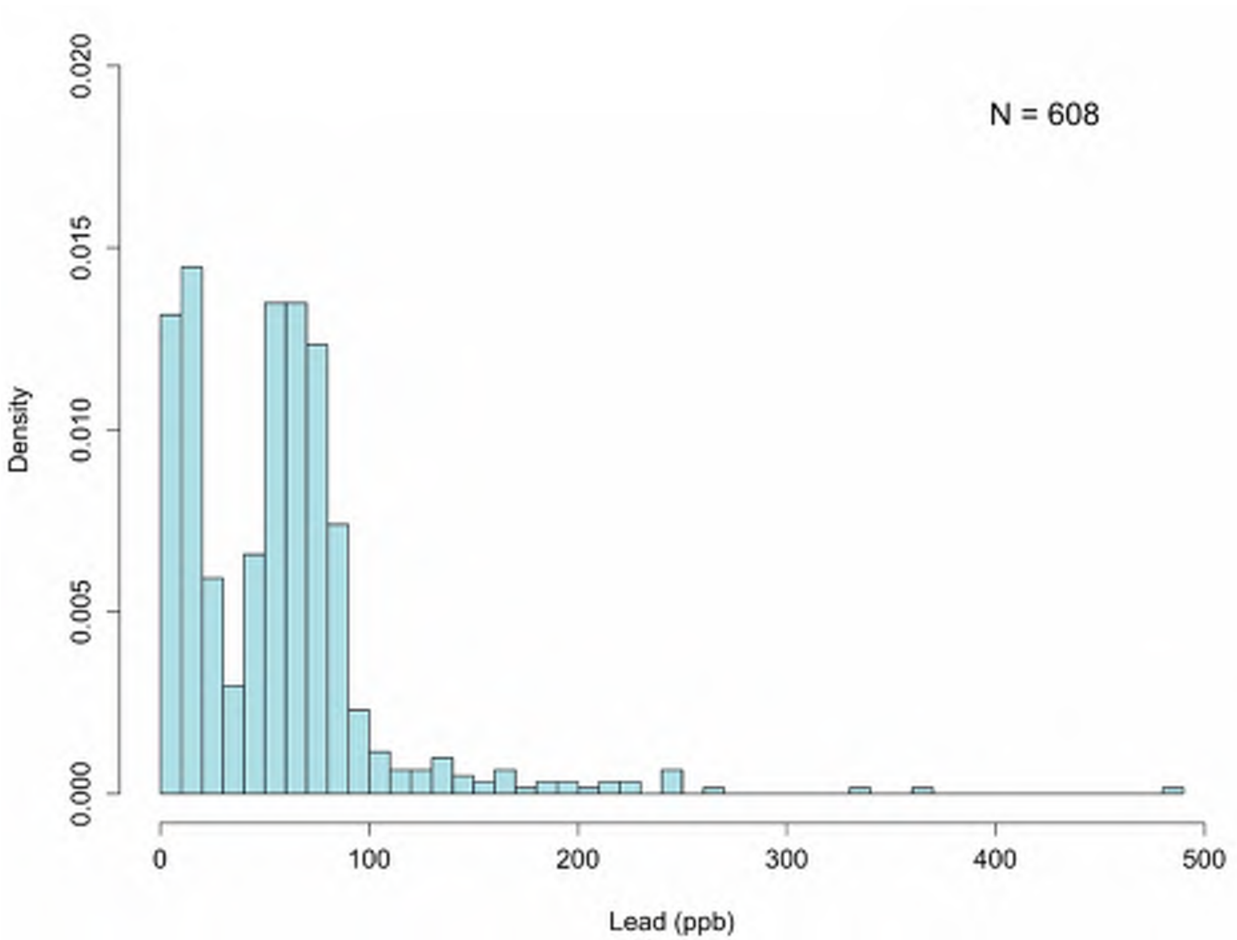
Input Data for Lead Service Lines

For lead service lines, the model uses lead concentration data from the pipe racks. For the first year, prior to the start of treatment, the model uses pipe racks lead concentration data from the Pre-Treatment period for the Control, Orthophosphate, and pH racks. To model lead concentrations after orthophosphate or pH treatment are implemented, the model uses input data from the pipe racks during the Post-Treatment period from the Orthophosphate racks and the pH racks, respectively.

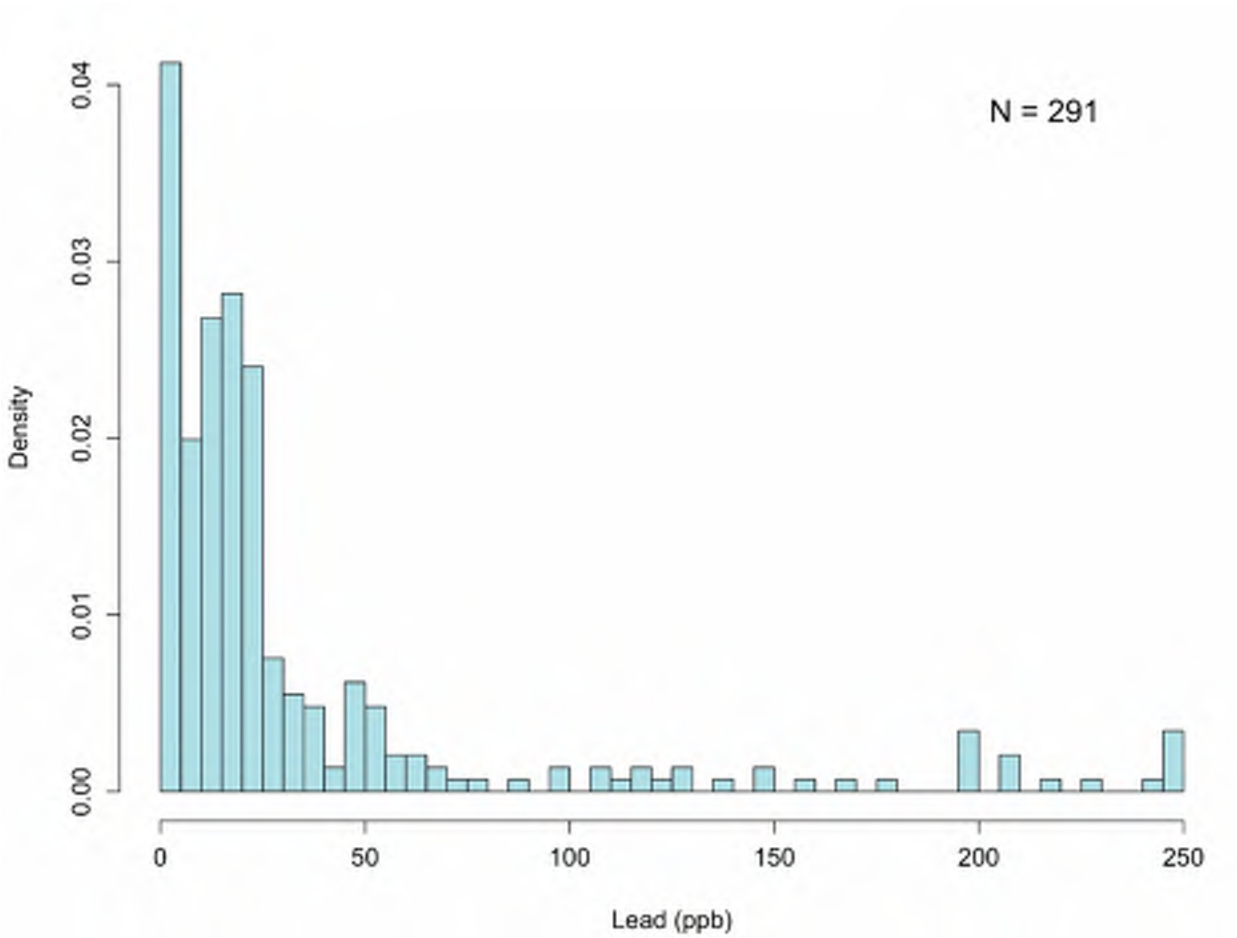
Marston No Treatment (Pre-Treatment):



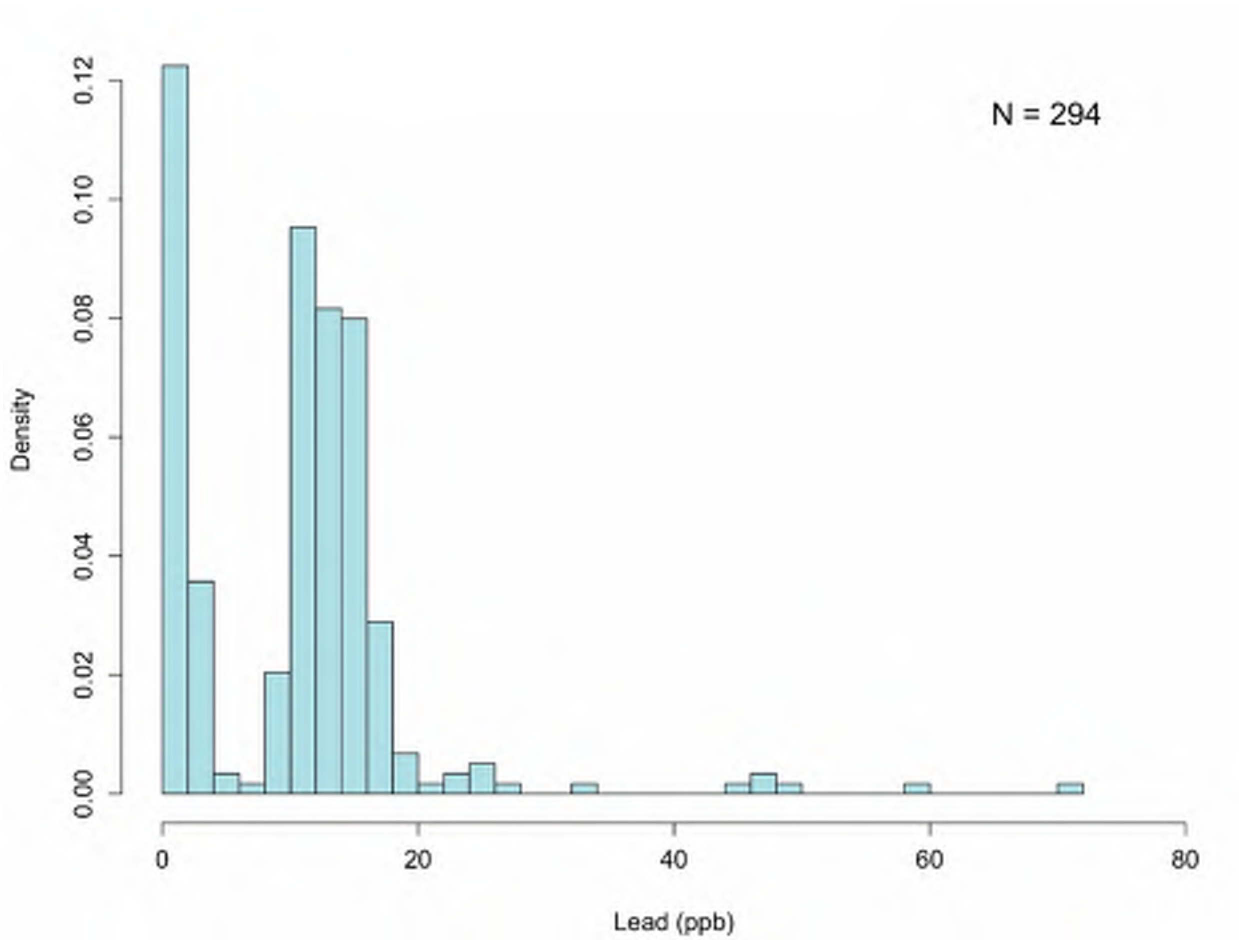
Moffat No Treatment (Pre-Treatment):



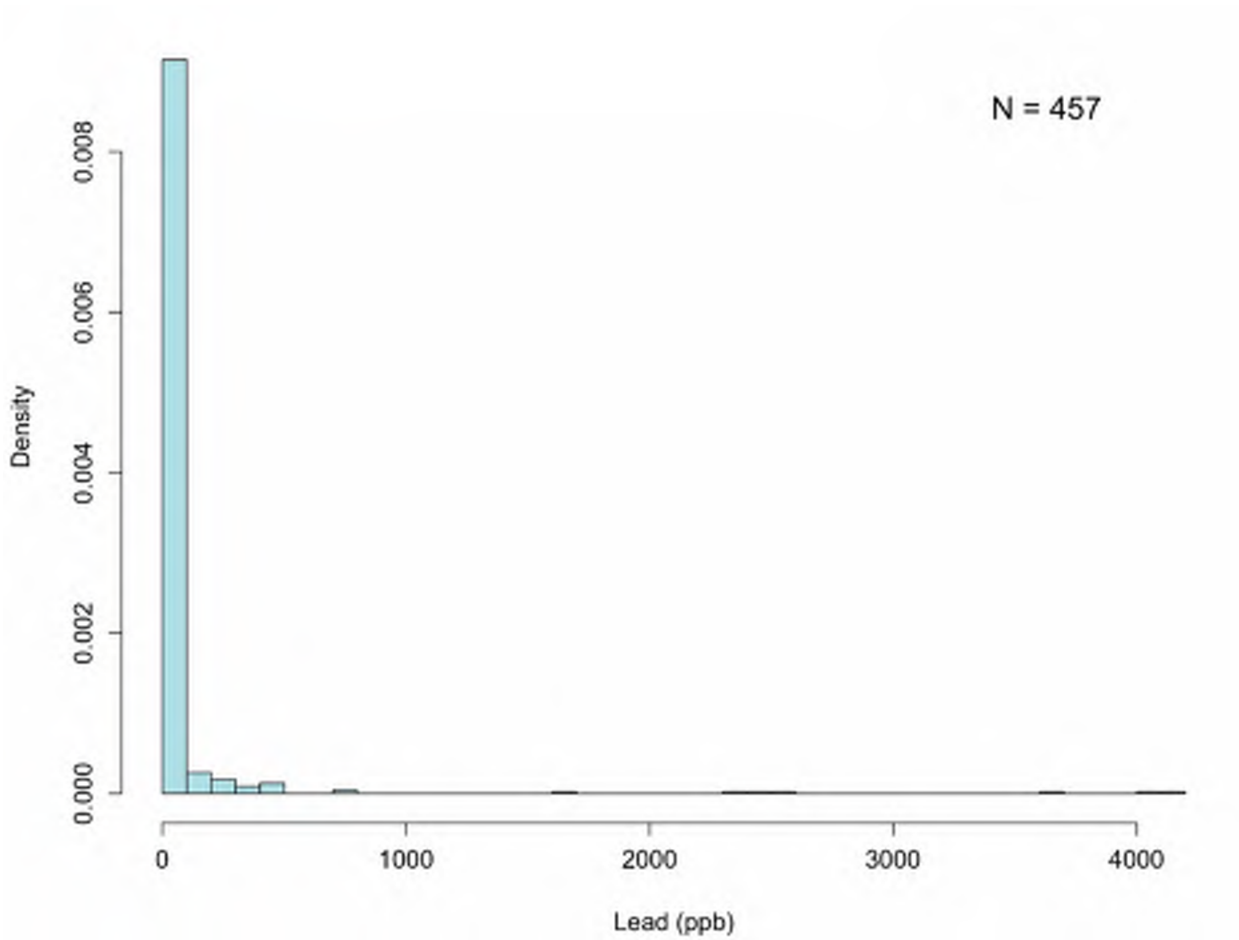
Marston Orthophosphate Treatment:



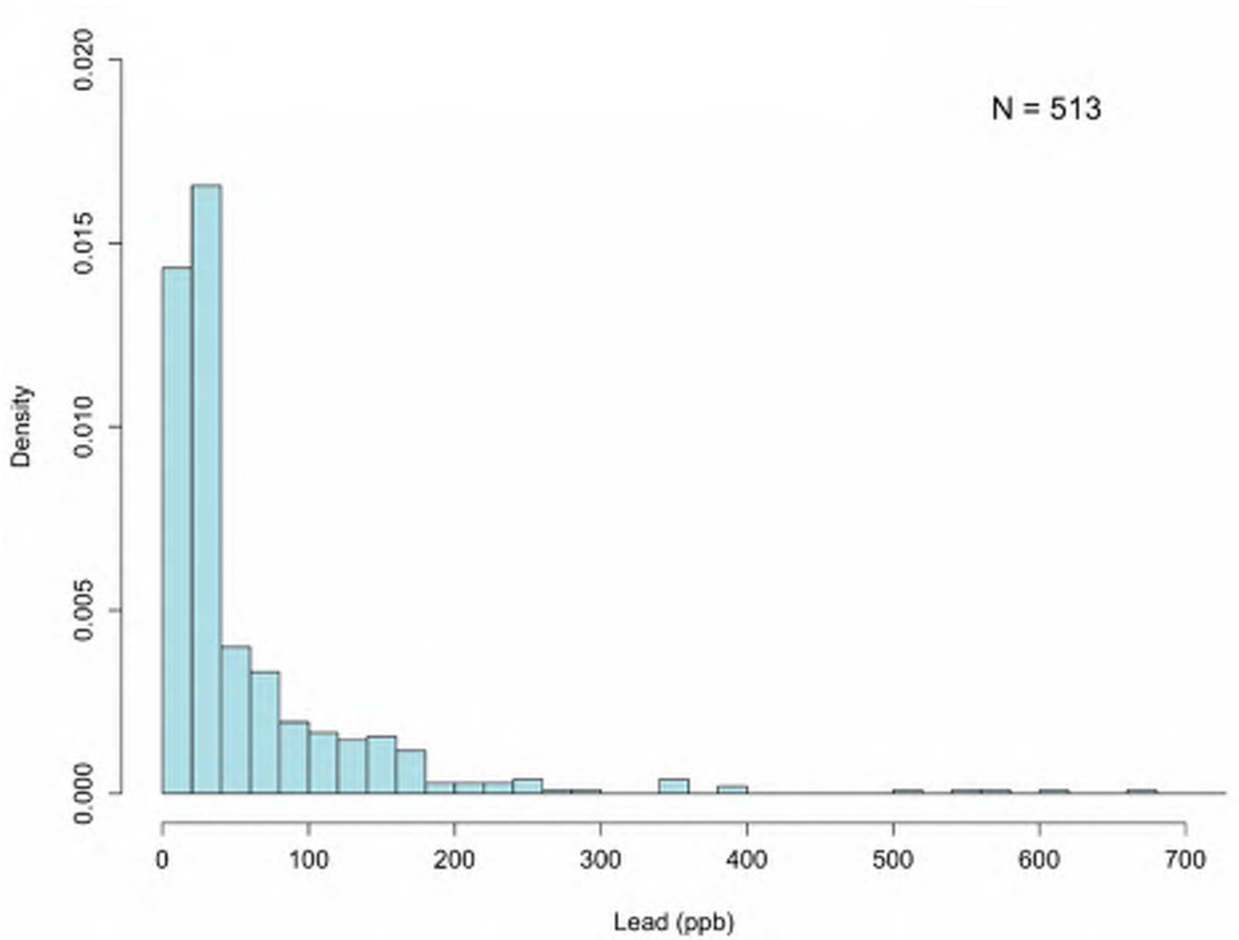
Moffat Orthophosphate Treatment:



Marston pH Treatment:



Moffat pH Treatment:



APPENDIX II.B - LEAD PILOT RESULTS

September 2019

DENVER WATER

Appendix II.B:

Lead Pilot Results

Date: Revised August 16, 2019
May 15, 2019

To: Denver Water

From: Corona Environmental Consulting, LLC

This appendix reports data from the two lead service line pilots located at Marston and Moffat treatment plants. These two sites were chosen to represent the South Platte River and the Fraser River which are the two major water supplies to the Denver Water system. Although the Foothills plant produces the most water, it is also located on the South Platte Supply with very similar water quality to Marston. Detailed information on the design and initial operation of the pilots can be found in Denver Water's "Optimal Corrosion Control Treatment Report," dated September 20, 2017.

The Marston pilot started operation in October of 2015, Moffat in May of 2016 with both plants continuing in operation at the time of this report. Average and ranges of influent water quality parameters over the period of operation are presented in Table 1.

Table 1. Summary of Influent Water Quality.

Parameter	**Marston Influent** Avg. (range)	**Moffat Influent** Avg. (range)
Temperature (°C)	13 (4-25)	12 (5-21)
pH	7.8 (7.4-9.1)	7.8 (7.2-8.3)
Alkalinity (mg/L as $CaCO_3$)	64 (36-83)	39 (14-70)
Calcium (mg/L)	30 (7-41)	16 (1-36)
Magnesium (mg/L)	8.0 (1.7-10.8)	2.9 (0.3-9.2)
Conductivity (µS/cm)	325 (35-450)	152 (92-330)
Total Chlorine (mg/L)	1.34 (0.03-8.00)	1.40 (0.12-1.78)

Each pilot consists of four racks of three whole lead service lines (and one segmented service line not included in sampling). Each pipe is run for three flow and stagnation cycles each day. The flow period is two hours, followed by a 5-hour stagnation period, then a 1-hour sampling period. Feedwater is supplied from the distribution system and piped back to the pilot rigs.

The Rack 1 is the control rack, which has no adjustment to water quality. The Rack 2 tests corrosion control using orthophosphate addition which was started at 3 mg/L as PO_4 and reduced over time. Orthophosphate was dosed as phosphoric acid and the pH was returned to match the existing distribution system of 7.8 with caustic soda. Rack 3 originally tested silicate addition but was later transitioned to an additional orthophosphate test where the test began at 1 mg/L as PO_4. Only the orthophosphate data are included in this report for Rack 3. Rack 4 uses pH modification for corrosion control. Target pH of 8.8 and 9.2 were tested using caustic soda as the base.

Rack 3 data through April 25, 2019 and Rack 4 data through May 2, 2019 are included. After this date, pilot operation was modified to begin testing other conditions. These tests are currently underway testing low dose orthophosphate at high pH and transitioning from high pH to orthophosphate should it be necessary in the future. Rack 1 and 2 data through July 18, 2019 are included.

Summaries of the lead release for each pilot are shown in Figure 1 and Figure 2. Lead was analyzed by the ICP/MS direct method EPA 200.8 with a minimum reporting level of 1 ppb (µg/L). Each pipe was run for a conditioning period to stabilize operation after the disturbance of harvesting the lead service lines. These are indicated by the "pre-treatment" gray box. Lead removal is calculated by dividing the median lead during treatment by the median lead during the pretreatment period for each pipe. The three pipes on each rack were averaged to get the values used in the summary figures. The only data excluded from the analysis were periods where the operational targets could not be maintained (i.e. the orthophosphate dose or pH were out of range). These are noted as upset periods indicated with gray rectangles and are discussed in further detail later.

Both plots show that orthophosphate and high pH reduce lead release, with orthophosphate performing better for lead control. An orthophosphate dose of 2 mg/L appears to be equal in performance to 3 mg/L, assuming dosing starts at 3 mg/L. See Corona Technical Memorandum "Reducing Orthophosphate Dose from 3 mg/L to 2 mg/L does not Result in Increased Lead Release in Denver Water Pilot Study" dated 5/24/2019 for additional information. While testing continues, an orthophosphate dose of 1 mg/L does not appear to result in equivalent reduction.

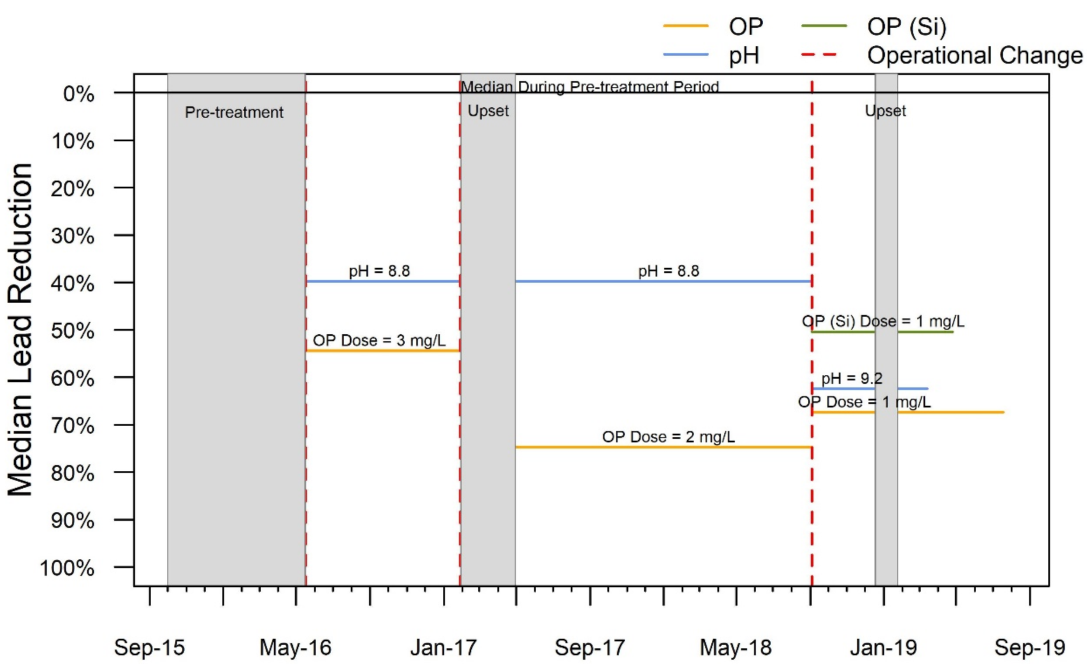


Figure 1: Marston Pilot Summary of Lead Reduction (orthophosphate doses shown measured as PO_4)

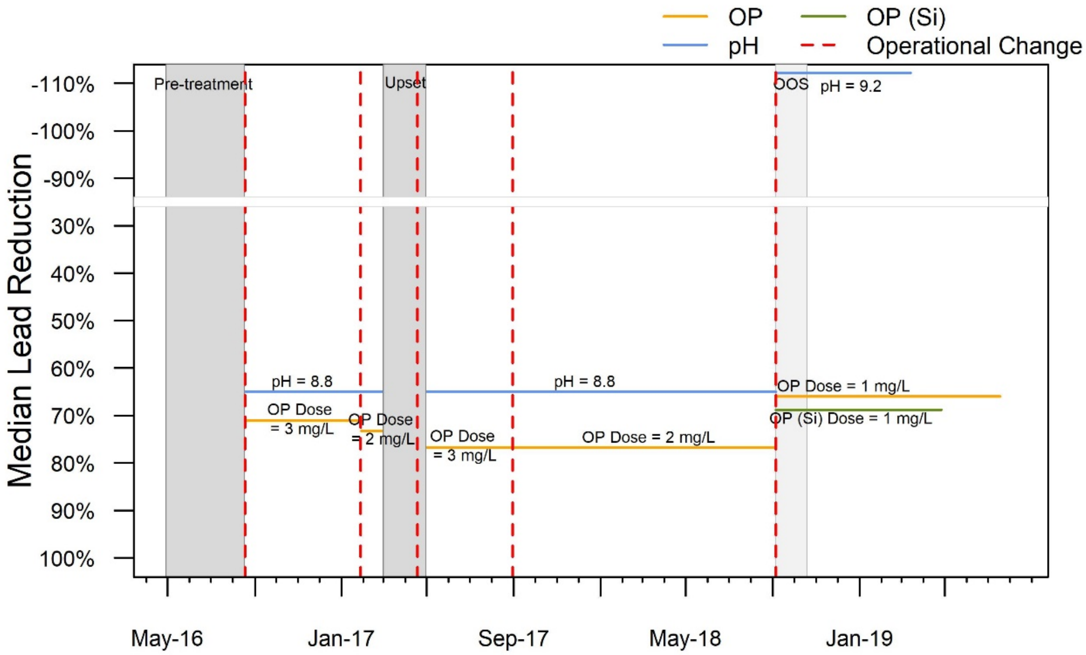


Figure 2: Moffat Pilot Summary of Lead Reduction (orthophosphate doses shown measured as PO_4)

Time series plots of lead release for all treatment conditions for both pilots are shown in Figure 3 through Figure 12. These plots include all data as distinct points with the y-axis in a log scale for lead concentrations to display all the data and demonstrate the pipe-to-pipe variability. Where appropriate, target orthophosphate dose and target pH are shown with a dashed red line.

The Marston pre-treatment period is shown with a gray rectangle in Figure 3 through Figure 7; during this time no chemical was being added. For the orthophosphate racks, shown in Figure 4 and Figure 5, the orthophosphate dose was started at 3 mg/L and stepped down to 2 mg/L then 1 mg/L. The dose was stepped down to determine whether a lower dose provided equivalent corrosion control to the 3 mg/L dose. The former silica orthophosphate racks stepped directly from no orthophosphate to a dose of 1 mg/L. This condition was selected to determine whether starting with a high dose and lowering the dose was equivalent to starting with a lower dose. The pH racks, shown in Figure 6 and Figure 7, ran with a pH setpoint of 8.8 and increased the setpoint to 9.2. The pH was increased to see whether a higher setpoint would provide further corrosion control.

Marston experienced two upset periods, shown with gray rectangles. Both upsets caused increased lead release. Both upsets were due to several minor electrical faults that prevented the pilot from running correctly as scheduled. As shown in the plots, many of the pipes have not returned to pre-upset conditions. This is especially true for pH pipe 4.

Figure 5 shows the orthophosphate measured in the sample after stagnation. This may not be representative of the applied dose early in the test where pipe scales are forming and consuming some phosphate. Overall, the orthophosphate results indicate it was fed consistently and accurately after the initial range finding. Figure 7 shows the measured pH in the sample after stagnation. Results indicate a drop in pH of about 0.3 units over the stagnation period.

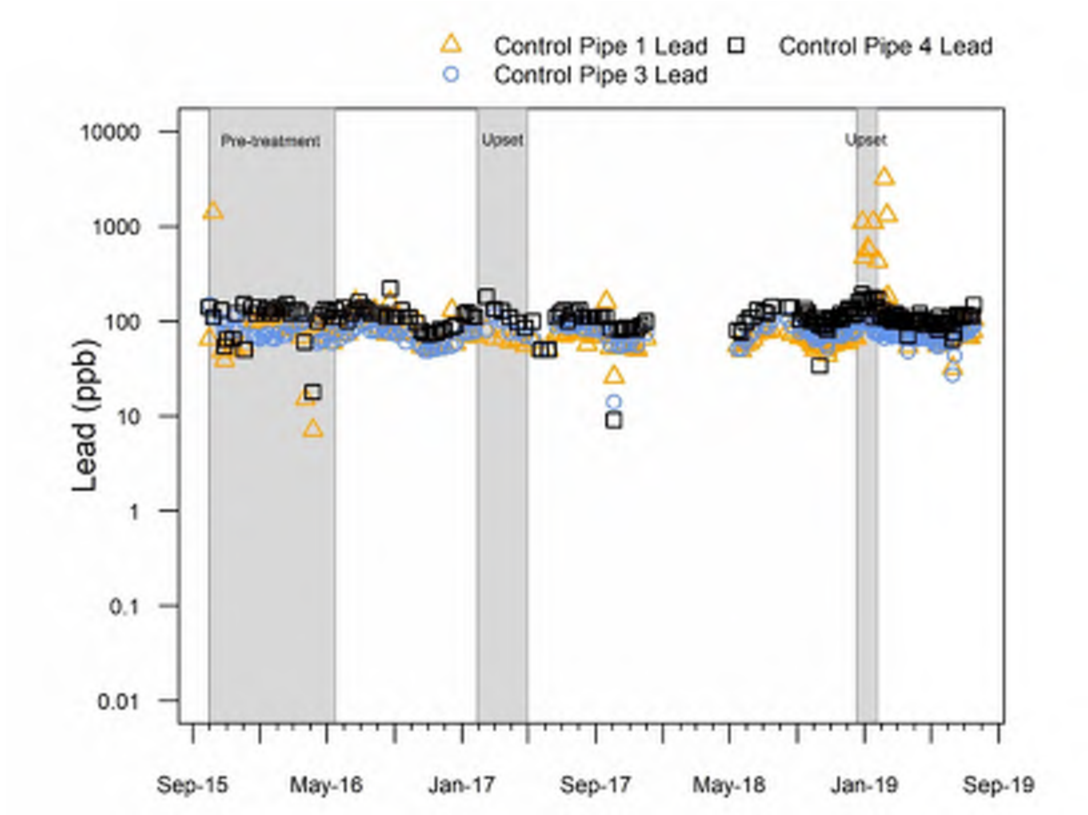


Figure 3: Marston Control Rack - Lead

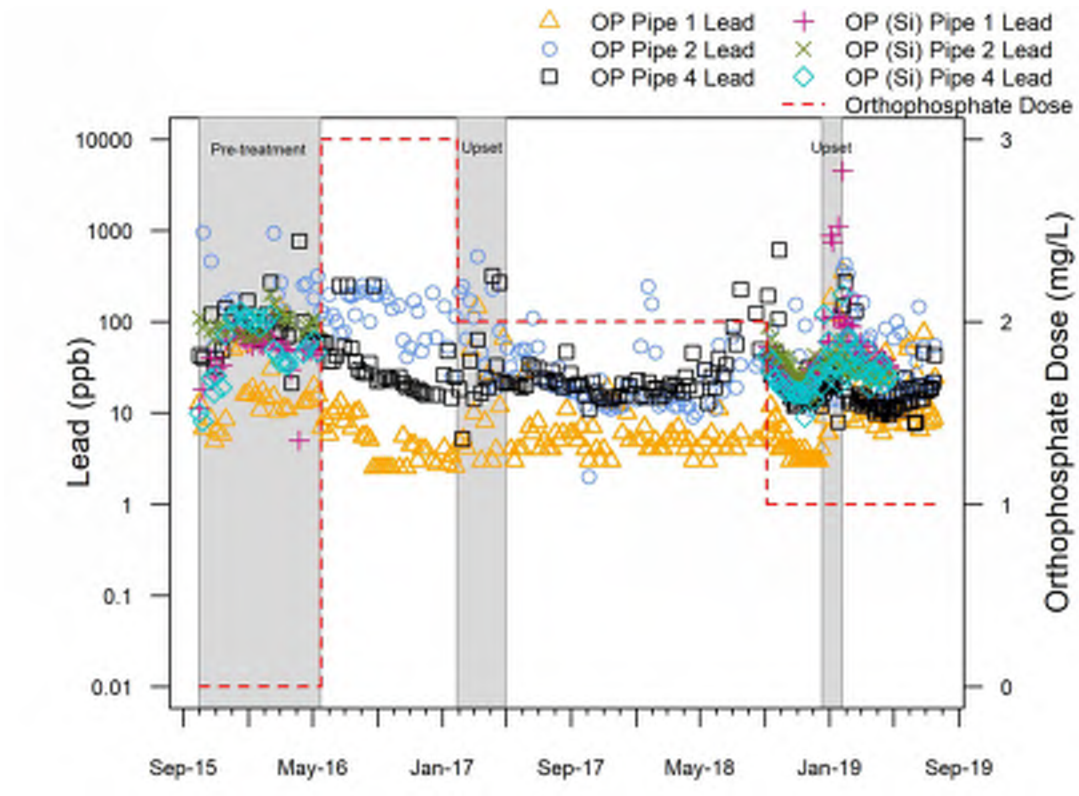


Figure 4: Marston Orthophosphate Racks - Lead

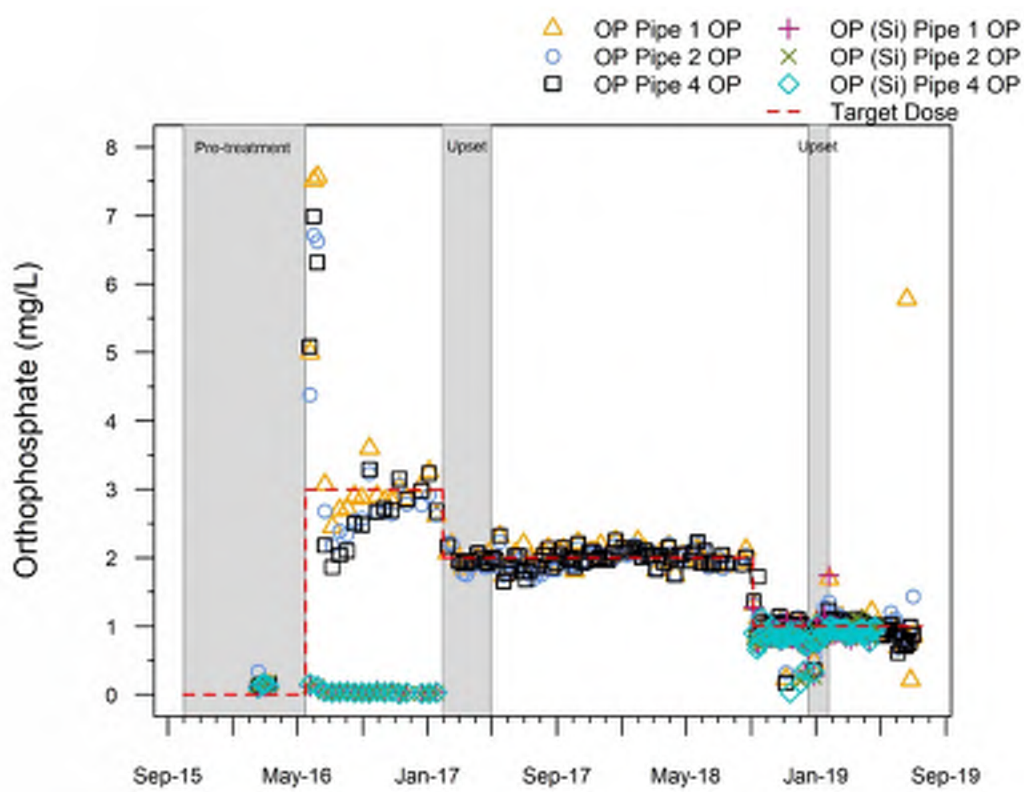


Figure 5: Marston Orthophosphate Racks - Orthophosphate Target Dose and Measured Residual

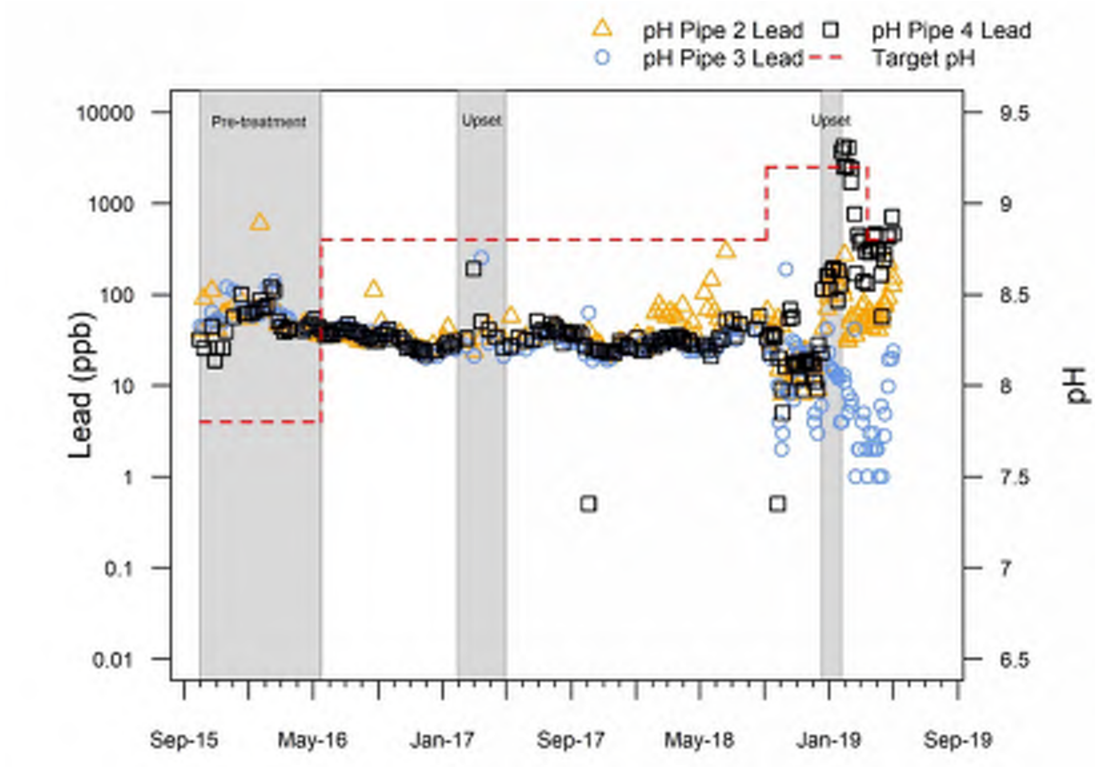


Figure 6: Marston pH Rack - Lead

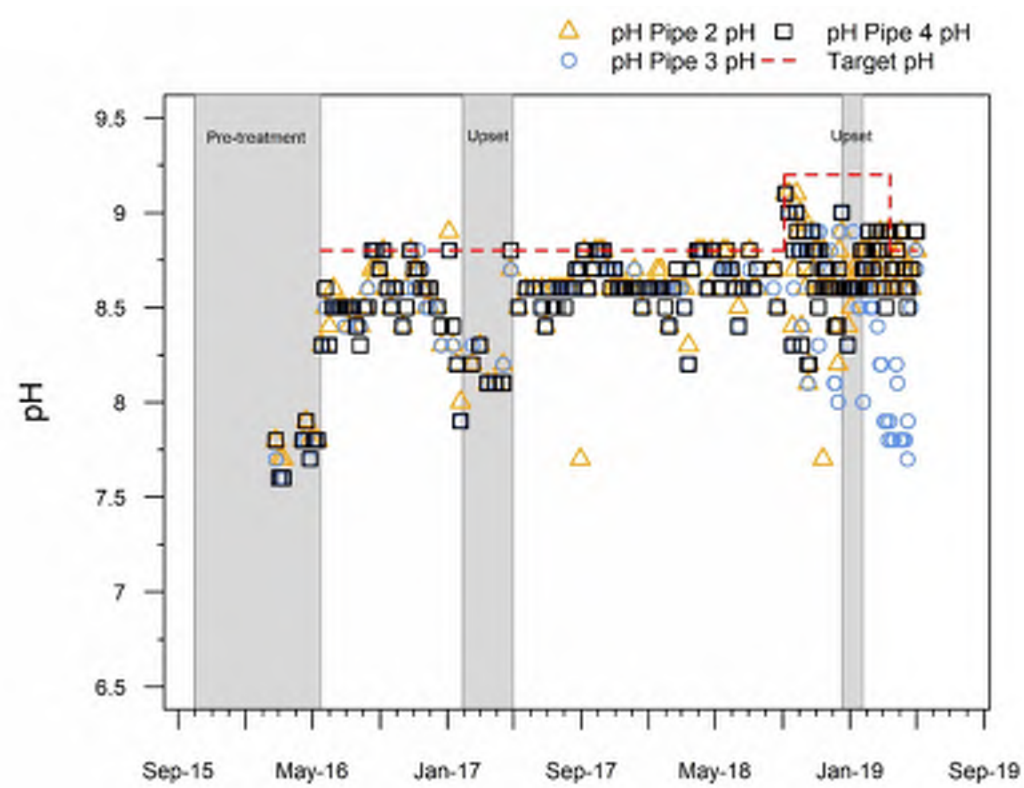


Figure 7: Marston pH Rack – pH Measured Post-stagnation

The Moffat pretreatment period is shown with a gray rectangle in Figure 8 through Figure 12. For the orthophosphate rack, dose was stepped down in a similar manner to Marston. The former silica rack and the pH rack were both controlled the same as Marston. Moffat experienced one upset due to a series of pump failures that resulted in the target conditions not being met. The orthophosphate dose was increased back to 3 mg/L to help stabilize lead release. A second area is highlighted in a light gray box when the Moffat plant was out of service. During this time, the pilot was being fed a water from the distribution fed by the Marston plant. The change in water quality caused a large response in lead release. All pipes (including the controls) saw an increase in lead release during the out of service period and some maintained the higher levels when the out of service period ended. Pipe 1 in the pH rack was affected most drastically. Because all operational parameters were maintained during this period and this is a normal occurrence, these data were included in the analysis.

Figure 10 shows the orthophosphate measured in the sample after stagnation. Like the Marston pilot, the orthophosphate results indicate it was fed consistently and accurately after the initial range finding. Figure 12 shows the measured pH in the sample after stagnation. Results also show some drift in pH but pH was more stable than at Marston.

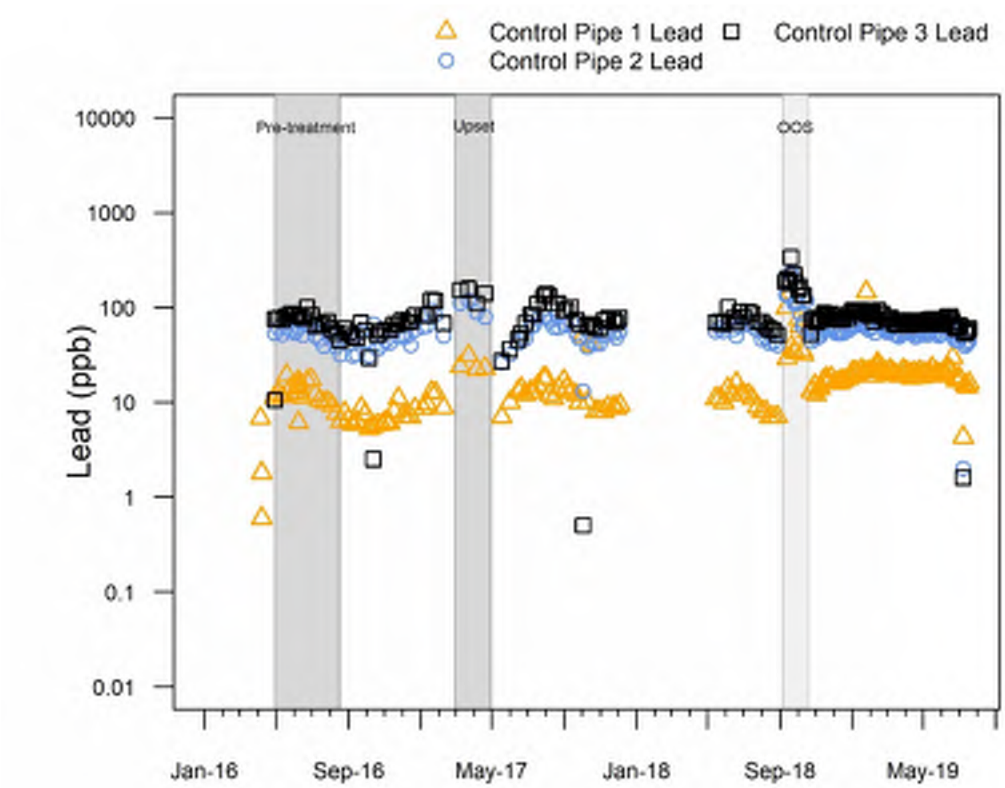


Figure 8: Moffat Control Rack - Lead

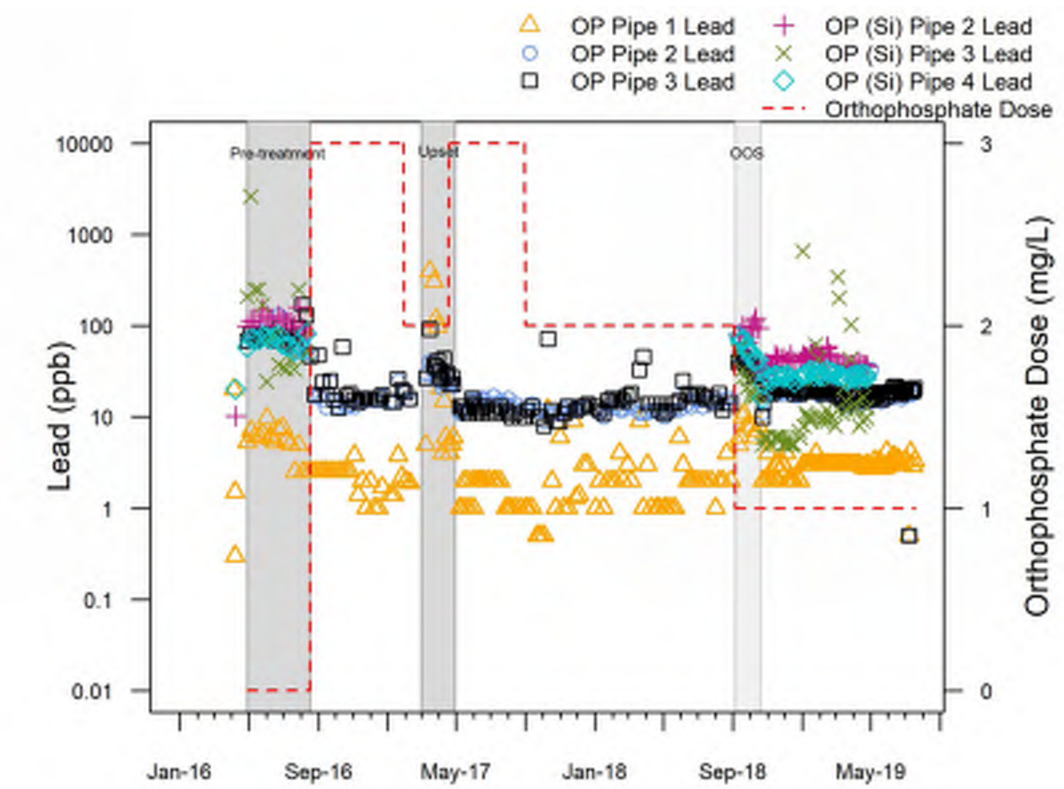


Figure 9: Moffat Orthophosphate Racks - Lead

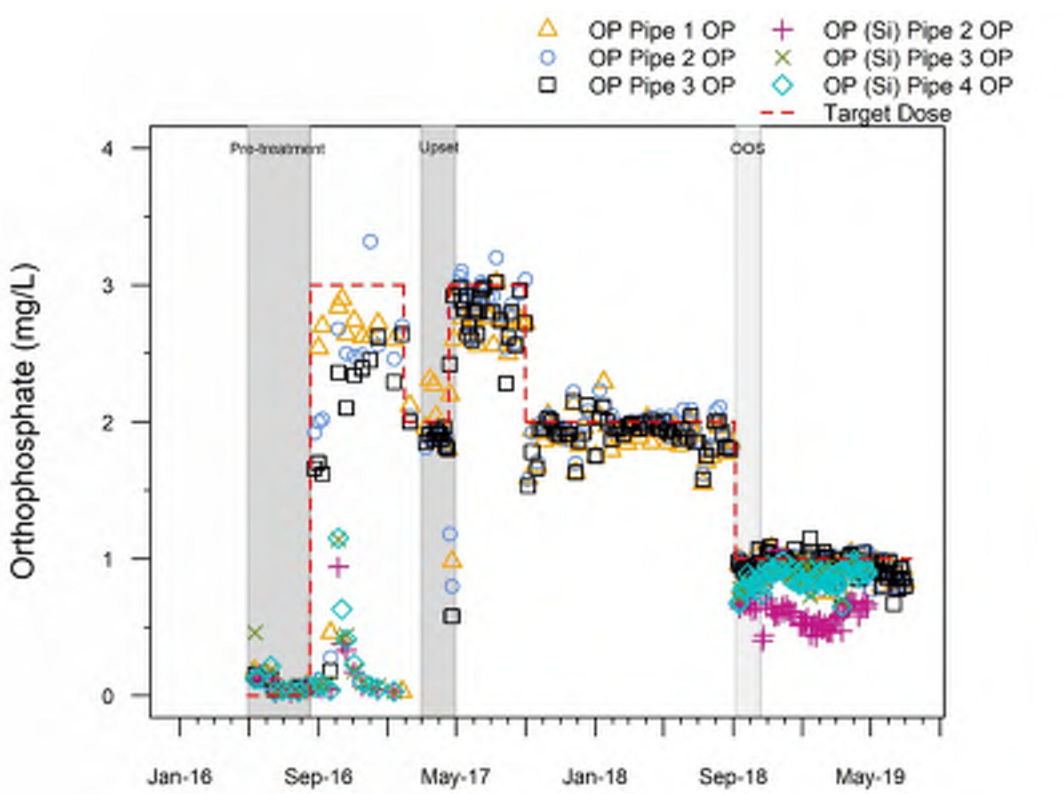


Figure 10: Moffat Orthophosphate Racks - Orthophosphate Target Dose and Measured Residual

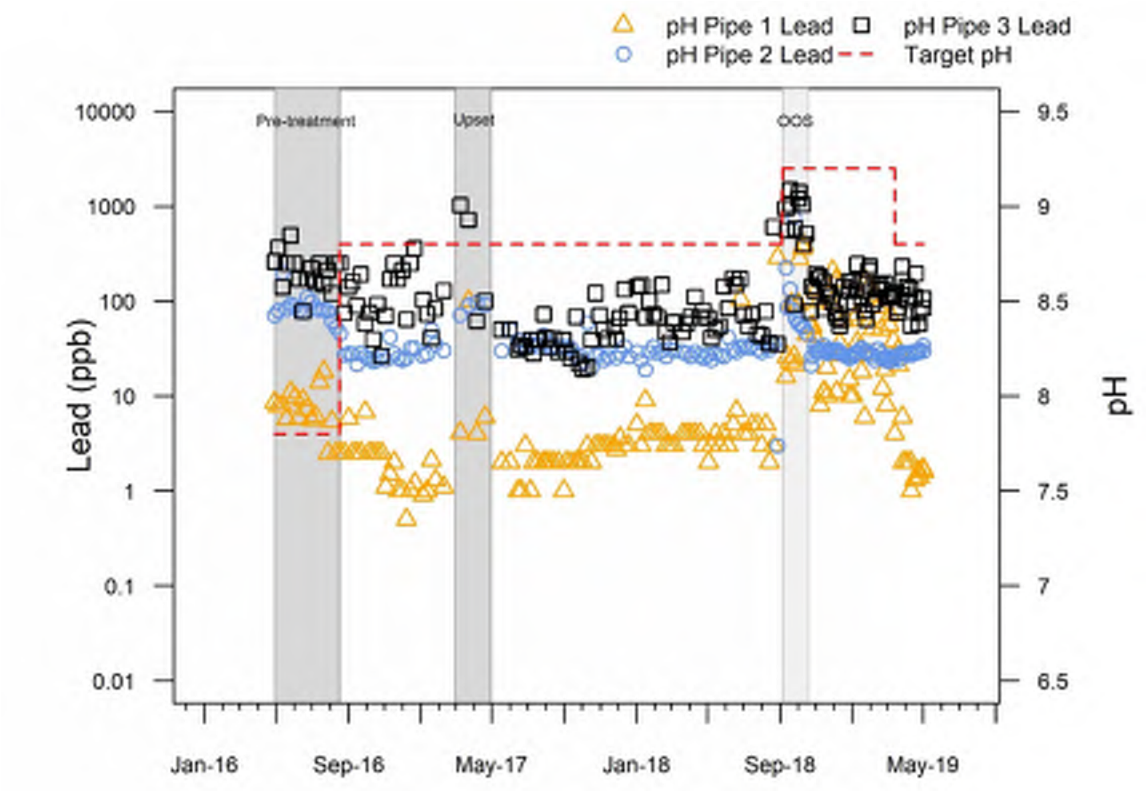


Figure 11: Moffat pH Rack - Lead

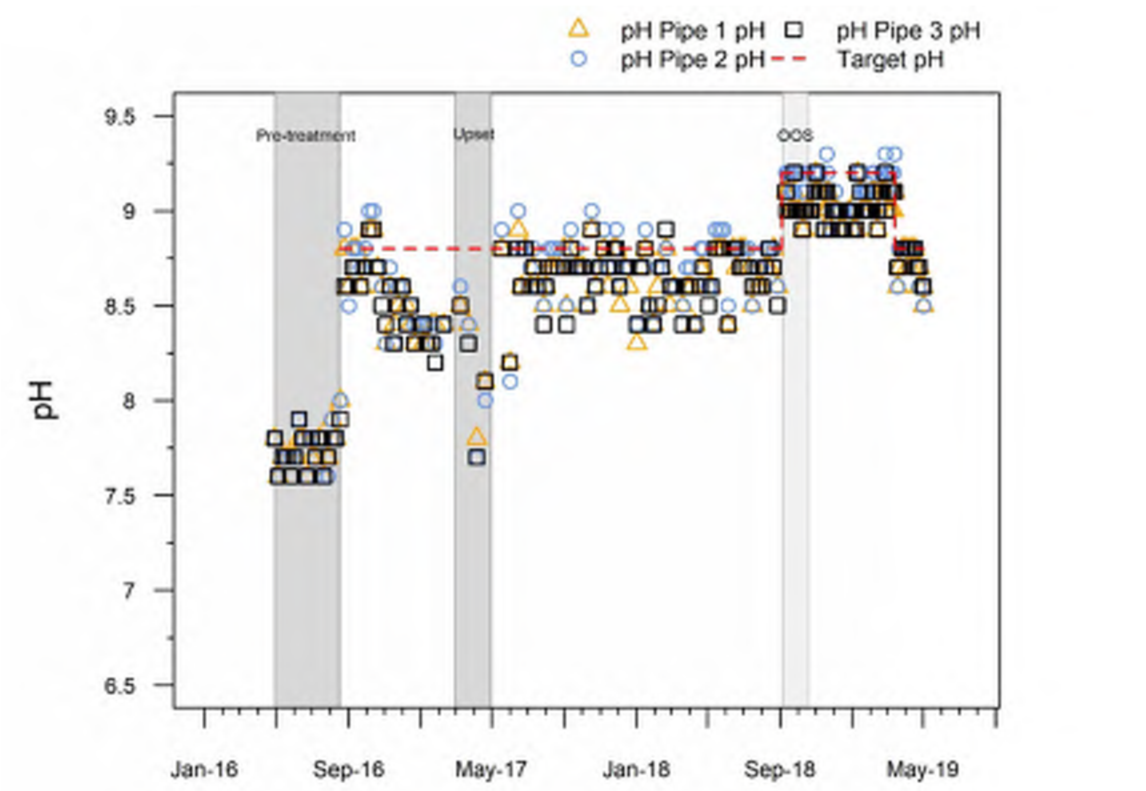


Figure 12: Moffat pH Rack – pH Measured Post-Stagnation

Box plots of lead release under the different treatment conditions are shown in Figure 13 through Figure 24. The quartiles are shown with horizontal lines; the mean is shown with a diamond. The whiskers represent the 5th and 95th percentile. Dots outside the whiskers show individual data points outside this range. The counts for each range of data are shown below the box. All plots use the same y-axis range of 0 to 250 µg/L. Because of high measurements, not all data are shown. Each treatment condition has a matching control box plot. All control box plots use the same data, but the data are split across the different boxes to match the times at which the corresponding treatment conditions were varied. For example, Figure 13 shows the control rack behavior when the OP rack was at 3 mg/L, 2 mg/L, and 1 mg/L.

The box plots are also divided by individual pipe, each shown in a separate pane, which shows the variability in lead release between different pipes under the same conditions. For example, as shown in Figure 14, OP Pipe 1 has always had low lead release in comparison to the other pipes in the pilot, even during pretreatment. Therefore, plotting individual pipes allows comparison of treatment conditions to pretreatment lead release, with each treatment condition shown as a separate box plot. The matching control plots are shown to account for the variability in pilot feed water affecting lead release.

The upset periods were removed from the calculations for all box plots because target operational conditions were not maintained.

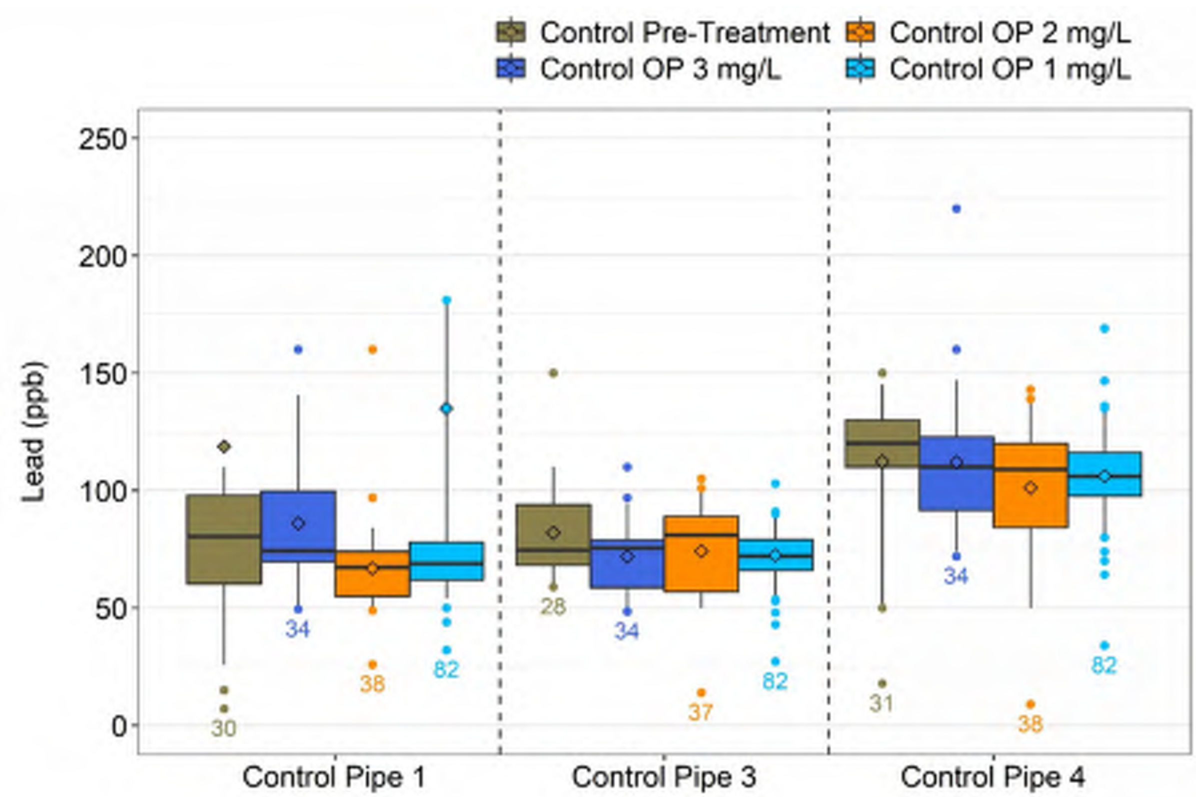


Figure 13: Marston Control Rack - Matching Orthophosphate Operation

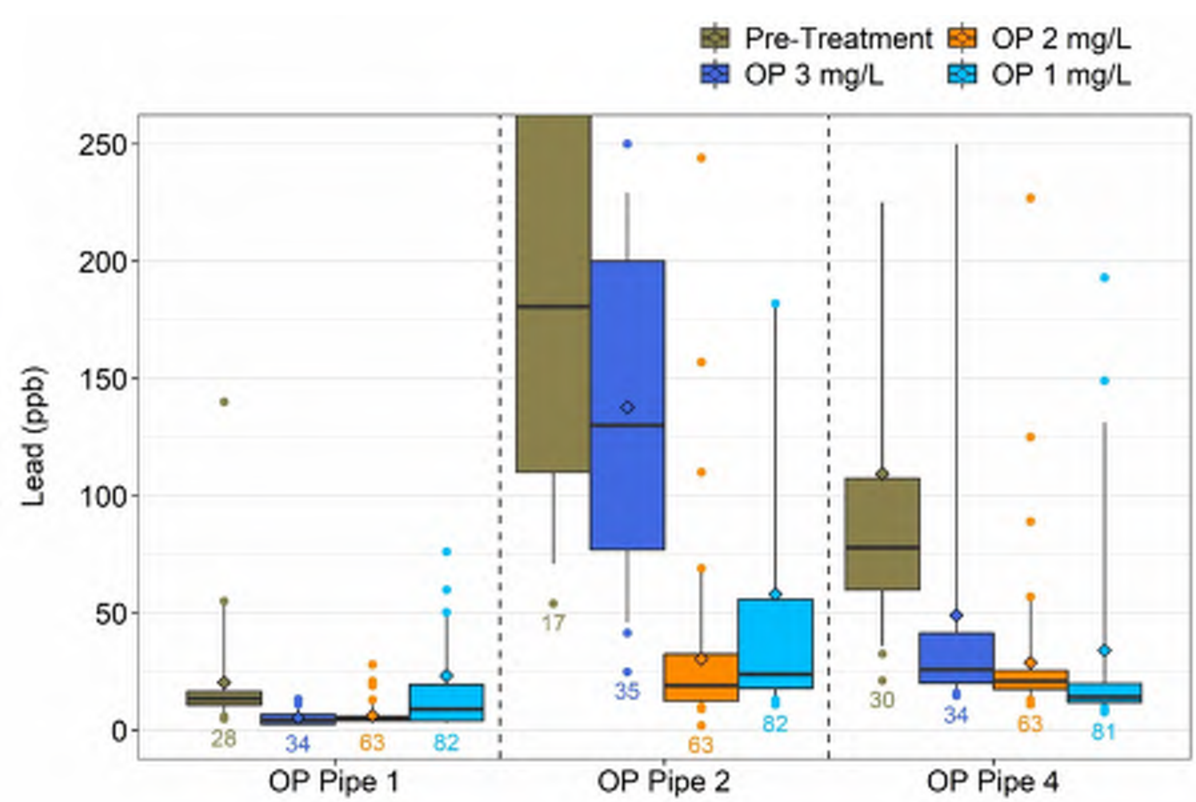


Figure 14: Marston Orthophosphate Doses Tested

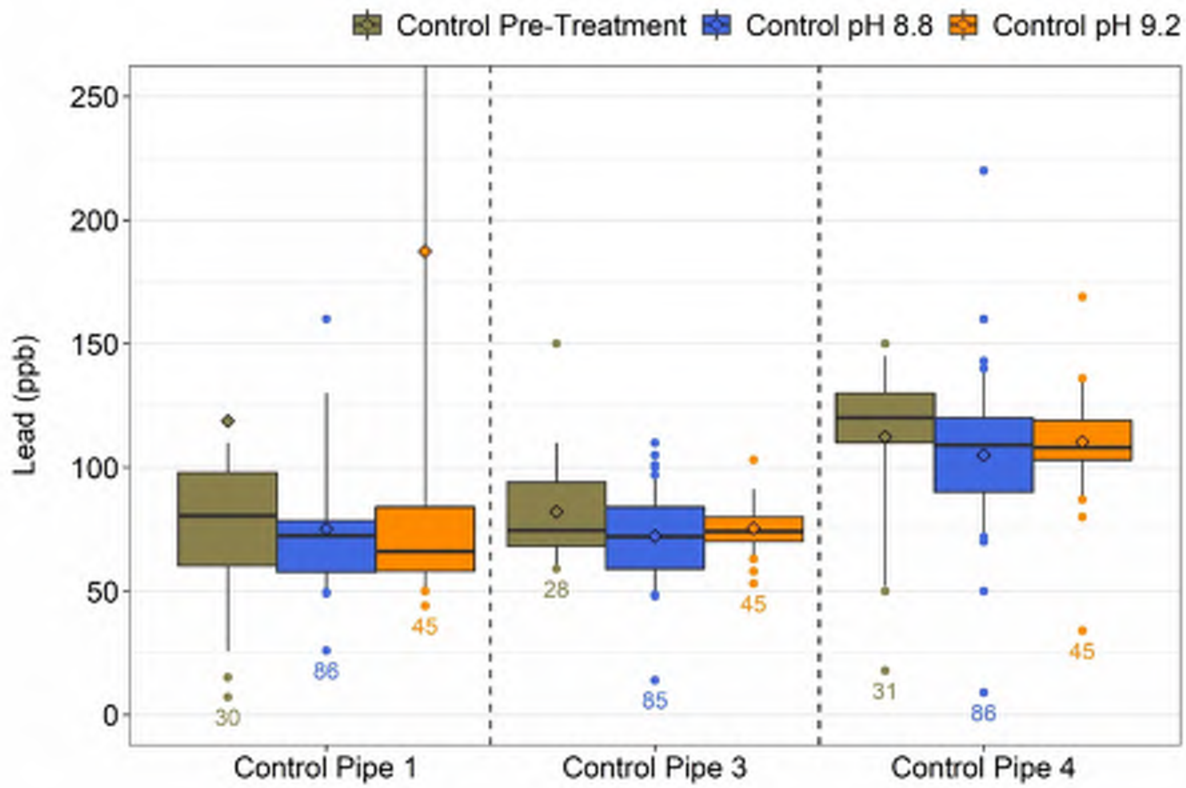


Figure 15: Marston Control Rack - Matching pH Rack Operation

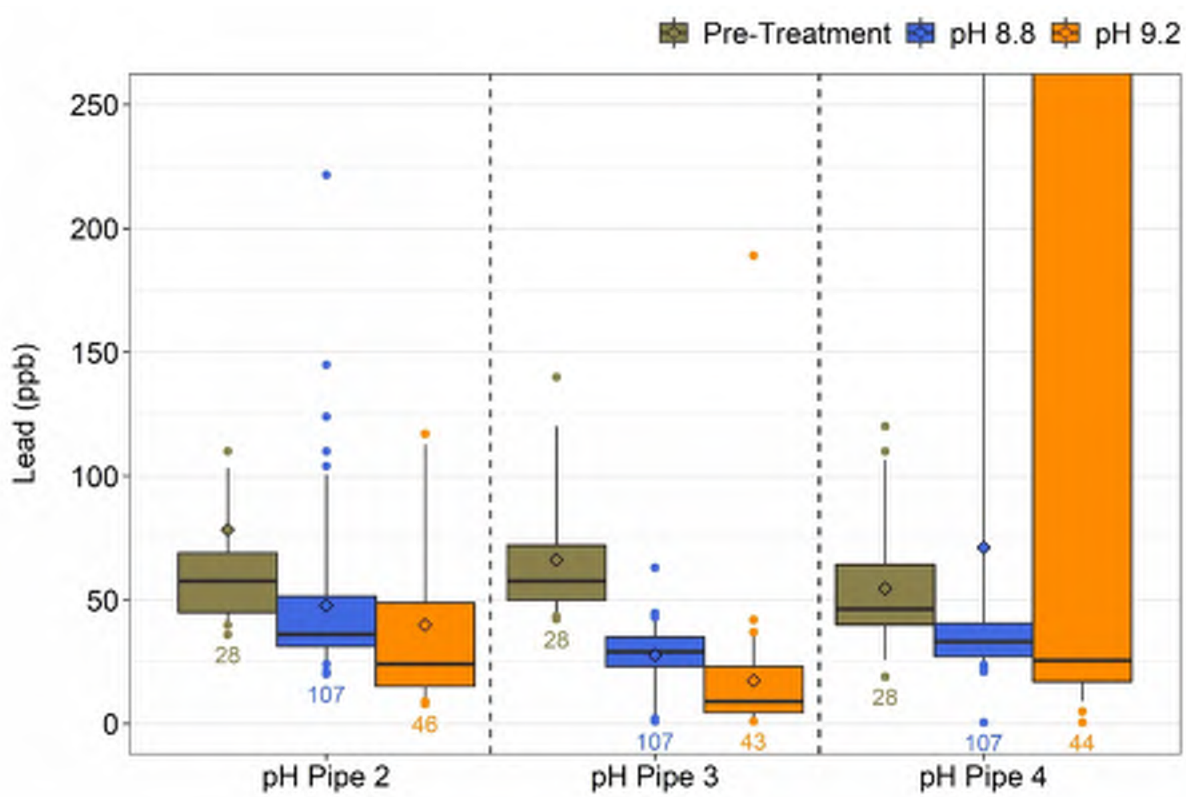


Figure 16: Marston pH Rack Conditions Tested

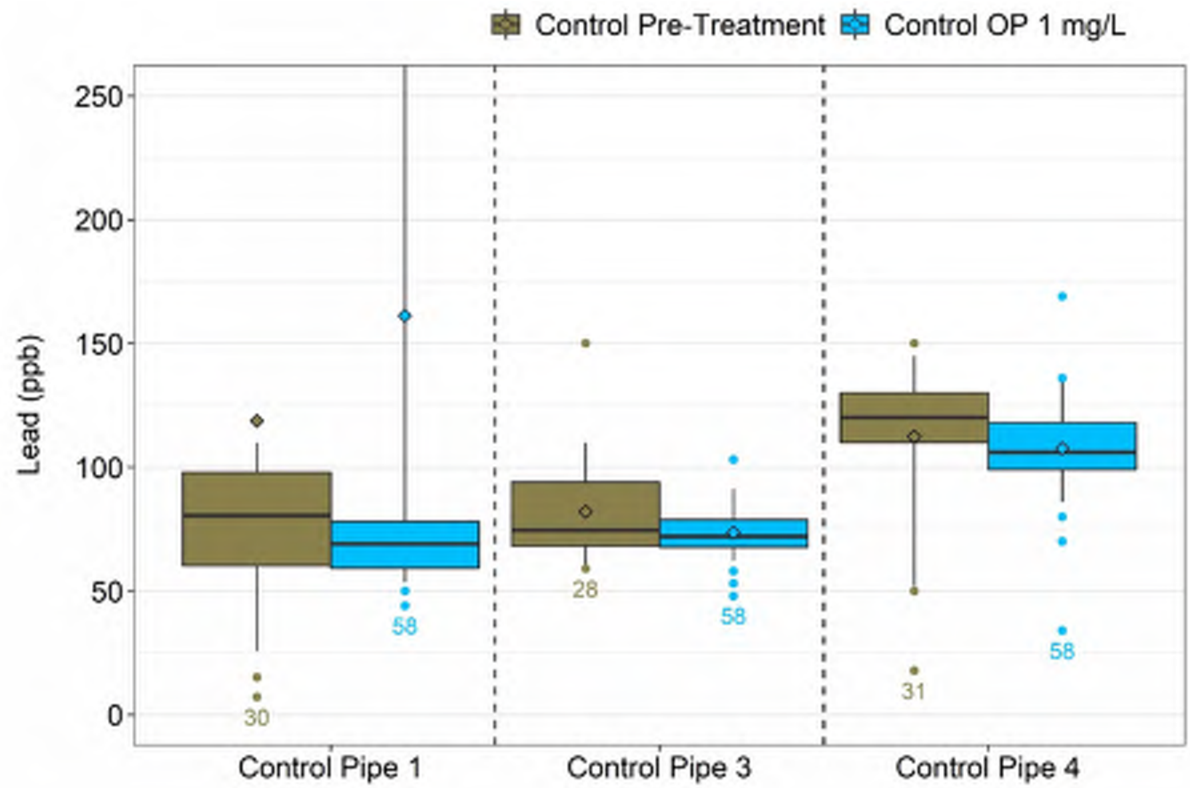


Figure 17: Marston Control Rack - Matching (Si) OP Rack Operation

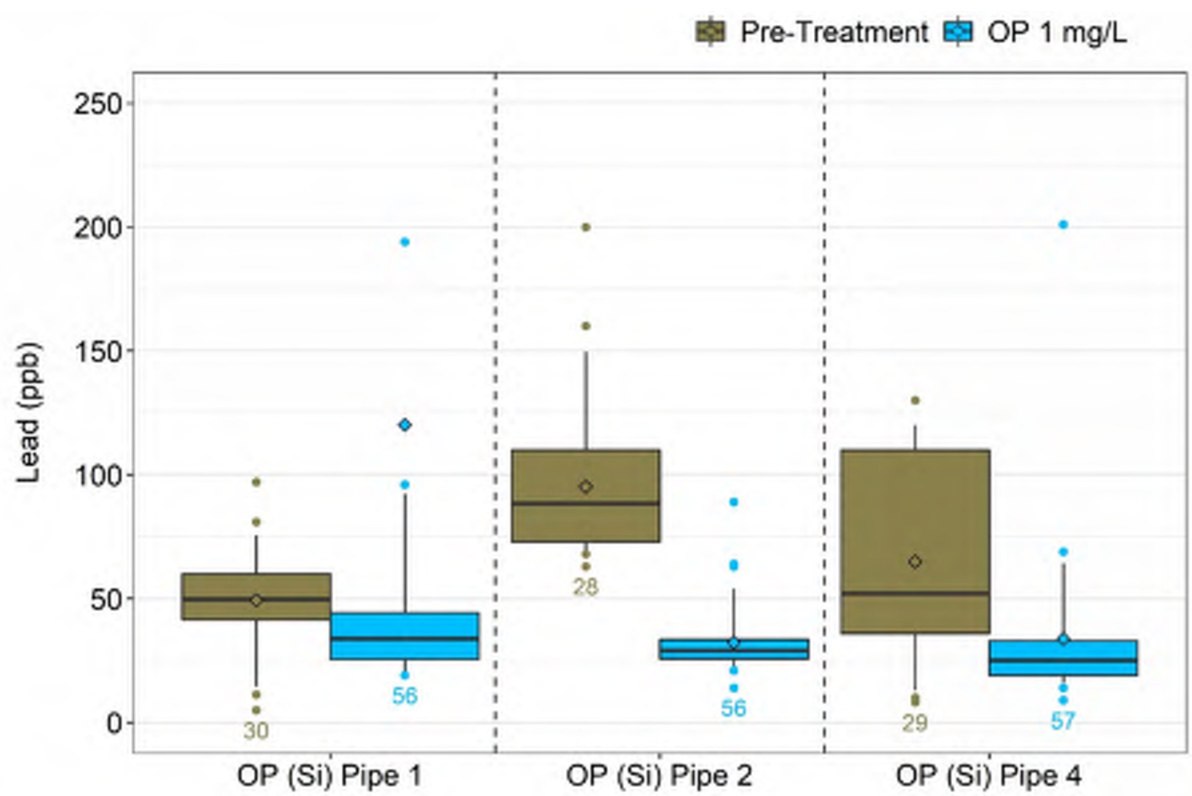


Figure 18: Marston (Si) Orthophosphate Rack Testing Going Directly to a Low Dose

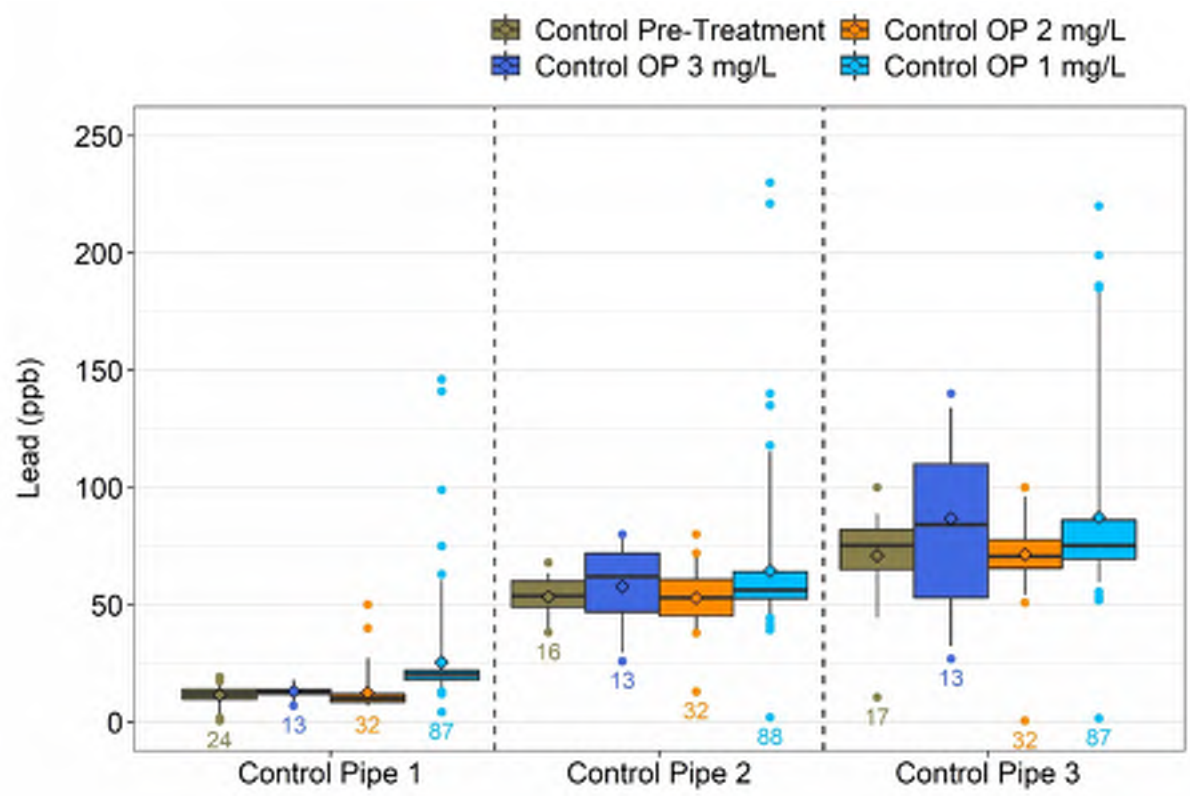


Figure 19: Moffat Control Rack - Matching Orthophosphate Rack Conditions

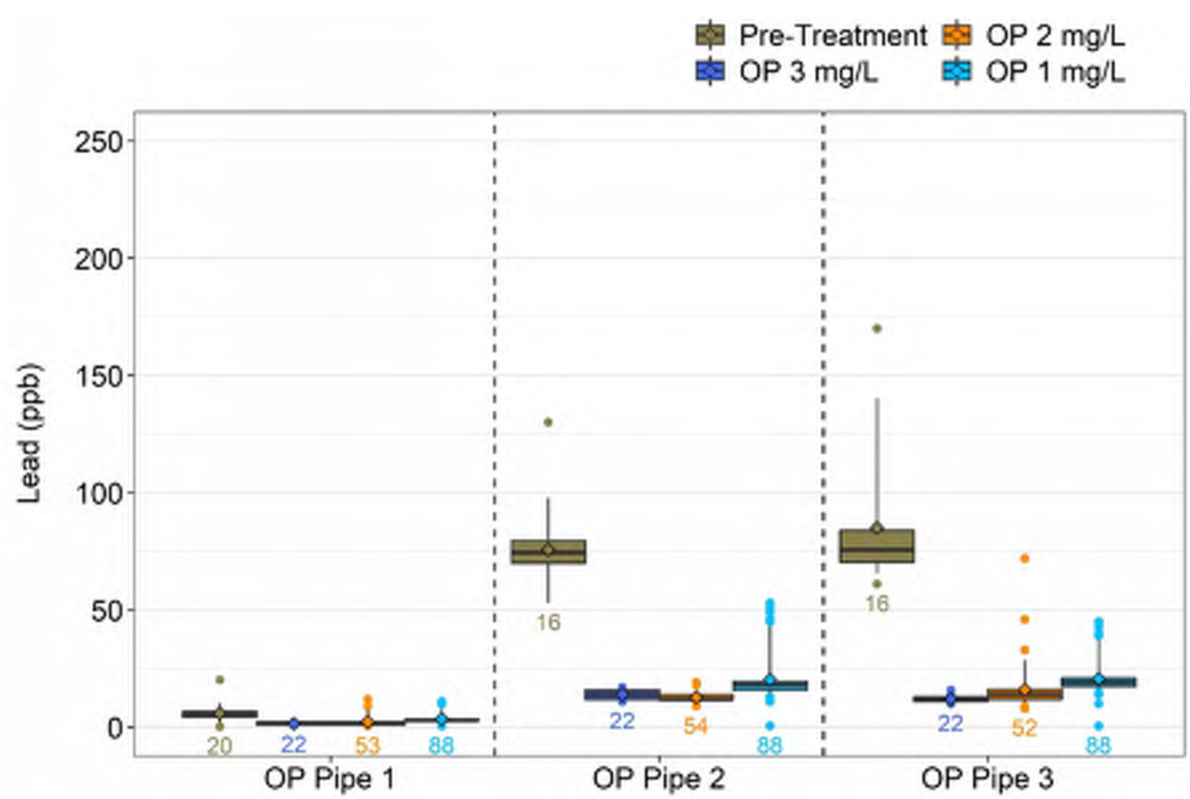


Figure 20: Moffat Orthophosphate Rack Doses Tested

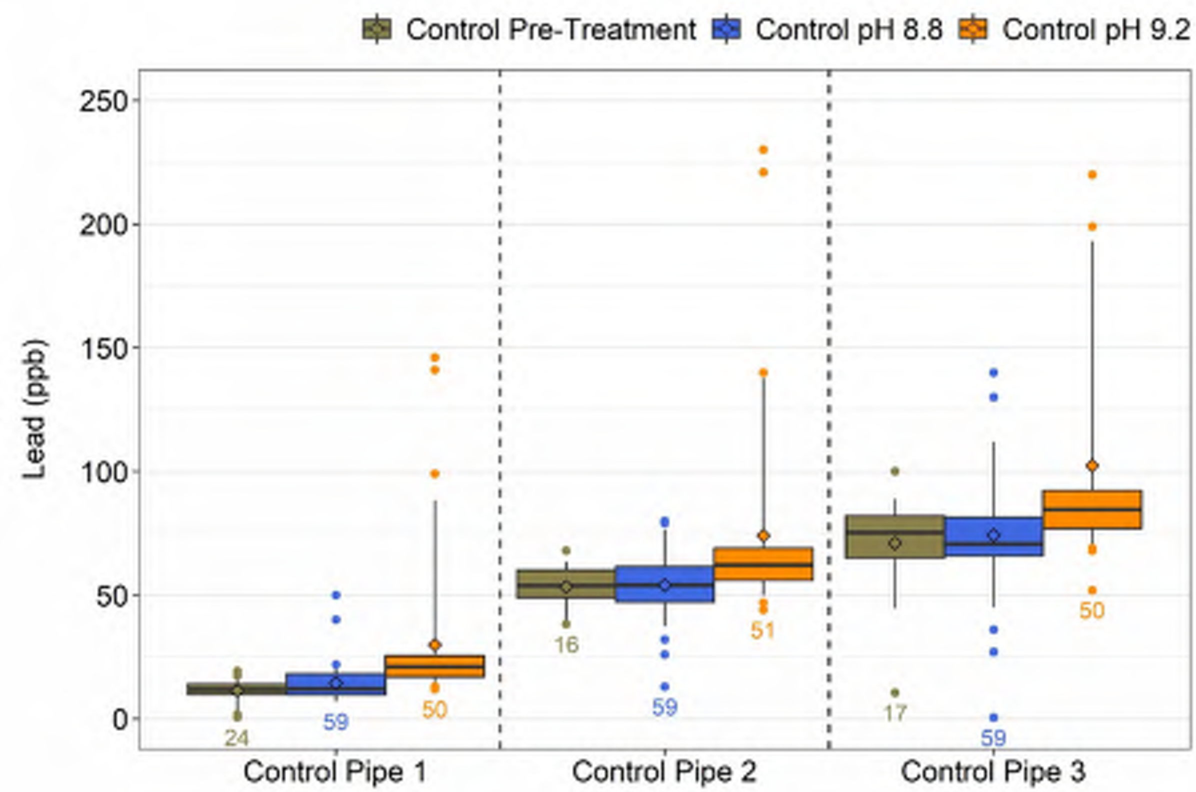


Figure 21: Moffat Control Rack - Matching pH Rack Conditions

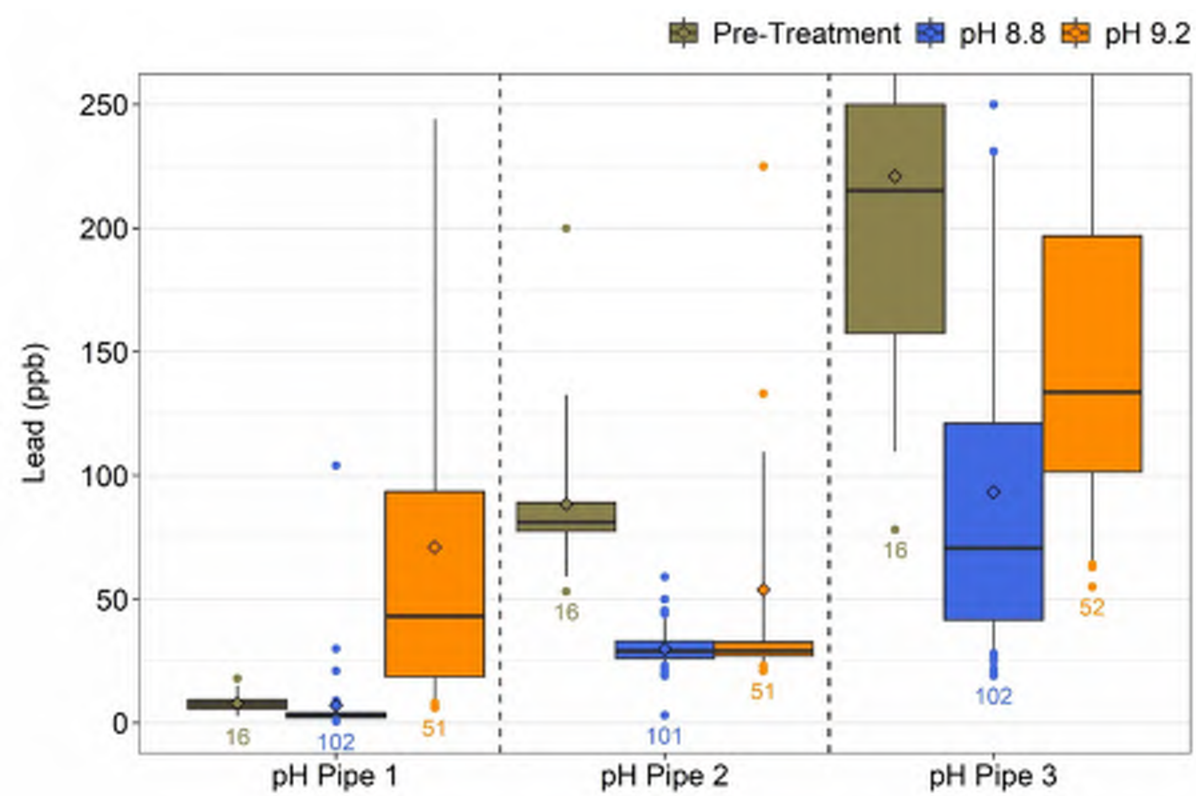


Figure 22: Moffat pH Rack Conditions Tested

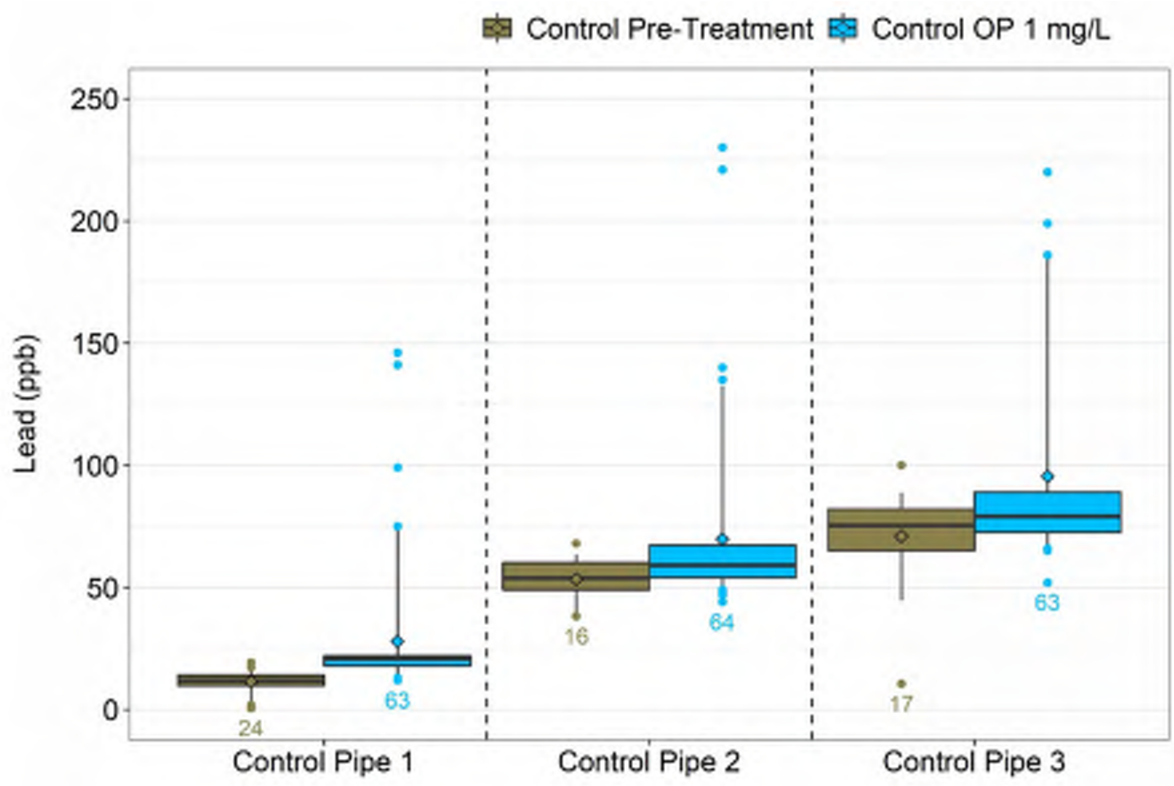


Figure 23: Moffat Control Rack - Matching (Si) Orthophosphate Rack Conditions

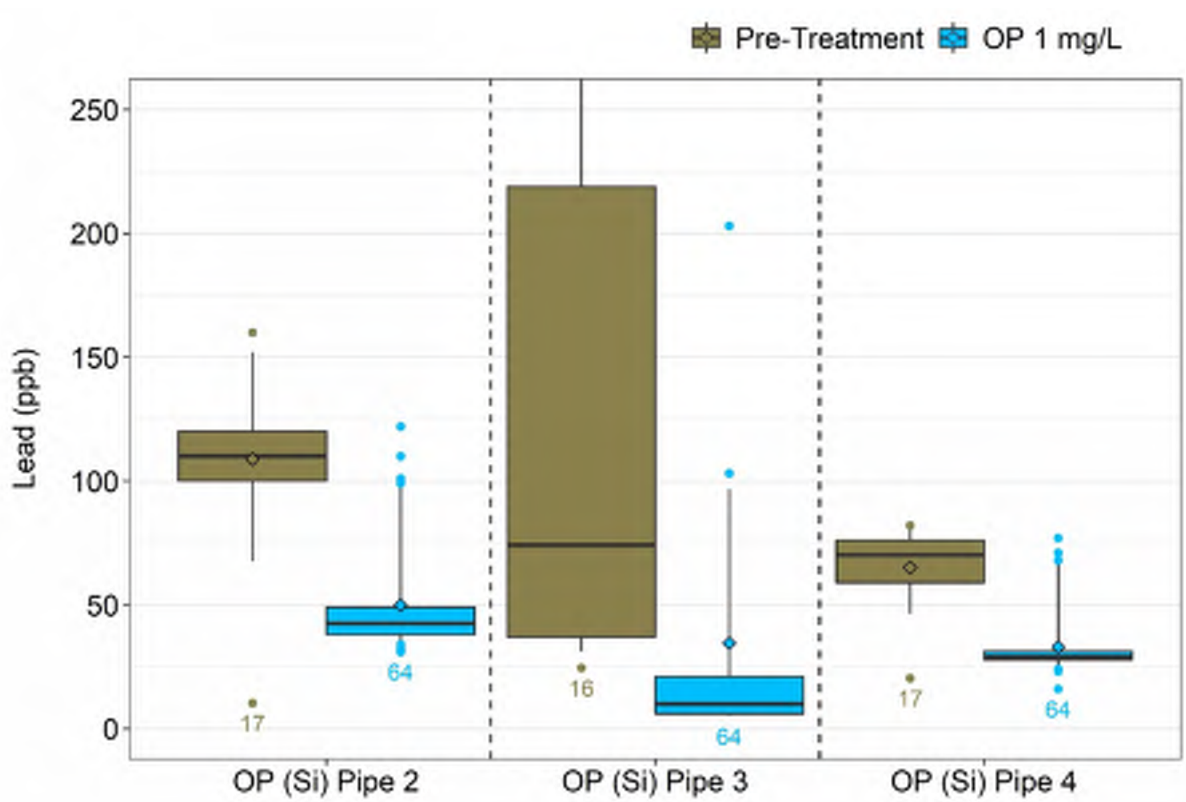


Figure 24: Moffat (Si) Orthophosphate Rack Testing Going Directly to a Low Dose

APPENDIX II.C - REVIEW OF LEAD CONCENTRATION OUTLIERS

September 2019

DENVER WATER

Appendix II.C

Review of Lead Concentration Outliers

Background:

Data from Denver Water's Lead and Copper Rule monitoring efforts at Tier 1 properties with copper piping and lead solder include some results above the action level of 15 ppb. Results from profile testing using a sequential testing protocol[1] confirmed that properties with copper piping and lead solder typically have lead measured up to 5 ppb in the first 1 L sample, followed by lead measured near the method detection limit in subsequent sample volumes. Please refer to Appendix III.E.1 for a detailed discussion of profile testing at copper piping with lead solder homes compared with lead service lines.

Denver Water has an extensive database of results for lead measured from properties with copper piping with lead solder. The purpose of this technical memorandum is to analyze the results from LCR compliance sampling and customer requested sampling to better understand typical lead release at properties identified as copper piping with lead solder homes. Of interest is the frequency with which outliers occur (i.e., when higher than expected lead concentrations are measured) and whether a higher lead concentration is indicative of a source of lead in addition to lead solder. If the source of the lead levels can be better understood, recommendations for follow up sampling and potential mitigation can be identified.

Methods:

Approximately 2,300 samples were included in the analysis of potential outliers:

- LCR compliance sampling at Tier I properties with copper piping and lead solder:
    - 1,184 samples were collected from 1997 through the first half of 2019
    - As these are LCR sites, many properties were sampled repeatedly over this time
    - A 1 L sample was collected after a minimum stagnation period of 6 hours
- Customer requested sampling:
    - All customer requested samples collected from 2016 through the first half of 2019 were reviewed against the Lead Service Line Inventory (see Appendix III.B.2) to identify likely properties with copper piping with lead solder; properties were selected based on the year that the property was constructed (1,196 have a build date from 1952 to 1987)
    - The 3-bottle test was used, with samples collected after a minimum stagnation period of six hours

As the customer is responsible for sample collection, the duration of the stagnation period used before the sample is collected can vary. For this analysis a stagnation period of six hours is assumed.

[1] See Appendix III.E.1. More than 20 aliquots of varying sample volume (125 mL to 1 L) were collected from 16 homes.

The Denver Water lab is certified by the Colorado Department of Public Health and Environment to test lead. All samples for lead are measured using method EPA 200.8. To perform the analysis, half the method detection limit was used for samples where the lead concentration was reported below the method detection limit (i.e., 50% of 1 ppb or 0.5 ppb).

The use of control charts is a commonly used to identify potential outliers in a given dataset. The assumption is that the data follow the behavior of a normally distributed dataset. Results can be used to identify results outside three standard deviations as outliers. Denver Water's LCR compliance data were analyzed using a control chart to identify an outlier result based on exceeding the sum of the average and 1 standard deviation, providing a more conservative approach than the customary three standard deviations.

Both data sets were reviewed to identify properties where:

- Lead was measured greater than 15 ppb in at least one sample at a given property; for customer requested sampling, data for the first bottle (or first draw) were used.
- Lead was measured greater than 5 ppb in at least five samples, where lead was measured on more than one sampling date; this applies mostly to the LCR data set as there were very few sites included in the customer requested sampling for which samples were obtained on multiple sampling.

The sub-set of data were subsequently reviewed for the:

- Build date, to identify homes built from 1951 to 1987.
- Tap date, to identify properties connected to a water main from 1951 to 1987.
- Original water main installation year.
- Additional data on service line material type (original material or an indication that the service line was replaced).

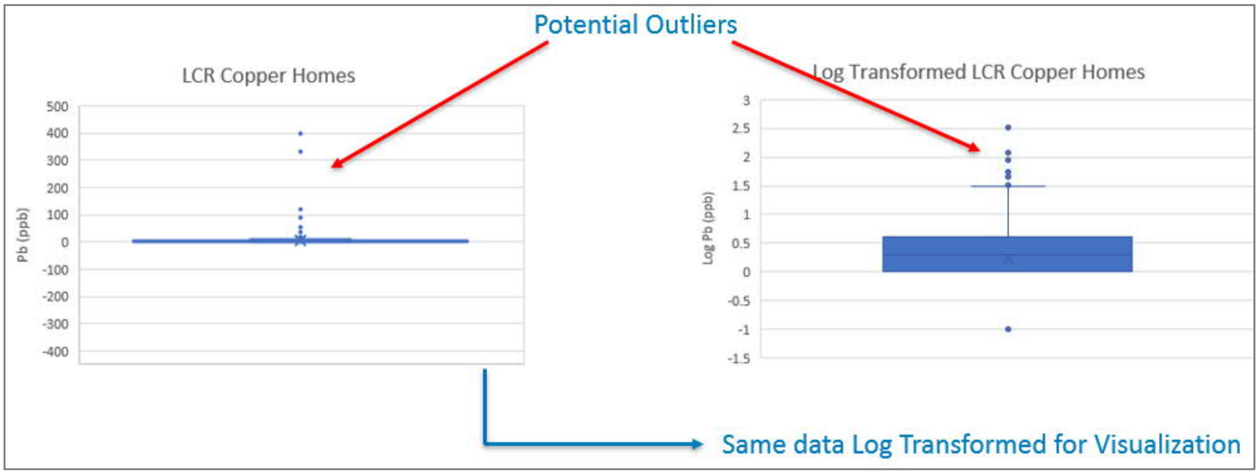
Analysis of LCR Compliance Samples from 1997 to 2019, Copper Piping with Lead Solder

The variability observed in the data available from LCR compliance sampling is shown in Figure 1, with a logarithmic scale used on the vertical axis on the right to exaggerate the details. Of the 1,184 Tier I copper piping with lead solder samples analyzed, 2.5 percent, or 25 samples were above the LCR action level of 15 ppb with the highest concentration reported was 400 ppb.[2] The average was calculated as 4.3 ppb and the standard deviation was 16.6 ppb.

Additional sampling occurred at several of these homes both before and after the reported testing, with lead level results reporting lower, particularly with some of the very high sample results that were originally reported.

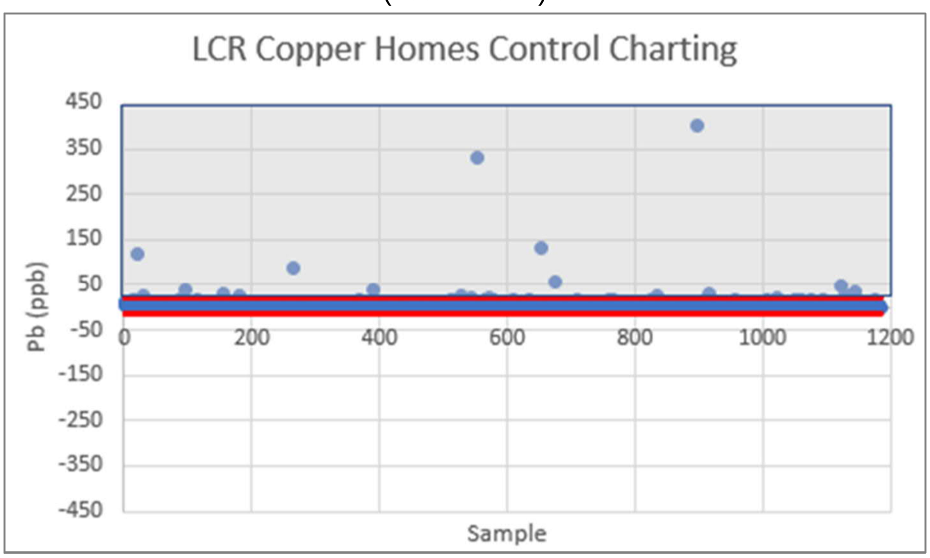
[2] This property was re-sampled and follow-up investigations and it was determined that the original sample had been collected from a tap that had been used for more than six months. Therefore, this outlier can be attributed to sample collection error. With one exception, lead was measured at less than 5 ppb in all other samples collected from 2013 through 2019.

Figure 1: Variability of LCR Compliance Samples Tier 1 Copper Piping with Lead Solder (1997 – 2019)



The same data set is presented using a control chart in Figure 2, based on the application of Gussain Curves which are usually set at ± 3 standard deviations from the mean. However, in this analysis, the control chart was prepared using ± 1 standard deviation.

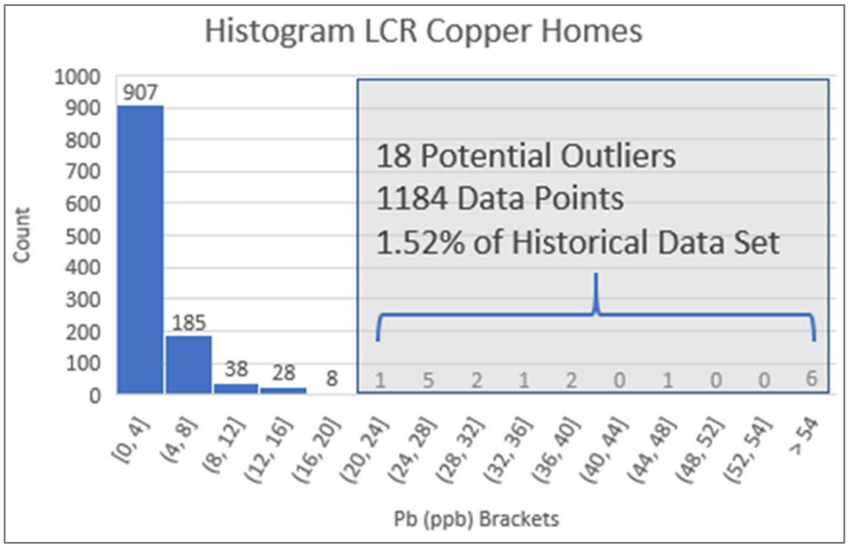
Figure 2: Control Chart Applied to LCR Compliance Samples Tier 1 Copper Piping with Lead Solder (1997 – 2019)



Note: The red lines represent the upper and lower control limits, based on ± 1 standard deviation.

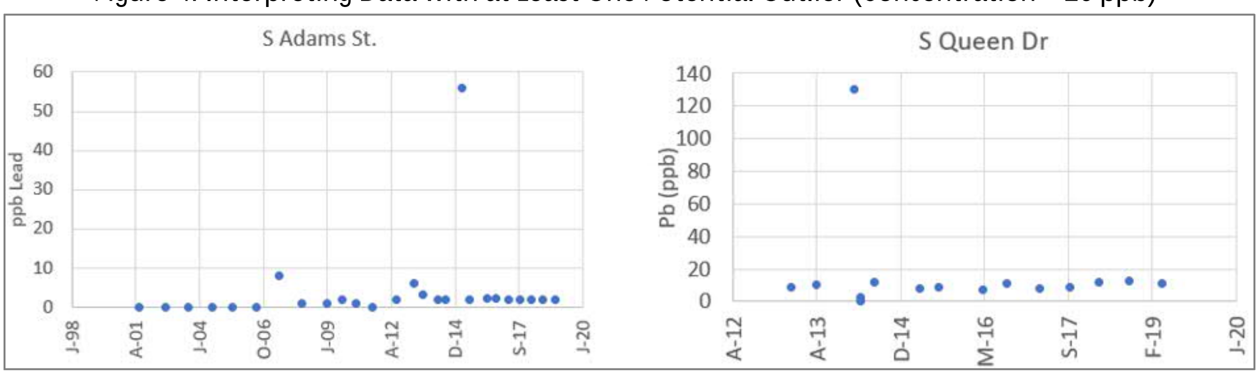
Using ± 1 standard deviation to define the upper and lower control limits is interpreted to mean that the chance is 68.3 out of 100 that the random uncertainty of any single measurement is no more than 1 standard deviation. For the 1997 to 2019 LCR compliance data, the upper control limit is 20.8 ppb, and any result measured greater than this is considered an outlier. Using this definition of outlier, the LCR compliance samples include 18 results greater than 20.8 ppb, or about 1.5% of the dataset. The LCR compliance samples are presented as a histogram in Figure 3 and reveal that the data do not follow a normal distribution (see Figure 3).

Figure 3: Histogram of LCR Compliance Samples Tier 1 Copper Piping with Lead Solder (1997 – 2019)



An example comparing two sites, each with at least one result for which lead was measured above 20 ppb, is presented in Figure 4 to show how the results were interpreted and the proposed follow-up steps to confirm the source of lead at the property. In the example from South Adams Street (shown on the left of Figure 4), only one result out of 26 samples was measured above 20 ppb and all but two of the remaining samples were measured below 5 ppb. The result from this site is considered an outlier, the property appears to be correctly identified as having copper piping with lead solder, and therefore not follow-up action is recommended.

Figure 4: Interpreting Data with at Least One Potential Outlier (Concentration > 20 ppb)

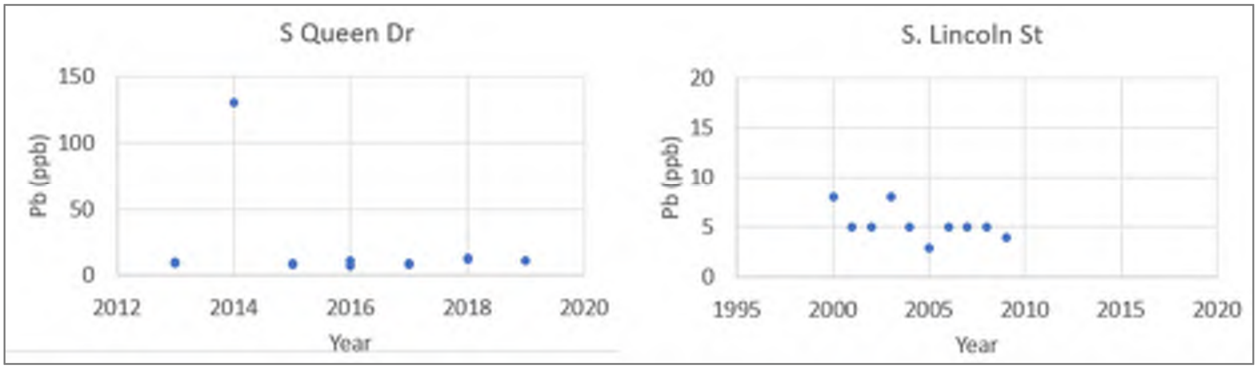


In contrast, the results for the South Queen Drive property shown on the right of Figure 4 prompted a recommendation for additional water quality sampling and field investigations to better understand the source of lead at this property. With one sample measured above 120 ppb, 12 of the 15 samples shown on the right of Figure 4 had lead measured between 7 and 13 ppb.

An example comparing two sites, each which have at least five results greater than 5 ppb, is presented in Figure 5 to show how the results were interpreted and the proposed follow-up steps to confirm the source of lead at the property. For the South Queen Drive results (on the left in Figure 5A), one outlier was measured but lead above 5 ppb was also measured on at least five occasions. In the case of the

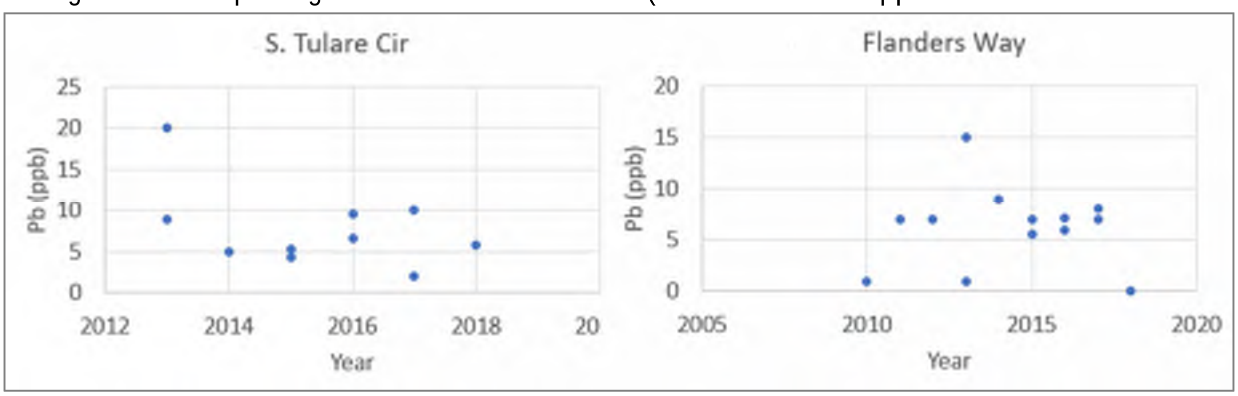
South Lincoln Street property shown in Figure 5A, multiple samples above 5 ppb, were measured. The presence or extent of lead at either of these properties cannot be confirmed from the available data and therefore additional water quality sampling and field investigations are recommended at both properties to better understand the source of lead.

Figure 5A: Interpreting Data with Persistent Lead (Concentration ≥ 5 ppb in at least Five Results)



Two additional sites with persistent lead release are provided as an example in Figure 5B. Persistent lead was measured at both properties and despite a build date of 1984, a source of lead in addition to solder is suspected at the Flanders Way property. Additional water quality sampling and field investigations are recommended for both properties to better understand the source of lead.

Figure 5B: Interpreting Data with Persistent Lead (Concentration ≥ 5 ppb in at least Five Results



In summary, several of the samples collected, analyzed and submitted to CDPHE are suspected to be anomalies, as follow up sampling produced sampling results much lower than the reported sample. Other sites may have full or partial lead service lines given the tap date, home age or main installation year. Water quality testing and filed investigations (such as pot holing and/or visual inspections) are recommended to confirm the service material. While not clearly conclusive, further sampling may confirm that high lead levels at these homes are unusual and can be explained. The homes that had follow up sampling should be contacted to try and gain an understanding as to why the submitted sample yielded such high lead concentrations.

Analysis of Customer Requested Samples from 2016 to 2019, Copper Piping with Lead Solder

Data available from customer requested sampling were also reviewed for outliers and persistent lead release. It is noted that the samples included in this analysis were selected based on historical data available to describe the characteristics of the property and visual or field investigations have not been performed to confirm the service line material type.

Of the 1,196 customer requested samples included in this review:

- 14 properties were identified for having lead measured that appeared to be an outlier or an indicator of persistent lead.
- Of the 14, 12 properties appeared to have a source of lead in addition to (or instead of) lead solder; additional water quality sampling and field investigations are recommended for these properties.

Analysis when the Two Datasets are Combined:

The results from sampling from both datasets were considered together to better understand the occurrence of outliers, based on all samples collected from customer requested sampling and a sub-set of the LCR compliance samples (2011 to 2019). Although Denver Water has data from LCR compliance sampling dating back to 1997 (1,184 samples), only results from samples collected since 2011 were included in the analysis (635 samples). Results from sampling prior to 2011 are considered less robust: Denver Water may have used different analytical methods with different detection limits, Denver Water's own procedures may have varied, and/or treatment objectives (and the resulting performance) at the three water treatment plants may have changed between 1997 and 2011.

From this, 40 properties were highlighted due to:

- outlier value > 15 ppb (LCR compliance data).
- at least five results ≥ 5 ppb at the same address (LCR compliance data).
- at least one draw from the 3-bottle test with lead > 5 ppb (customer requested data).

Of these 40 properties, 18 appeared to have a source of lead in addition to solder. This includes 6 out of the 26 LCR compliance sampling properties and 12 out of the 14 of the customer requested sampling properties.

Table 2: Outliers Analysis from Copper Piping with Lead Solder Properties

Sample Source	Number of Samples included in Analysis	Estimated Number of Outliers	Samples with Potential Lead Source in Addition to Solder
LCR Compliance Samples (2011 to 2019)	635 samples included in Tier I sampling (1983 to 1987)	26 (or 4.1%)	6* (or 1.0%)
Customer Requested Sampling (2016 to 2019)	1,196 total samples with a build date from 1951 to 1987	14 (or 1.2%)	12* (or 1.0%)
Total	1,831	40 (or 2.2%)	18* (or 1.0%)

* This number is included in the total number of outliers in the column to the left.

In general, both datasets are susceptible to outliers: some samples are true outliers, but some also appear to come from a property with a lead source other than lead solder. For these, additional water quality testing and/or field investigations are needed to confirm the source of lead at the property.

Discussion:

The LCR compliance sampling includes properties built from 1983 to 1987 in Tier 1 sampling to capture the impact of lead solder. However, all homes in the Denver Water service area built from 1952 to 1987 potentially have lead solder, unless updates were made to plumbing inside the home. An understanding of the typical release of lead from the 1983 to 1987 homes compared with all homes that potentially have lead solder (1952 to 1987) was evaluated. The results from this analysis was used as part of the equivalency test of the Lead Reduction Program compared with orthophosphate addition to drinking water for corrosion control.

The build date of all homes included in the Denver Water service area was reviewed based on decade of construction (see Table 3). The number of service connections built between 1983 and 1987 is relatively low, representing less than 5% of all connections in the Denver Water service area.

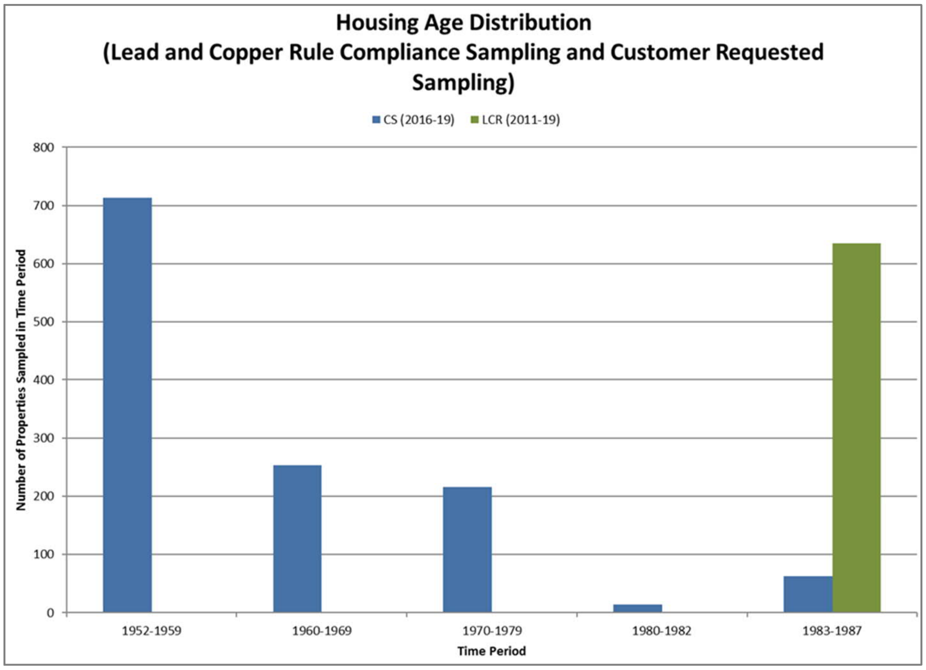
Table 3: Estimated Number of Service Lines by Housing Age, by Decade

Service Line Material Type	Estimated Build Date	Estimated Number of Service Lines
Lead Service Lines	≤ 1951	63,955
Copper Piping with Lead Solder	1952 - 1959	46,429
	1960 - 1969	37,699
	1970 - 1979	49,427
	1980 - 1982	11,961
	1983 - 1987	14,089
	Total 1952 - 1987	159,605
Non-Lead Service Line	≥ 1988	96,140

*Source: See Appendix III.B.2 and Tables 6, 8 and 9 in the Lead Reduction Program Plan.

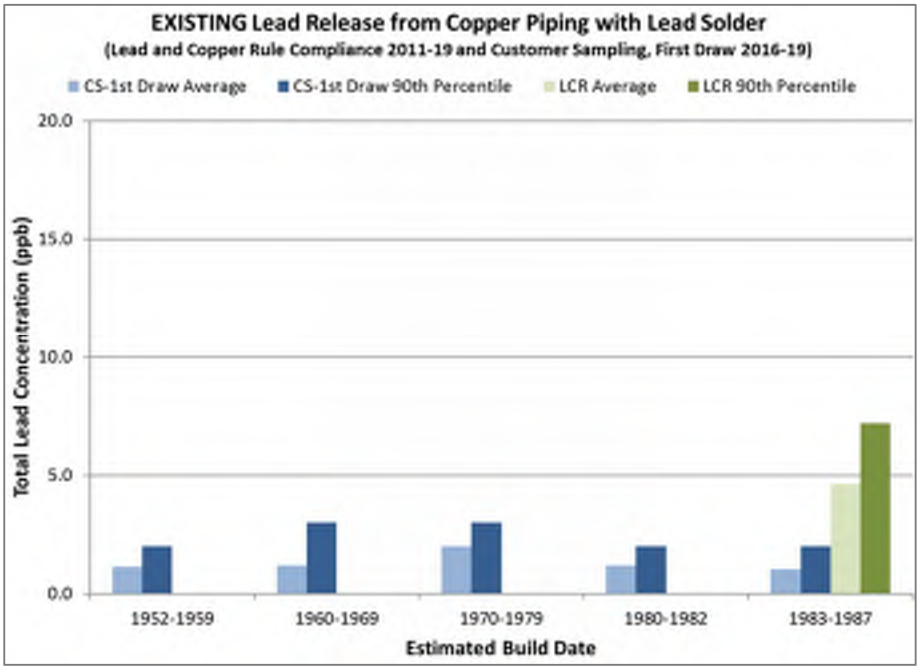
Water quality data from all properties identified as having copper with lead solder that are included in the LCR compliance dataset (collected 2011 to 2019) and customer requested sampling (2016 to 2019) dataset were reviewed as a function of the build date of the property. A summary of the number of properties included in this analysis by decade is shown in Figure 6, with a build date of 1983 to 1987 assumed for samples included in LCR compliance sampling.

Figure 6: Distribution of Available Water Quality Samples, by Decade



The analysis by decade of lead concentrations measured at homes with copper piping with lead solder are presented in Figure 7. Most results for lead concentration are relatively low and typically below 5 ppb, although higher lead release (8.0 ppb) is observed from homes constructed between 1983 and 1987. Although this group contributes less than 5% to the total housing stock in the Denver Water service area, the elevated lead that has been reported for the 1983 to 1987 properties warrants the further investigation of outliers to better understand the source of lead. If a property currently included in the 1983 to 1987 LCR compliance sampling set is found to have a lead service line it should be added to the list for replacement and a request to remove the property from the LCR compliance sampling set should be made to CDPHE.

Figure 7: Analysis of Lead Release from Copper Piping with Lead Solder with Existing Corrosion Treatment, by Decade



Recommendations:

There are several reasons why elevated lead is measured higher than would be expected at a property classified as having copper piping with lead solder, such as:

- Faucet material
- Incorrect sampling location and/or sample collection protocol by customer
- Contamination of sample in the field
- ICP-MS Matrix effects during analyses
- Inappropriate classification of property due to inconsistencies with build date and tap date

Additional water quality sampling and field investigations are recommended to better understand the source of lead and the service line material used, to allow the appropriate remediation strategy to be employed to reduce lead as measured at the tap. The choice of follow-up method for additional sampling (3-bottle test or sequential profile testing) and/or field investigations (visual, potholing, excavation) will depend on the availability of results from water quality sampling completed to date as well as historical information to characterize the property. Development of a standard operating procedure to capture potential follow-up steps is recommended.

APPENDIX III.A - OVERALL COMMUNICATIONS, OUTREACH AND EDUCATION PLAN

September 2019

DENVER WATER

APPENDIX III.A.1

OVERALL COMMUNICATIONS, OUTREACH & EDUCATION PLAN

Version 3.0: August 19, 2019

Presented by: Denver Water External Affairs

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EXECUTIVE SUMMARY

There is no lead in the water Denver Water sends to customers. But lead can get into water as it moves through lead-containing household plumbing and service lines. When it comes to lead in drinking water, no levels are considered safe. Therefore, the intent of the Lead Reduction Program is to ultimately replace customer lead service lines outside the home, while controlling/reducing lead exposure until the lead lines can be replaced and reducing lead release associated with lead solder inside a home's premise plumbing.

In 2012, Denver Water's routine testing of homes with known lead services lines and plumbing to comply with the federal Lead and Copper Rule had results that exceeded the action level for lead, prompting the utility to implement its largest public health education campaign and initiate follow-up action. Since 2012, Denver Water's ongoing lead campaign has involved sharing information with customers, stakeholders and community leaders about lead service lines, solder and fittings, proactive lead identification and replacement programs, offering free water quality testing and informing customers about what they can do to minimize their lead exposure.

In addition to those actions, Denver Water conducted detailed studies and analyses to evaluate corrosion control treatment methods to reduce lead exposure for customers with lead service lines or plumbing. In 2018, CDPHE designated orthophosphate as the Optimal Corrosion Control Treatment, or OCCT, for reducing lead exposure in homes with lead service lines or plumbing as required per the Safe Drinking Water Act. Denver Water requested an Environmental Protection Agency variance from this decision in order to implement a multipart Lead Reduction Program designed to maximize public health for customers while minimizing impacts to the environment. Both options will benefit public health by improving water quality and protection from lead. Also, in 2018, Denver Water and several parties (including Denver Water and CDPHE) entered into a collaborative agreement to address lead via an ongoing technical and stakeholder (public) workgroup process. Specifically, this group is working toward long-range regional solutions that protect public health and the environment per the Safe Drinking Water Act and the Clean Water Act, while additionally minimizing impacts to water supplies, wastewater treatment plants and watersheds.

Communications, outreach and education is a critical foundation for successful implementation of the LRP. Denver Water will continue to communicate proactively and transparently to help define relevant information for customers and provide a foundation for a well-informed public dialogue.

CURRENT AND ONGOING ACTIVITIES

Delivering safe water to 1.4 million people in the metro area is Denver Water's most important responsibility, and the utility long ago adopted a proactive approach that includes adapting its ongoing communications, operations and monitoring efforts as science and regulations have evolved. When it comes to lead in drinking water, no levels are considered safe.

The utility has tested water from inside customer homes with known lead service lines or lead solder once a year since 1992, per the EPA's Lead and Copper Rule. Information about lead is included as part of the sample collection process. In 2012, Denver Water's routine testing turned up results that exceeded the Action Level for lead, prompting the utility to implement its largest public health education campaign and initiate follow-up action, which included testing two times a year.

Since 2012, Denver Water's ongoing lead campaign has involved sharing information with customers, stakeholders and community leaders about lead service lines, solder and fittings, proactive lead identification and replacement programs, and what customers can do to minimize their lead exposure. The utility has used a variety of strategies and tactics, including direct mailings to customers, bill inserts, sharing information at community gatherings, meeting annually with elected officials and using traditional and social media for mass communications and engagement on the issue.

Denver Water communications, outreach and educations efforts include free water quality testing for customers who want to know if the water from their taps contains lead. Information about the testing program, as well as general issues surrounding lead, is included on Denver Water's website, in bill inserts, on social media, in presentations to groups touring Denver Water's facilities, and is the focus for discussions at Denver Water's water trailer, which supports numerous neighborhood events throughout the metro area. Denver Water also has a youth education program that reaches thousands of local families and Denver-area youth by directly engaging with schools in Denver Water's service area every year.

Denver Water has tested more than 15,000 samples of water from schools within its service area for lead and are working with the school districts on their remediation efforts. Starting in 2016, Denver Water partnered with Denver Public Schools and conducted multiple rounds of sampling and testing, developed strategies to remediate different sources of lead (plumbing, faucets, water fountains), and replaced the only two lead service lines remaining at their schools. Results from testing were posted on the Denver Public Schools website, along with the description and timeline of the school district's remediation efforts.

Additional coordination efforts with Denver Public Schools included developing sampling procedures adapted from EPA's 3Ts (Training, Testing, and Taking Action) tool kit, as well as communications and signage, which were then offered to other utilities in the country. Denver Water performed a single round of testing for Littleton Public Schools and helped with the communications and signage to parents and teachers. Douglas County Schools, Clayton Early Learning, and Children's Colorado KidStreet were three additional partnerships that included sample testing, communications and other efforts on a much smaller scale. The procedures, signage examples, and other protocols were provided to CDPHE and other utilities and schools both in Colorado (Loveland, Byers, Thompson School District and Colorado Springs) and elsewhere in the United States (Maryland and New York).

Denver Water has adapted its information campaign as technology has evolved. As the use of social media has increased in the community, Denver Water has augmented its ongoing communications efforts to include new platforms and strategies, including using its own Facebook and Twitter accounts to share information and call customers to action.

For example, in fall 2018, Denver Water's community relations staff posted an informational message about lead on Nextdoor, the neighborhood social media platform. The message included links to additional information on Denver Water's website and TAP news site. Since then, that Nextdoor post has garnered more than 15,000 views and continues to gather comments, indicating customers are reading and reacting to the information. Denver Water also highlighted the issue of lead in plumbing in a Facebook live interview in November 2018 via a partnership with 9Health, a highly respected local nonprofit group. The segment to date has received more than 7,300 views.

Moving forward, Denver Water will deploy tactics the utility has used successfully for years, and adapt as new strategies emerge, to communicate with people, families, neighborhoods and communities in Denver Water's service area. Tools and tactics include direct mail notification letters and postcards, website postings, video instructions, traditional and social media outreach and engagement, news sites stories, videos and infographics and advertisements. Outreach and engagement will include ongoing dialogue with diverse community groups, community members, as well as local and state government officials through a wide variety of variety of stakeholder engagement activities, such as town hall meetings, neighborhood meetings, community events and presentations, small group and one on one meetings, etc.

GOALS, OBJECTIVES, STRATEGIES AND TACTICS

Phase I: Pre-Variance (June 2019–October 2019)

Detailed communications, outreach and education plans for the pre-variance phase laid the foundation for the development of future communications, outreach and education plans. EPA, CDPHE and Denver Water agreed on goals and objectives for this phase. The group has also finalized key messages and a commonly asked questions document to serve as the foundation for communication materials.

Goal(s)

Denver Water, CDPHE and EPA agree on the benefits of carrying out education and outreach prior to the OCCT variance decision. More specifically, the agencies will:

- Educate, engage and seek input/feedback from residents, customers, local public health agencies, local government stakeholders and other targeted audiences about ways Denver Water could address reducing lead exposure (OCCT designation and variance alternative).
- Develop a framework that will create a shared understanding of lead education and reduction efforts to help ensure consistent information is being shared and distributed among stakeholders and the broader community.

Objectives

- Develop outreach strategies and tactics to educate, engage and seek feedback from target audiences. Educate residents on the following:
  - A historical overview leading up to the 2012 exceedance.
  - The Lead and Copper Rule, 2012 exceedance and Denver Water programs currently in place.
  - CDPHE's March 2018 decision regarding OCCT and subsequent Denver Water activities.
  - Clear communication on the impacts of lead exposure and what can be done to lower risk in the short-term.
  - Denver Water's Lead Reduction Program proposal, study plan and impacts to residents.
  - Milestones timeline for addressing the problem.
  - Use of filters through the Filter Pilot.
- Engage and seek input and feedback on the following one of two paths forward to address lead — state decision re: OCCT and variance.
  - Designation: Orthophosphate treatment spoken in layman's terms.
  - Alternative: Denver Water's Lead Reduction Program (accelerated lead service line replacement, filter program).
- Gather input and feedback to be used in the following ways:
  - Inform CDPHE and EPA of public sentiment regarding the alternative path forward.
  - Inform Denver Water on methods to increase engagement and implementation of the Lead Reduction Program. In particular the Filter Pilot will begin to educate customers on and encourage filter use, gathering input and lessons learned to apply to the full-scale filter program.

Strategies

- Develop communications and outreach plan.
  - Target audience analysis which includes those listed in the table.
  - Key messaging points developed in tandem with CDPHE and EPA for any agency that comes into contact with the public.

  - Refine strategies as needed and identify tactics for communications and outreach.
  - Identify multicultural outreach services needed (documents, meetings, etc.).[1]
- Communications and education outreach for internal staff.
  - Determine audience(s).
  - Organizational communication.
  - Training for Denver Water Call Center, Customer Service Field, Water Quality, and Safety and Security staff.
  - Support documents and communication materials.
- Implement external communications, outreach and education.
  - Implement filter and potholing pilot programs.
  - Industry Day for contractors interested in bidding on project to proactively answer questions and ensure these individuals know where to direct inquiries they may receive.
    - Coordinate with various City and County of Denver departments, Council Members and Mayor's office to prepare their offices for inquiries.
- Initiate public outreach and input opportunities.
  - Detailed outreach plan incorporated into separate document.
  - Provide pilot study participants with feedback opportunities for participants to share their thoughts on the process and filter preferences.

Phase II: Post-Variance Stakeholder Outreach (October 2019–January 2034)

Goals

The overarching goals for communications will be to scale up education and outreach efforts to achieve the following:

[1] Denver Water is using multiple sources of information to identify language and cultural needs for communications and translation services. Those include the federal interagency Limited English Proficiency webpage, CDPHE Community Health Equity Online Map and Denver Public Schools language information by neighborhood and zip code as well as information from peer cities. All documents include translation into Spanish and are available upon request into additional languages. Denver Water's call center and communications team have Spanish speakers.

- Inform customers and stakeholders of EPA's final decision.
- Raise awareness among all customers of the change and its impacts.
- Emphasize the outcome of implementation of the LRP, namely improved water quality and reduced risk of exposure to lead in drinking water for those with lead service lines and plumbing.
- Provide clear and consistent messaging and branding.

Objectives

Denver Water will further aim to:

- Build a platform for communitywide education and engagement regarding the Lead Reduction Program that includes communications and outreach, and gathers feedback to improve the program as it moves forward.
- Facilitate training for contractors, employees and vendors to educate these groups on where to direct customer inquiries and to support consistent communications on the program.
- Provide clear, accurate and timely information and messaging about the Lead Reduction Program to target audiences.
- Educate and engage with customers, residents, families and communities in order to create a common understanding of and instill confidence in the Lead Reduction Program.
- Support a specific communications, outreach and education program targeted at expectant and existing families with formula-fed infants/children up to age 2 living in homes with copper piping with lead solder built 1983-1987.
- Educate customers to encourage consistent, proper and ongoing filter usage.
  - Develop materials that easily demonstrate how to use the filters.
- Encourage customers to consider in-home plumbing updates and to flush the tap before drinking, cooking or preparing infant formula after prolonged periods during which water is not used, such as first thing in the morning or when returning home from work or school.
- Seek feedback from customers and others about the Lead Reduction Program to learn best practices and effective ways to implement program activities.
- Incorporate the Learning by Doing approach to improve outcomes during the life of the Lead Reduction Program.

Strategies

- Develop communications, outreach and education plans.
  - Target audience analysis including those listed in the table.
  - Key messaging points developed in tandem with CDPHE and EPA.
  - Identify translation services needed (e.g., documents, meetings).

    - Develop customized tools and techniques.[2]
- Communications, outreach and education for distributors.
    - Share customizable outreach materials to support distributors' customer communications.
- Communications, outreach and education for internal Denver Water staff.
    - Determine stakeholders.
    - Organizational communication.
    - Intranet.
    - Training for Call Center, Water Sales, Customer Service Field, Water Quality and Water Distribution staff.
    - Support and standard procedure documents.[3]
- Communications, outreach and education for contractors.
    - Training.[4]
    - Support documents and communication materials.
- Implement external communications, outreach and education.
    - Notification to all customers.
    - Targeted notifications to impacted customers (e.g., with known or suspected LSLs).
    - Target outreach campaign to impacted customers.

LEAD REDUCTION PROGRAM COMPONENTS

Each component requires clear goals, strategies, objectives and tactics specific to the component. For example, the strategies and tactics will differ for the Accelerated Lead Service Line Replacement and the Filter Program.

[2] Tools and Techniques will be customized by target audiences to include direct mail notification letters and postcards, website postings, video instructions, traditional and social media outreach and engagement, news site stories, videos and infographics, advertisements, public engagement activities, such as town hall meetings and neighborhood meetings, as well as collaborative efforts with community organizers, Spanish-speaking community groups and government officials.

[3] Documents include FAQs about the program, fact sheets, brochures, website information, maps, customer surveys for filter program, newsletters, news site stories, videos and infographics and bill inserts.

[4] Denver Water will offer seminars for contractors for education on best practices for replacement, following our standards and post-replacement flushing protocol.

There are several phases for all program components phases, including development, initial launch and implementation and sustained program management that incorporates course corrections along the way (i.e., learning by doing). Components vary in the timing of when each phase begins or ends which has implications for overall messaging and engagement.

Lead Service Line Inventory (In progress)

Goal

Continuously update and publish the inventory of lead service lines throughout the service area to improve estimate of number of lines that require replacement.

Objectives

- Inform and educate customers about their service lines — ownership, material types and plumbing.
- Engage suburban distributors to assess lead service lines within Denver Water's integrated system.
- Work with municipalities to develop better records regarding service line material.

Strategies

- Develop communications plan.
    - Target audiences (e.g., customers in homes with known or suspected lead service lines, local governments, elected officials, public health agencies). As lead inventory is updated, follow up and messaging differs by group.
    - Key messaging points.
    - Translate documents.
    - Tools and techniques.
- Communications, outreach and education for distributors.
    - Share customizable outreach materials to support distributors' customer communications.
- Communications, outreach and education for internal Denver Water staff.
    - Determine stakeholders.
    - Organizational communication.
    - Training for Call Center, Water Sales, Customer Service Field, Water Quality and Water Distribution.
    - Support and standard procedure documents.
- Communications, outreach and education for contractors collecting inventory data.

    - Training on service line inspection and identification including photo documentation.
    - Support documents and communication materials.
- Implement external communications, outreach and education.
    - Direct mail marketing and outreach.
    - Utilize existing internal resources to engage with distributors**.**
    - Mapping tool to show:
        - Unknown, suspected and known lead service line locations.
        - Known copper service line locations.
    - Links to water quality test requests and filter program.
    - Website information about service line verification techniques.
    - Training resources for plumbers.
- Review, revise and reinforce components of communications, outreach and education.

Filter Program (October 2019)

Goal

Provide customers with known or suspected lead service lines with a filter and educational materials to encourage consistent, ongoing and proper use of filters.

Objectives

- Inform and educate customers about the Filter Program.
- Engage with customers with known or suspected lead service lines to ensure they receive a filter.
- Work with property owners, local housing authorities and tenants to share information and encourage filter use with residents in rental and multi-family properties.
- Encourage filter use for drinking, cooking and when preparing infant formula.
- Encourage changing the filter cartridge according to the manufacturer's instructions.
- Educate customers about flushing and provide flushing instructions to encourage flushing the tap before drinking, cooking or preparing infant formula after prolonged

periods during which water is not used, such as first thing in the morning or when returning home from work or school.

Strategies

- Develop communications plan.
  - Target audiences, including those listed in the table.
  - Key messaging points.
  - Translate documents.
  - Tools and techniques.
- Develop a specific communications, outreach and education program targeted at expectant and existing families with formula-fed infants/children up to age 2 living in homes with copper piping with lead solder built 1983-1987. The program will:
  - Work with area healthcare providers to deliver educational material.
  - Encourage people to run the cold water tap before drinking, cooking or preparing infant formula after long periods of stagnation (per recommendation from profiling studies).
  - Encourage households to get their water tested.
  - Provide free filters and replacement cartridges for households with formula-fed infant/children up to age 2, where lead level results exceed 3 ppb, per CDPHE guidance.
- Communications, outreach and education for distributors.
  - Share customizable outreach materials to support distributors' customer communications.
- Communications, outreach and education for internal staff.
  - Determine stakeholders.
  - Organizational communication.
  - Training for Call Center, Water Sales, Customer Service Field, Water Quality and Water Distribution.
  - Support and standard procedure documents.
- Communications, outreach and education for contractors performing filter distribution work to ensure they can direct customers to appropriate resources and channels to get questions answered.
  - Training on flushing, filter types, installation methods and replacement protocols.

  - Support documents and communication materials.
- Implement external communications, outreach and education.
  - Notify impacted residents.
  - Complete distribution (mail and door-to-door delivery).
  - Ensure implementation of registration, tracking (i.e., QR code).
  - Utilize local opportunities to engage with residents.
  - Implement feedback surveys on filter adoption.
  - Initiate replacement filter process including how-to videos and use verification.
  - Implement voucher program, if used, for replacement cartridges.
- Review, revise and reinforce components of communications, outreach and education plan.

Accelerated Lead Service Line Replacement Program (December 2019)

Goal

Replace customer-owned lead service lines and provide information on post-replacement flushing procedures.

Objectives

- Inform and educate customers about their service lines — ownership, material types and plumbing.
- Inform and educate customers about their premise plumbing – sources of lead, known potential health risks, and options or strategies to reduce the risk of lead exposure from premise plumbing.
- Obtain property-owner consent to replace their lead service line and share information with the owner and residents of the property on what to expect from service line replacement.
- Provide support and information on post-replacement filter use and flushing.
- Provide customers with appropriate education and resources on water quality testing and the results of testing following lead service line replacement.
- Offer Denver Water staff and contractors strategies to obtain the consent of property owners who have refused to have their lead service line replaced.

Strategies

Communications efforts for this part of the program will build on work done during the inventory and filter programs. As part of the replacement segment of the program, customers will be supplied educational materials on how to eliminate additional sources of lead from premise plumbing, will be provided with lead filter cartridges for an additional six months and be offered a water quality test following replacement of the LSL. This will include the best practices found for post-replacement flushing to minimize lead particles.

- Develop communications plan.
    - Target audiences, including those listed in the table.
    - Key messaging points.
    - Translation.
    - Tools and Techniques.
- Communications, outreach and education for distributors.
    - Share customizable outreach materials to support distributors' customer communications.
- Communications, outreach and education for internal staff.
    - Determine stakeholders.
    - Organizational communication.
    - Training for Call Center, Water Sales, Customer Service Field, Water Quality and Water Distribution.
    - Support and standard procedure documents.
- Communications, outreach and education for contractors.
    - Training on replacement standards and flushing guidelines.
    - Training to provide talking points and business cards to direct customer inquiries.
    - Support documents and communication materials.
- Implement external communications, outreach and education.
    - Develop messaging around lead service line identification and inventory process.
    - Before LSL replacement.
        - Website information, direct mail and educational materials.

        - Notify impacted property owners via letter in advance of construction.
        - Carry out appointments with property owners to discuss construction and gain property-owner consent for LSL replacement.
        - Notify within 24 hours of service shut-off for construction activities.
- During and post LSL replacement.
    - Encourage continued filter use through the first six months following LSL replacement.
    - Educate customers on flushing protocol.
    - Offer water quality testing for follow-up.
        - If water quality results remain above the action level, walk through educational materials with the customer on how to reduce lead in their premise plumbing and refer them to community organizations and funding programs that can assist with investigating and removing lead from their home.
- If LSL replacement is declined, provide customers with educational information and follow appropriate protocols for documentation, notification and escalation if needed.
- Review, revise and reinforce components of communications, outreach and education plan.

Corrosion Control Treatment (CCT)

Goal

Educate and inform customers about how Denver Water treats water to help minimize the release of lead into water from lead service lines and household plumbing and fixtures that contain lead.

Objectives

- Provide information on the Lead and Copper Rule and metal corrosion for general audiences.
- Inform and educate residential and commercial customers about the sources of lead in plumbing.
- Raise awareness among customers of the upcoming water treatment change and how it will or will not impact water quality, including little-to-no noticeable impacts to Denver Water customers, their plumbing and appliances; no anticipated changes to taste and odor; and specific considerations for chemistry dependent uses.

- Emphasize the outcome of increasing the pH — improved water quality and reduced risk of lead exposure in drinking water for customers with lead service lines and lead plumbing.
- Educate customers about flushing and provide flushing instructions to encourage flushing the tap before drinking, cooking or preparing infant formula after prolonged periods during which water is not used, such as first thing in the morning or when returning home from work or school.
- Provide clear and consistent messaging and branding.

Strategies

- Develop communications plan.
    - Target audiences, including those listed in the table.
    - Key messaging points.
    - Translation.
    - Tools and Techniques.
- Communications, outreach and education for distributors.
    - Share customizable outreach materials to support distributors' customer communications.
- Communications, outreach and education for internal staff.
    - Determine stakeholders.
    - Organizational communication.
    - Training for Call Center, Water Sales, Customer Service Field, Water Quality and Water Distribution.
    - Support and standard procedure documents.
- Communications, outreach and education for contractors.
    - Training on replacement standards and flushing guidelines.
    - Support documents and communication materials.

- Implement external communications, outreach and education.
    - Outreach to industrial commercial customers whose processes may be impacted by water chemistry changes.
    - Educate customers about flushing and provide flushing instructions for best water quality practices.

- Review, revise and reinforce components of communications, outreach and education plan.

APPENDICES

Appendix A: Pre-Variance Stakeholder Outreach

Goal

Denver Water, CDPHE and EPA agree on the benefits of carrying out education and outreach prior to the optimal corrosion control treatment variance decision. More specifically:

- The agencies will educate, engage and seek input/feedback from residents, customers, local public health agencies and providers, local government stakeholders, distributors and other targeted audiences about ways Denver Water could address reducing lead exposure (OCCT and variance paths).

Objectives

- Develop outreach strategies and tactics to educate, engage and seek feedback from target audiences. Educate audiences on the following:
  - The scope and history of the problem
    - The Lead and Copper Rule, 2012 exceedance and Denver Water programs currently in place.
    - CDPHE's March 2018 decision regarding OCCT and subsequent Denver Water activities.
  - Risk communication on the impacts of lead exposure and what can be done to lower risk in the short-term.
  - Denver Water's Lead Reduction Program proposal, study plan and impacts to residents.
  - Timeline for addressing the problem.
- Engage and seek input and feedback on the alternative path forward to address lead — state decision re: approval of the variance.
  - OCCT designation: Orthophosphate treatment spoken in layman's terms.
  - Alternative path (variance): Denver Water's Lead Reduction Program (accelerated lead service line removal, Filter Program).
- Gather input and feedback to be used in the following ways:
  - Inform CDPHE and EPA of public sentiment regarding the alternative path forward

- Inform Denver Water on methods to increase engagement and implementation of the Lead Reduction Program (e.g., filter program).

Introduction

EPA, CDPHE and Denver Water agree that seeking stakeholder feedback regarding the alternative path to reduce lead is critically important to the success of the communication, education and outreach efforts related to the full Lead Reduction Program.

This document outlines various components required to educate and gather feedback about the OCCT designation and alternative path to reduce lead exposure before a variance decision (October 2019) including:

- Timeline — provided below (updates happening frequently).
- Outreach framework including audiences — complete.
- Key messages — in a separate document.

Outreach Framework (Target audiences and timeline)

Communication strategies relate to program audiences, which have been placed in categories based on associated influences and communication goals. Timeline column denotes when the activity was or will be completed.

Timeline	Target Audience	Agency lead	Objectives	Method of Communication
Beginning 2/2019 and ongoing.	**Denver Water customers (Pre-1951 homes)**	Denver Water	Create awareness about LSLs. Provide information to learn more (e.g., water quality testing, loans for service line replacement).	Direct mail, and others as identified through communications plans.
Quarterly	**Denver Mayor's Office**	Denver Water	Provide information to elected officials and staff about the reason for implementing OCCT. Provide assistance for handling citizen calls. Obtain input and guidance on approach to council districts.	Meetings. Informational materials.
Beginning 6/2019 and ongoing.	**Denver City Council**	Denver Water	Provide information to elected officials and staff about the reason for implementing OCCT. Provide assistance for handling any citizen calls. Obtain input and guidance on approach to council districts.	Meetings. Informational materials. Presentations as requested.
Beginning 7/2019 and ongoing.	**City and County of Denver departments** (includes Planning, Public Works, Engineering, Office of Environmental Justice and Health Equity, etc.)	Denver Water	Create awareness about CCT variance request. Determine areas requiring coordination for construction and community affairs.	Meetings. Informational materials. Presentations as requested.

Timeline	Target Audience	Agency lead	Objectives	Method of Communication
Beginning 5/2019 and ongoing.	**Public health agencies and public health providers**	Denver Water	Enlist support for water quality improvements for the benefit of public health. Inform about the benefits of CCT. Inform about the impacts of any change in water quality. Gain support from the health department as a communications partner with special, targeted audiences, including general public, physicians, etc.	Meetings. Informational materials. Presentations as requested. Others as identified through communications plans.
6/2019 7/10/2019 7/16/2019 8/2/2019 8/5/2019 others pending.	**Denver Water Distributors (wholesale/retail large account holders)**	Denver Water	Create awareness. Obtain input.	Meetings. Informational materials. Presentations as requested. Others as identified through communications plans.
6/2019 6/20/19 7/18/2019 others pending.	**Denver Water - Citizens Advisory Council**	Denver Water	Create awareness. Obtain input.	Meetings. Informational materials.
7/2019 – 8/2019	**Customers/participants in filter pilot**	Denver Water	Educate and engage to gauge viability of a filter distribution program and adoption rates by Denver Water customers that have known or suspected lead service lines.	Letters, informational materials, phone calls, door-to-door outreach.
Beginning 6/2019 and ongoing.	**Advocacy organizations: public health, children's health advocacy, environmental groups**	CDPHE & Denver Water for public health and children's health; EPA & Denver Water for enviro groups.	Create awareness. Build interest. Obtain input.	Meetings. Informational materials. Presentations as requested. Others as identified through communications plans.

Timeline	Target Audience	Agency lead	Objectives	Method of Communication
Monthly	**MOU stakeholder group**	CDPHE	Present overview of variance option and input requested.	Meetings.
Beginning 7/2019 and ongoing.	**Customers and residents**	Denver Water	Implement a comprehensive, strategic, integrated public communication and outreach program. Create awareness about program approach. Obtain input.	Various, including those listed above and others identified through communications plans.
Beginning 7/2019 and ongoing.	**Commercial customers**	Denver Water	Create awareness about program approach. Obtain input.	Various, including those listed above and others identified through communications plans.
Beginning 7/2019 and ongoing.	**Impacted customers (with known or suspected LSLs)**	Denver Water	Educate and engage with customers about LSLs, coordinate LSL removal.	Various, including those listed above and others identified through communications plans.

Outreach Timeline

2012
Denver Water exceeds Lead Copper Rule (LCR) Action Level

Mass communication campaign, Denver Water begins increased monitoring

2012 Communications
Direct mail: 700,000+
Social media: 30+ tweets
News media: 20+ news stories
Outreach with elected officials

2013
Desktop study completed

2015-2017
Pipe study conducted

2016 Communications
Bill inserts & e-bill: 136,000
TAP story: 1,000
Social media: 6 tweets
Events: 7
Direct mail & email campaigns: 2,000
Water quality test request: 918
News media: 10+ news stories; 93M potential reach
Outreach with elected officials

2017 Communications
Bill inserts & e-bill: 195,000
TAP Story: 1,726
Social media: TBD
News media: 4 stories; 2.3M potential reach
Events: 18
Direct mail & email campaigns: 65,000
WQ test request: 1,331
Outreach with elected officials

September 2017
Denver Water submits final OCCT report

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

2018 Communications
Bill inserts & e-bill: 263,000
TAP Story: 3,260
Social media: 18,000
News media: 6 news stories; 5M potential reach
Events: 21
Direct mail & email campaigns: 2,000
WQ test request: 2,458
Outreach with elected officials

March 2018
CDPHE designates orthophosphate

May 2018
Formal complaint filed in district court, Water Quality Control Commission (WQCC)

July 2018
CDPHE, Denver Water, Greenway Foundation, Metro District and other entities enter into MOU agreement

October 2018
First OCCT public meeting held

November 2018
Drinking water, wastewater and watershed technical working groups meet to evaluate impacts of OCCT

2019 Communications
Bill inserts & e-bill: 58,000
TAP Story: 1,021
Social media: TBD
Events: TBD
Direct mail & email campaigns: 2,000
WQ test request: 694
Outreach with elected officials

February 2019
Denver Water begins drafting variance request, develops timeline for submittal and review.

April 2019
Lead Service Line (LSL) Pothole Pilot Program Start

May 2019
Provided Distributor Update

Summer and Fall 2019
- MOU Public Meetings with Stakeholders
- Point of Use (POU) Filter Pilot Program Start
- Meetings with City Council and Denver Department of Public Health and Environment (DDPHE)
- Local Health Department Outreach
- Elected Official Outreach
- Denver Water Distributor Outreach
- Denver Water Citizens Advisory Committee Outreach
- Community and Advocacy Organizations (Health & Environment)
- News Media Outreach
- Public Notice
- Commercial Customers

APPENDIX III.B.1 - INTEGRATED AND CONSECUTIVE SYSTEMS

September 2019

DENVER WATER

Appendix III.B.1: Integrated and consecutive systems

DENVER WATER DISTRIBUTORS

Denver Water provides water to two types of systems: integrated and consecutive. Consecutive systems are entities that receive some of their water supply from Denver Water and blend it with other sources, examples include Broomfield, Inverness and East Cherry Creek Valley. Consecutive Systems are not included in the lead service line inventory because they do not conform to Integrated System requirements defined by Denver Water.

Integrated System Agreements include three distinct types of districts: Master Meter, Read and Bill and Total Service. These districts have a total of over 160,000 service lines with approximately 6,000 pre-1951 taps, which have been included in the lead service line inventory. Additional factors, as spelled out in lead service line inventory section and Appendix III.B.2, may result in more homes being included in the final count of known or suspected lead service lines.

The districts are being included in the identification and verification efforts for the lead service line inventory. These efforts include records review, site surveys, potholing, and water quality sampling. Prior to the execution of Phase II of the Lead Reduction Program Plan, an agreement will be reached with the Integrated Service Agreement districts to comply with the program elements and schedule as outlined in the plan.

READ AND BILL

Read and Bill districts are also integrated systems where the distributor owns and is responsible for construction, operation, maintenance, and replacement of its water system into which Denver Water delivers water. Denver Water reads the meter of each individual customer and bills each individual customer at the established "Read and Bill" rate.

Read & Bill District	***Total***	***< 1951***	***> 1950***
North Lincoln	***248***	40	205
Phillips Petroleum	***4***	0	4
Country Homes Metro	***39***	0	37
South Sheridan	***1111***	0	1109
Alameda	***503***	0	501
Southgate	***11943***	22	11778
Southwest Metro	***14355***	6	14112
Bear Creek	***3201***	0	3161
Platte Canyon	***6095***	11	6031
Suncor	***3***	0	3
Lockheed Martin	***1***	0	1
Colorado DNR	***9***	0	8
Willows	***1131***	0	1127
Totals	***38643***	79	38077
Percentage		***0.20%***	***98.50%***

Based upon available tap date data

TOTAL SERVICE

In Total Service areas, Denver Water owns the water system and is responsible for its operation, maintenance and replacement. Denver Water reads each individual customer's meter and bills each individual customer at the established "Total Service" rate. In Total Service areas, the water service provided to the customers is identical to that provided to customers inside the City and County of Denver.

Total Service District	***Total***	***< 1951***	***> 1950***
Southeast Englewood	***12200***	5	12039
Holly Hills	***803***	1	802
HI-LIN	***259***	4	254
Bennett Bear Creek Farm	***220***	1	213
Fehlmann	***19***	0	19
Sheridan	***1606***	115	1470
Cherry Hills North	***146***	0	146
Mansfield Heights	***181***	1	175
Littleton	***11387***	49	11199
Lloyd King	***10***	0	10
Loretto Heights	***83***	23	58
Columbine	***748***	0	733
Lochmoor	***58***	0	58
Cherry Hills Heights	***52***	4	48
Southwest Plaza Metro	***37***	1	32
Havana	***2442***	0	2394
Southwest Suburban	***2234***	0	2232
Grant	***776***	0	775
Hillcrest	***262***	0	262
Devonshire	***68***	3	65
Panarama Park	***71***	0	61
Galleria Metro	***55***	0	55
Greenwood Village	***269***	14	254
South University Place	***36***	12	24
Cherry Hills Village	***1287***	19	1230
Arapahoe Estates	***282***	0	282
Holly Mutual	***48***	0	47
Colorado Academy	***39***	0	39
Berkeley	***1361***	361	986
Castlewood	***2957***	3	2902
East Cherry Hills Village	***58***	0	57
Totals	***40054***	616	38921
Percentage		***1.50%***	***97.20%***

Based upon available tap date data

MASTER METER

Master Meter districts are integrated systems that are solely supplied by our water through one or several meters, but they set their own rates and maintain their own infrastructure. These systems can reside in municipalities that have several water sources.

Master Meter District	***Total***	***< 1951***	***> 1950***
Con Mutual	***16,249***	213	15902
Wheat Ridge	***6,160***	2065	4053
Edgewater	***1,522***	42	1467
Bow-Mar	***290***	68	222
Alameda	***352***	2	346
Bonvue	***172***	0	172
Cherry Creek Valley	***2,422***	13	2333
Northgate	***11***	6	5
High View	***975***	2	950
Valley	***1,896***	39	1825
South Adams County	***183***	2	179
Lakehurst	***5,756***	4	5713
North Washington	***3,787***	5	3750
Cherry Creek Village	***472***	9	458
Meadowbrook	***1,365***	1	1356
Willowbrook	***3,875***	0	3825
North Pecos	***708***	3	676
Ken-Caryl Ranch	***4,388***	3	4326
Bancroft-Clover	***9,380***	57	9296
Lakewood	***835***	364	459
Green Mountain	***10,375***	17	10319
Crestview	***5,156***	2420	2706
Glendale	***285***	6	271
Willows	***4,746***	0	4746
Totals	**81,360**	5341	75355
Percentage		***6.60%***	***92.60%***

Based upon available tap date data

APPENDIX III.B.2 - PRELIMINARY IDENTIFICATION OF LEAD SERVICE LINES

September 2019

DENVER WATER

MOTT MACDONALD

Technical Memorandum

To Denver Water
From Mott MacDonald
Cc Denver Water, Corona Environmental, and AECOM
Date August 8, 2019
Project No. 507100139

Subject Denver Water Lead Reduction Program
Appendix III.B.2 – Refinement of the Lead Service Line Inventory

I. EXECUTIVE SUMMARY

Based upon additional information and further analysis of the data presented in the Preliminary Identification of Lead Service Lines and other data, a refinement to the service line inventory for the Denver Water service area was completed. The refinement resulted in service lines being removed from inventory and adjustments to the probability of a service line being lead pipe. Results of the refinement to the inventory are:

- 319,700 service lines used for drinking water in the Denver Water service area
- 84,546 service lines identified as known, suspected and possible lead service lines – these premises are candidates for the filter program
    - 63,955 service lines are estimated to be lead services lines – this is the lead service line inventory and the basis for the annual 7.0% ALSLR
    - 20,591 service lines are estimated to be non-lead services lines – these will be investigated and confirmed non-lead

This technical memorandum documents the background, analysis and results of the refinement to the inventory.

II. BACKGROUND

As Denver Water does not own its customers' service lines, an inventory of lead service lines was compiled based upon available data. It should be noted that compiling and analyzing available data sets to develop a service line inventory is an extensive and challenging process. For Denver Water this is compounded by the fact that service line materials were not historically recorded until this past decade and the analysis of available data (dates service lines were tapped to the water main, building dates, parcel dates, water main installation dates, and other data) collected in multiple databases over the past century results in numerous scenarios to determine the probability of lead. Incomplete or missing data and changes to service line replacement policies and procedures over time further complicate these efforts.

The starting point for our analysis is the *Preliminary Identification of Lead Service Lines* prepared by Corona Environmental Consulting dated August 7, 2019 (included as

ATTACHMENT 1). The *Preliminary Identification of Lead Service Lines* includes details on lead service line background, data sources, data preparation and clean-up, results, and next steps. An earlier version of this initial inventory technical memorandum was included in the July 11, 2019 draft submittal. The estimated inventory of service lines in the Denver Water service area developed in the *Preliminary Identification of Lead Service Lines* is shown in Table 1.

Table 1. Preliminary Inventory

	Preliminary Identification of Lead Service Lines	
Service Type	July 11, 2019	August 7, 2019
Known LSL	1,118	926
Suspected LSL	63,597	62,816
Possible LSL	36,533	36,388
Unlikely LSL	83,543	83,312
Not LSL	150,666	152,015
Total Services	335,457	335,457
Lead Service Lines	75,036	72,158

III. METHODOLOGY

Additional detailed records analysis of the *Preliminary Identification of Lead Service Lines* inventory was completed, which resulted in an update to the estimated lead service line inventory. The purpose of this Technical Memorandum is to document the analysis and refinements to the inventory. The framework for the analysis is as follows:

Category A: Service Lines Removed from Inventory

- Re-evaluation of source information
- Resolution of data discrepancies from different record systems

Category B: Adjustment to the Probability of Lead

- Adjustment based on evaluation of baseline data and new data
- Modification of rules due geographic applicability of the logic
- Resolution due to data discrepancies

Category C: Service Lines Excluded from Filter Program

- Inactive accounts
- Vacancies
- Service lines not associated with a parcel
- Water use types

This update documented is through defined accounting procedures and replaces the numbers estimated in the lead service line inventory dated July 11, 2019.

IV. VERSION CONTROL

The starting point for our analysis is the results from the Technical Memorandum titled *Preliminary Identification of Lead Service Lines* prepared by Corona Environmental Consulting dated August 7, 2019 (included as ATTACHMENT 1).

The new analytics applied to the lead service line inventory allotted the necessity to manage tracking of changes for version control and tracking for changes in the inventory. In order to manage changes between version, new rules were added as follows:

Rules for Removing or Updating Records

Two additional fields were added to the lead service line inventory to prevent double-counting of a service line which may be included in multiple categories. The two additional fields include:

1. **lsli_remove_20190802** is a flag if a record is removed (Category A)
   - 1 if removed, 0 if not
2. **lsli_update_20190802** is a flag if a record is updated (Category B)
   - 1 if updated, 0 if not

Updates to the inventory were applied using the two flags in the order as presented herein. The two flags were applied to ensure that a record is only counted for removal or update the first time it is encountered during the sequence of data processing.

V. CATEGORY A: ANALYSIS AND FINDINGS

A review of the source data to develop the lead service line inventory compared to the output identified locations that needed further refinement based on the outcome of the probabilities of lead.

A.1 – Distributor Contracts

In May 2019, a list of Distributor Contracts was annotated by Denver Water (MS Excel file ISA_LSL_Clarification_Final20190507.xlsx) to identify service lines that should be included in the inventory. Denver Water provided data for the initial inventory that included Distributor Contracts noted as "Include in LSL Inventory".

A further analysis was completed to confirm service lines associated with Distribution Contract are captured in the inventory, which is highlighted below.

- *A.1.1 – Raw Water (4,489 removed)*

  A geographic review of the inventory with Denver Water staff identified the inclusion of service lines from North Table Mountain Water and Sanitation District (NTMWSD). Although NTMWSD contract (M169) was listed as "Include in LSL Inventory", it was determined that the NTMWSD contract (M169) is for Raw Water only.

  Denver Water provides the Raw Water distributors with untreated raw water only and Denver Water is not responsible for distribution water quality. The distributor is responsible for treating and delivering the water. Service lines associated with "Raw Water" distributors are not included in the lead service line inventory.

  As such, 4,489 service lines associated with NTMWSD contract (M169) were removed from the inventory.

- *A.1.2 – Emergency Connections (3 removed)*

  A search of records that have Distributor Contracts listed as "Include in LSL Inventory" was completed. The initial inventory included three (3) service lines identified with E000 - Emergency Interconnect.

  In some cases, water is provided to distributors or neighboring cities during emergency scenarios (main break, major fire, etc.) through an emergency connection. Under normal operations, the distributor is responsible for treating and delivering the water. Service lines associated with "Emergency Connection" distributors are not be included in the inventory.

  Three service lines (X34069(6"), 335073 (16"), X25117B (6")) with Distributor Contract E000 were removed from the inventory.

Based upon the above, Denver Water reviewed and confirmed the updated Distributor Contracts noted as "Include in LSL Inventory" (ISA_LSL_Clarification_Update20190723.xlsx).

<u>*A.2 – Service Point Types, Irrigation (3,166 removed)*</u>

Denver Water uses the service point type field to identify the use of water associated with a customer's service line. In some cases, water use defined by service point type is not for drinking. In May 2019, Denver Water identified service point types that should be included in the inventory, which are listed in Table 2.

Table 2. Service Point Types as Selected by Denver Water May 2019

Service Point (SP) Type	SP Type Description	Selected for LSLI
TAP-BHMM	TAP Behind Master Meter	X
TAP-BBYF	TAP Behind Master Meter Bypass Meter Fire Line	
TAP-BCOM	TAP Behind Master Meter Commercial	X
TAP-BFIR	TAP Behind Master Meter Fire Line (non-metered)	
TAP-BIRR	TAP Behind Master Meter Irrigation	X
TAP-BMFM	TAP Behind Master Meter Multi-Family	X
TAP-BRES	TAP Behind Master Meter Residential	X
TAP-BYFL	TAP Bypass Meter Fire Line	
TAP-COM	TAP Commercial	X
TAP-EMCY	TAP Emergency Interconnect	X
TAP-FIRE	TAP Fire Line (non-metered)	
TAP-IRR	TAP Irrigation	X
TAP-MAST	TAP Master Meter	X
TAP-MFM	TAP Multi-Family	X
TAP-RAW	TAP Non-Potable/Raw Water	
TAP-PLAN	TAP Planning	
TAP-QUAL	TAP Quality Control	
TAP-RECY	TAP Recycled Water	
TAP-RES	TAP Residential	X
TAP-TEMP	TAP Temporary	

Further evaluation of service point type records was completed. Multiple service point types may be associated with a single service line.

It was concluded by Denver Water that irrigation services should be excluded from the inventory, as follows:

- service point type = "TAP-IRR" and no other service point types listed; or
- service point type = "TAP-IRR" and all other service point types are also excluded from the inventory, as noted in Table 2.

Irrigation services do not fall into the guidelines of the LRP – their service point type is not for drinking and they should be removed from the inventory.

Denver Water will implement a policy that prevents the reclassification of existing "TAP-IRR" services to a service point type for drinking unless there is confirmation of non-lead service or replacement of the lead service. In addition, COE efforts will be completed to educate on why not to use irrigation for water consumption.

The results of this analysis identified 3,444 service lines as “TAP-IRR”. However, 278 had another service point type that fit the criteria in Table 2 and these service lines should remain in the inventory. The remaining 3,166 service lines were removed from the inventory.

A.3 – Data Reconciliation (8,099 removed)

Denver Water provided data for the initial inventory from multiple sources. The initial inventory did not include data from Denver Water’s internal tap lifecycle status fields. Denver Water uses tap lifecycle status fields to record information on service line tap work completed. However, other departments such as Water Sales routinely use other internal fields, such as additional address fields to add notes about lifecycle status. Based upon a review by Denver Water of these additional tap lifecycle status fields, it was concluded that services lines with a tap lifecycle status indicating “Cancelled Stub-in”; “Cancelled Tap”; “Customer Cancelled”; “Tap Cut”; and “License Change – See New Tap” indicate cut, cancelled, replaced, or non-drinking use water service lines which should be removed from the inventory. Some of these services may have been active once but per Denver Water these service lines currently are not in service. These premises will be flagged by Denver Water to not become active service lines in the future until the service line is confirmed non-lead or a new service is installed. Since tap lifecycle status fields are from different sources, Denver Water developed a list of suspect service lines, falling into the following four broad data fields from the records:

1. *A.3.1 – Resident ID (3,463 removed)* - The field indicated cut, cancelled, or replaced service line.
2. *A.3.2 – Address Line 4 (41 removed)* - The field indicated service line cut, abolished, or fire line.
3. *A.3.3 – Tap Remarks (3,610 removed)* - The field indicated service line cancelled or cut.
4. *A.3.4 – Data Source Combination (3,015 removed)* - The tap lifecycle status and other fields indicated abolished or disconnected.

The Water Sales group within Denver Water will continue to investigate these service lines. This is a manual desktop review of various data sets and it is expected for this to be completed by October 2019. An initial review by Denver Water indicates that approximately 80-90% of the manual reviews confirmed that the service line should be removed from the inventory. At most 10-20% of the service lines identified for removal could be re-added to the inventory. Accordingly, a 20% contingency was applied to account for this possibility, resulting in the inclusion of 2,030 service lines as item A.3.5. However, the best information available at present indicates these service lines should be removed from the inventory.

- *A.3.5 – 20% Readjustment (2,030 added)* – Contingency for re-added service lines.

VI. CATEGORY B: ANALYSIS AND FINDINGS

B.1 – Service Line Replacements (189 adjusted)

Denver Water confirmed that service line replacement work completed after July 2016 was a full replacement (water main to house). As such, service lines with a "Replaced Date" after July 2016 were changed to have a p-value of "0".

B.2 – Manifolds (1,191 adjusted)

A geographic review of the initial inventory identified some recently developed areas having a high probability of lead. Based upon further review of the data in those areas, a "." entry for the "Tap Date" was identified. Denver Water confirmed that service lines with a "." entry for the "Tap Date" indicates that the service line is tracked as part of a manifold. Denver Water provided a list of parent and child service lines. The parent manifold tap date is provided as the "Tap Date" for the child and the p-value has been updated using the logic rules 31-37 as noted in the *Preliminary Identification of Lead Service Lines*.

- *B.2.1 – Manifolds with Tap Date (1,143 adjusted)*
  1,144 service line p-values were updated due to having a "." entry for the "Tap Date".
- *B.2.2 – Manifolds without Tap Date (48 adjusted)*
  48 service lines were updated based on the parcel date alone.

B.3 – Geographic Considerations (Littleton) (3,846 adjusted)

A geographic review of the initial inventory identified some recently developed areas with results having a high probability of lead. Upon further review, the initial inventory of service lines in the Littleton service area were identified as having the same "Tap Date" of 1971. Denver Water's evaluation of this record determined that 1971 was the year Littleton entered into a service agreement with Denver Water and is not reflective of the actual "Tap Year". For this reason, the processing performed for the initial inventory removed this tap year. In lieu of using "Tap Year", the "Parcel Year Built" will be used for Littleton as an indicator of the likelihood of a lead service line using the logic rules 31-37 as noted in the *Preliminary Identification of Lead Service Lines*. In addition, to ensure that re-developed properties that were originally built prior to 1952 were not included in the adjustment, only those service lines with a "GIS Main Install Year" and "GIS Abandoned Main Year" greater than 1951 (if present) were adjusted. Based upon the above, resulting analysis included 3,846 adjustments to p-values.

B.4 – Scrape-Offs (783 adjusted)

A geographic review of the initial inventory identified services in areas under development with high probability of lead, which are known as scrape-offs. Recent aerial photography was utilized to confirm development. Denver Water maintains a database tracking "scrape-offs" in the City and County of Denver as far back as 2013. Starting in July 2016, Denver Water required full-service line replacement (water main to house) for all scrape-offs.

- *B.4.1 – Completed Scrape-Offs (779 adjusted)*
  Service lines located at a post July 2016 scrape-off are considered "non-lead" (p value = 0), resulting in 783 p-value adjustments (779 are completed, 4 are pending). The inclusion in the post-July 2016 scrape-off list takes precedence over the tap date to assign the p-value.
- *B.4.2 – Pending Scrape-Offs (4 adjusted)*
  Pending scrape-offs were only included if there was a one-to-one relationship between the premise ID and the tap number, since the provided list of pending scrape-offs included only a premise ID and not the tap number.

B.5 – Tap and Parcel Year Mismatched (5,045 adjusted)

The initial inventory applied a conservative set of logic rules to analyze the lead service line inventory for conflicting date ranges for "Parcel Built Year" and the "Tap Year". When both the "Parcel Built Year" and the "Tap Year" are after 1951 but one or the other is before 1958, a year mismatch resulted and a p-value of 0.5 was applied according to rule 38 in the *Preliminary Identification of Lead Service Lines*. However, if both the tap year and parcel year are after 1951, the likelihood of lead is very low and should have a similar probability of lead as those service lines subject to rule 34 (where both the parcel year and tap year are between 1952 and 1958) in the *Preliminary Identification of Lead Service Lines*. Like the B.3 adjustment, p-value adjustments were only made to service lines where the "GIS Main Install Year" and "GIS Abandoned Main Year" were both after 1951 to ensure that older redeveloped properties that could have a lead service line are not included in the adjustment. Accordingly, the p-values for the 5,045 service lines with a mismatched tap and parcel year have been updated to "0.03" to reflect the low likelihood of a lead service line.

B.6 – Geographic Considerations (District 11) (59 adjusted)

A geographic review of the initial inventory identified some recently developed areas having a high probability of lead. Development in Denver Council District 11 primarily occurred after 1971, with the construction of Denver International Airport and the redevelopment of the Stapleton area. Based upon further review of the data, several service lines in District 11 were missing a tap year and were therefore categorized with p-value showing possibility of lead. Evaluation of the records with a missing tap year indicates lead is highly unlikely. Due to the inconsistency of this record (tap year) in

District 11, the "Parcel Year Built" field was the primary field used to evaluate the probability of lead resulting in an update to the p-value using the logic rules 31-37 as noted in the *Preliminary Identification of Lead Service Lines*. This analysis caused 59 service lines to have their p-values adjusted (after the previous adjustments). A remaining eight service lines with no parcel year or tap year remain in the dataset due to insufficient records to determine their likelihood of lead. Further record review and investigation will be needed to identify their status in the lead service line inventory.

B.7 – Systems Data Exchange Integration (Default: 01/01/1901 Tap Date) (225 adjusted)

Data processing between systems may have resulted in a date conversion error based on the manner that different systems interpreted field types and null values. During data migration, the date field defaulted to populate cells with no data with 01/01/1901. In conjunction with a Denver Water geographic review of areas that should not have a high probability of lead, fields with 01/01/1901 taps dates were reviewed to verify this date. It was established that the 01/01/1901 date is an error in data transfer. It was concluded that service lines with a "Tap Date" of 01/01/1901 will prioritize the "Parcel Year Built" and "GIS Main Install Year" as the primary fields to determine the probability of lead (p-value) instead of the "Tap Date" field. Based on the evaluation of these records, adjustments to the inventory are as follows:

- *B.7.1 – Parcel and GIS Main After 1972 (62 adjusted)*
- *B.7.2 – Parcel and GIS Main After 1952 (163 adjusted)*

B.8 Distributor Evidence (207 adjusted)

Additional information from the City of Edgewater indicated that some service line replacements were in fact only partial replacements. Information from the provided Excel file "edgewater_Lead_Line_Replacements_2014.xlsx" was used to assign a p-value of "1" to service lines known to have lead material between the meter and the premise while others were assigned p-value "0.5" indicating uncertainty with further investigation required. This analysis resulted in adjustments of the p-value to 207 service lines.

B.9 Potholing Data (20 adjusted)

In 2019, Denver Water began performing field investigations by "potholing" service lines to determine the service material type. The standardization of potholing efforts is evolving, and past work completed may not identify when a service line transitions from one material to another. As a result, pothole information was used to confirm lead and assign a p-value of "1" to 20 service lines. However, determination of a different material resulted in no change to the p-value. In other words, potholing information can confirm a lead service line but is not applied to confirm a non-lead service line. Future investigation will use other available information such as water quality results to better estimate locations with a non-lead service line.

B.10 Water Quality (37 adjusted)

Denver Water has two primary sources of water quality data showing lead levels in the customer's plumbing / service line: Lead and Copper Rule (LCR) compliance testing, and Customer Service (CS) requested testing. The LCR tests involves first draw single liter test results, while CS tests involve a series of three one-liter tests to determine lead levels through the customer's plumbing and service line. Review of the available LCR data from 1997 to the present proved inconclusive as elevated lead levels in the first liter can indicate an issue with customer plumbing (e.g. brass fixtures or lead solder) independent of the presence of a lead service line. Alternatively, the CS data were well-suited to estimating the presence of a lead service line. Using the most recent test at each testing site, a p-value of "0.8" was assigned to all tests where the second or third bottle had a result of 5 μg/L or higher. P-values were only adjusted when the pre-existing p-value was less than 0.8. Like B.9 potholing data, water quality information is not currently being applied to confirm a non-lead service line. This analysis resulted in p-value changes to 37 service lines. Further investigation will be performed to incorporate LCR water quality data, including investigation to determine if water quality testing can be used to identify premises with copper with lead solder.

B.11 Universal Metering (none adjusted)

A universal metering project was completed in 1989-90 and the meter installation worksheets included observations of service line material type. A database from the scanned meter installation worksheets from the universal metering project was completed by Denver Water. Review of these records indicated the following:

- Eight (8) service lines identified as lead, however these lines were already listed in the inventory with a p-value ≥ 0.8.
- 1,127 lines identified as galvanized
  - 183 services have a current p-value <0.5.
- 783 service lines were identified as copper
  - 458 have a p-value >= 0.5.

Since many records have information contradicting other information sources, data from the universal metering program was not used to confirm a non-lead service line at this time. No adjustments were made.

VII. CATEGORY C: ANALYSIS AND FINDINGS

This category consists of identifying service lines that do not directly affect activities related to the Filter Program and/or are a low priority for Accelerated Lead Service Line Replacement (ALSLR). These service lines include those associated with inactive customer accounts, vacant properties, and others that are not used for drinking water.

Service lines identified in Category C will be fully developed by October 2019, prior to the implementation of the Filter Program. These service lines will remain a part of the lead service line inventory and Denver Water will track for future administrative action when the status changes.

C.1 – Inactive Customer Accounts

If there is no water use at a property for an extended period, the service is shut-off at the meter / curb stop and the customer account is considered inactive. A review of the Denver Water customer account status (active/inactive) shows that 3,918 service lines in the lead service line inventory are inactive. On August 7, 2019, the number of inactive service lines is 2,718. Identifying and tracking active/inactive customer service accounts will be integrated into the program. Filters will not be distributed to inactive customer accounts and they will not be prioritized for ALSLR.

C.2 – Vacant Property

Vacant properties were considered for removal when determining the lead service line inventory, as their service lines are not in use. Because service lines may not remain vacant, they are preserved in the lead service line inventory, though filter distribution is not required at vacant properties. Identifying and tracking vacant properties will be integrated into the program. Filters will not be distributed to vacant properties and they will not be prioritized for ALSLR.

C.3 – Service Lines Not Associated with a Parcel

Geographic inspection of some service lines indicates that some service lines do not seem to be associated with a parcel. Denver Water has begun a review of geolocation results and may recommend action based on the results of this analysis. However, no action is taken at present. Reconciling these service lines is expected to be completed by October 2019. Filter distribution may not be required for these service lines if there is no identifiable entity to receive a filter.

C.4 – Fire Lines and Hydrants

Service lines associated with fire lines and hydrants have been flagged for further review. Service lines identified in these categories have not been removed as the evaluation of these service lines has not ruled out splices to properties services or association with other service types on the same service line that are to be included in the inventory. These service lines will be reviewed on a case by case basis for inclusion in the lead service line inventory.

VIII. RESULTS

The *Preliminary Identification of Lead Service Lines* inventory included 335,457 service lines and an estimated 72,158 lead service lines. As part of this analysis,

- Removals documented in category A resulted in an inventory reduction of 15,757 service lines, resulting in a service line total of 319,700.
- The adjustments in category B resulted in revised p-values for 11,602 service lines.
- Based upon the above, the inventory estimate of lead service lines is 63,955.

Table 3 below highlights the service line inventory breakdown from July 11, 2019 to date.

Table 3. Refinement to Inventory - Summary

	Preliminary Identification of Lead Service Lines		Refinement of Inventory
Service Type	July 11, 2019	August 7, 2019	August 8, 2019
Known LSL	1,118	926	1,066
Suspected LSL	63,597	62,816	61,374
Possible LSL	36,533	36,388	22,106
Unlikely LSL	83,543	83,312	89,388
Not LSL	150,666	152,015	145,766
Total Services	335,457	335,457	319,700
Lead Service Lines	75,036	72,158	63,955

Tables 4, 5, 6 & 7 on the following pages provides a detailed breakdown of removals and adjustments to the lead service line inventory.

Service lines identified in Category C will be fully developed by October 2019, prior to the implementation of the Filter Program. These service lines will remain a part of the lead service line inventory and Denver Water will track for future administrative action when the status changes.

Table 4. Refinement to Inventory – Service Lines Removed

Update Description	Refinement to Inventory: Service Lines Removed	Refinement to Inventory: Change in LSLI
A.1) Distributor Contracts - Removed Raw Water / Emergency Connections	-4,492	-391
A.2) Removed Irrigation Only Services	-3,166	-199
A.3) Removed Service Lines with Tap Lifecycle Status = Service Line Cut, Cancelled, Abolished, Replaced, etc.	-8,099	-2,024
	-15,757	-2,614

Table 5. Refinement to Inventory – p-value Adjustments

Update Description	Refinement to Inventory: p-value Adjustments	Refinement to Inventory: Change in LSLI
B.1) Recent Service Line Replacements	189	-106
B.2) Newer Service Lines Have Manifolds: Use Parent Tap Year or Parcel Year Built	1,191	-595
B.3) Littleton Tap Year was 1971: Use Parcel Year Built & Main Install Date	3,846	-1,923
B.4) Scrape-offs	783	-500
B.5) Tap Year and Parcel Year > 1951 Adjusted to p-value <0.5	5,045	-2,523
B.6) District 11 (newer development)	59	-29
B.7) Data Exchange Had 01/01/1901 Tap Date: Use Parcel Year Built & Main Install Date	225	-112
B.8) New Data - City of Edgewater	207	180
B.9) Potholing Data	20	4
B.10) Water Quality Data	37	15
		-5,589

Table 6. Refinement to Inventory – Details Removals and p-value Adjustments

Key
A: removed from LSI, Filters and ALSLR
B: p-value adjustment - remain in LSI, Filters and ALSLR

		p-value	1	0.9	0.8	0.7		0.5	0.05	0.04	0.03	0.02	0.01		0	
			Known	Suspected				Possible	Unlikely						Not lead	Total
		July 31, 2019 Inventory	926	28,417	33,837	562	62,816	36,388	766	637	31,383	46,869	3,657	83,312	152,015	335,457
Distributor Contracts	A.1.1	Raw Water	-	-	-	(1)	(1)	(782)	(1)	(83)	(190)	(753)	-	(1,027)	(2,679)	(4,489)
	A.1.2	Emergency Connections	-	-	-	-	-	-	-	-	-	-	-	-	(3)	(3)
Service Point Types	A.2	Irrigation	-	(17)	(25)	(8)	(50)	(319)	(55)	(15)	(452)	(35)	(1,391)	(1,948)	(849)	(3,166)
Data Reconciliation	A.3.1	Resident ID	(4)	(137)	(114)	(70)	(321)	(1,132)	(54)	(88)	(394)	(134)	(79)	(749)	(1,257)	(3,463)
	A.3.2	Address Line 4	-	(1)	(7)	-	(8)	(6)	-	-	-	(1)	(4)	(5)	(22)	(41)
	A.3.3	Tap Remarks	(4)	(65)	(86)	(46)	(197)	(1,419)	(23)	(22)	(108)	(160)	(46)	(359)	(1,631)	(3,610)
	A.3.4	Data Source Combination	(7)	(252)	(279)	(21)	(552)	(691)	(22)	(8)	(98)	(91)	(110)	(329)	(1,436)	(3,015)
	A.3.5	20% Readjustment	3	91	98	28	217	650	20	24	120	78	48	290	870	2,030
Service Line Replacements	B.1	Service Line Replacements	(18)	(51)	(44)	(1)	(96)	(14)	(3)	-	(24)	(33)	(1)	(61)	189	-
Manifolds	B.2.1	Manifolds with Tap Date	-	-	-	-	-	(1,143)	-	-	635	508	-	1,143	-	-
	B.2.2	Manifolds w/o Tap Date	-	-	-	-	-	(48)	3	-	45	-	-	48	-	-
Geographic Considerations	B.3	Littleton	-	-	-	-	-	(3,846)	1,568	2,131	147	-	-	3,846	-	-
Scrape-Offs	B.4.1	Completed Scrape-Offs	(2)	(226)	(218)	(11)	(455)	(224)	(9)	(2)	(36)	(43)	(8)	(98)	779	-
	B.4.2	Pending Scrape-Offs	-	-	-	-	-	(2)	-	-	(1)	(1)	-	(2)	4	-
Tap and Parcel Year	B.5	Tap and Parcel Year Mismatched	-	-	-	-	-	(5,045)	-	-	5,045	-	-	5,045	-	-
Geographic Considerations	B.6	District 11	-	-	-	-	-	(59)	-	-	-	59	-	59	-	-
Systems Data Exchange Integration	B.7.1	Parcel and GIS Main >= 1972	-	-	-	-	-	(62)	-	-	-	-	62	62	-	-
	B.7.2	Parcel and GIS Main >= 1952	-	-	-	-	-	(163)	-	-	163	-	-	163	-	-
Distributor Evidence	B.8	Distributor Evidence	152	-	-	-	-	55	-	-	-	-	-	-	(207)	-
Potholing Data	B.9	Potholing Data	20	(5)	(10)	-	(15)	(5)	-	-	-	-	-	-	-	-
Water Quality	B.10	Water Quality	-	-	37	(1)	36	(27)	-	-	(1)	(1)	-	(2)	(7)	-
Universal Metering	B.11	Universal Metering Records	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 7. Refinement to Inventory – Lead Service Line Inventory Details

	p-value											
	1	0.9	0.8	0.7	0.5	0.05	0.04	0.03	0.02	0.01	0	Total
Total Service Line Inventory	1,066	27,754	33,189	431	22,106	2,190	2,574	36,234	46,262	2,128	145,766	319,700
	Known	Suspected			Possible	Unlikely					Not lead	Total
	1,066	61,374			22,106	89,388					145,766	319,700
Change from Preliminary Inventory	140	(663)	(648)	(131)	(14,282)	1,424	1,937	4,851	(607)	(1,529)	(6,249)	(15,757)
Updated LSLI*	1,066	24,979	26,553	303	11,054						-	63,955
	Known	Suspected			Possible						Not lead	Total
	1,066	51,835			11,054						-	63,955

* = Total Service Line Inventory X p-value when p-value >= 0.5

ATTACHMENT 1 TO APPENDIX III.B.2:

Preliminary Identification of Lead Service Lines

Date: Revised August 16, 2019
March 21, 2019

To: Denver Water

From: Corona Environmental Consulting, LLC

Background

The purpose of this Technical Memorandum is to present how the estimate of lead service lines (LSLs) was generated. An inventory of LSLs is needed to determine how many and where to deploy point-of-use filters as well as determine how many LSLs must be replaced each year. The inventory is also used in the Lead Exposure Model to compare the effectiveness of the variance versus OCCT of orthophosphate for public health protection.

This estimate of LSLs in Denver Water's integrated system is based on data available from several sources available at each tap. No fieldwork has been performed to verify this effort to date. While the logic has been substantiated, and the mapping results appear to match our expectations, the estimate is only as good as the underlying data. No warranty is expressed or implied that these data are correct. These data represent the best available information.

Data Sources

Data used in this effort were aggregated from multiple sources. Data used are summarized in the following table:

Data	Use	Source
OM Current	Data from the field recorded in CCB, reported to O&M. Includes >=2018. Current service line material	CCB
OM Previous	Data from the field recorded in CCB, reported to O&M. Includes >=2018. Previous service line material	CCB
PBCU SERVICE	Service line material from LCR Sample Sites materials survey	Water Quality
ARG Full/Partial	ARG historical data. Goes up to 2018. Records of full and partial service line replacements.	ARG
Year Built	The year the parcel was developed.	Counties
Year Tapped	Year the tap was made to the main.	CCB
Main Install Date	Year the main was constructed.	ARG
Tap Size	Tap size.	CCB
Service Line Size	Service line size. Lead was rarely used for large diameters.	CCB
Distributor Name	Distributor name.	CCB
Service Area	Service area.	CCB
WQ Count	Number of lead samples at the tap.	Water Quality
WQ Max	Highest concentration of lead at the tap.	Water Quality
WQ Avg	Average concentration of lead at the tap.	Water Quality
Tap Cut Date	Full date of the tap cut.	CCB
Aban Install Date	Date the first time a water main was available to tap.	ARG

Data Preparation and Clean-up

1. File contains 335,457 records of taps that are for active, treated water. Provided by Denver Water GIS on 6/17/2019.
   Read in additional file of service line replacement dates, provided by Denver Water on 7/12/2019. Keep only Tap.Number and Date.Replaced and remove duplicates.
   Files merged into one dataframe by Tap.Number.
2. Created three new fields:
   - "p-value" the probability that the service has some lead materials. For example, a p-value of 0 indicates that tap does not contain lead, and a p-value of 1 indicates that a tap does contain lead. A for the p-values of 0.5, half of them would be expected to contain lead. The p-value will be used to produce a numeric estimate of the total number of LSLs in the Denver Water service area.
   - "Category" the categorical classification of the likelihood of an LSL. This should be used for communicating the results.

- “Basis” which reports what data was used in the p-value and categorical determination. This is used to supplement our knowledge of the estimate.

3. Populate new “CCB.Service.Line.Type” column with “OM_Current” information. Service line material reflected in this field did not always reflect the material from the main to the house, depending on the main install year and service line replacement date.
    a. Populate column with abbreviated service line material. For example: “Copper meter to main, Lead meter to house” becomes “COPPLEAD”
    b. For records with Main Install Date before 2010, change to UNKUNK unless they are lead or galvanized. Complete service line replacement during main installs and replacements was not standard practice at this time.
    c. For records from 2010 to 2016, change to COPPUNK unless they are lead or galvanized. Lines were typically replaced only to the property line during this time period.
    d. For records 2016 and later, change any COPPUNK, UNKUNK, and UNKCOPP to COPPCOPP. Service lines were replaced entirely beginning in 2016.
    e. Repeat steps b-d using Date Replaced. This overrides all previous assignments; the replacement date is considered more accurate.
4. Prioritize distributor provided tap dates when possible. These records are presumed to be more accurate than Denver Water records.
    a. Rename “TappedYear” column “DW_TappedYear”
    b. Create new “TappedYear” column that populates first with “D_ISA_Tapped_Date” then with “DW_TappedYear”
5. Clean up City of Littleton data. 1971 was the year Littleton became part of the integrated system and some data reflects that rather than the actual tap or main install dates. The dates being removed were selected based on large peaks in the number of records on a specific date close to 1971.
    a. Filtered by “DistributorName” for “City of Littleton”. Deleted all “TappedYear” and “TappedDate” with “TappedDate” = 01-01-1971. 4,727 records.
    b. Filtered by “DistributorName” for “City of Littleton”. Deleted all “GISMainInstallYear” and “GISMainInstallDate” with “GISMainInstallDate” = 05-12-1970. 1,821 records.
    c. Filtered by “DistributorName” for “City of Littleton”. Deleted all “GISAbanMainInstallYear” and “GISAbanMainInstallDate” with “GISAbanMainInstallDate” = 05-12-1970. 48 records.

Estimation Procedure

The estimation procedure can be outlined as follows:

- Identify service lines where there is a record of observation (direct evidence) of the service line material
- Service lines installed before 1950 were required to be lead. However, a portion of those LSLs will have been replaced with non-lead materials.
- In 1971, lead was prohibited as a service line material. Services after this date are considered to not contain any lead.
- Services installed between 1950 and 1971 will have a low rate of lead occurrence. Lead had already fallen out of favor for service lines by the time Denver Water allowed use of other materials in mid-1949.
- Denver Water has some records on full and partial replacements that they have made.

- The model is further refined with data from retail areas in the integrated system and other evidence that is available (e.g. water quality tests).

The detailed procedure follows.

Use CCB OM records first because these records are considered the most accurate by Denver Water. These are completed by field workers on leak repairs and line replacements.

1. Filtered by “CCB.Service.Line.Type” for “COPPLEAD”, “LEADLEAD”, “LEADCOPP”, or “LEADUNK”.

p-value	Category	Basis	No. Records
1	Known LSL	Direct Evidence	29

   These records were not considered further in the analysis based on other data. This data field is considered to be known when complete and contains the most reliable records.

2. Filtered by “CCB.Service.Line.Type” for “COPPGALV” and “OM_Previous” to “Lead meter to main, galvanized meter to house”. These are considered to behave as LSL.

p-value	Category	Basis	No. Records
1	Known LSL	Direct Evidence	5

   These records were not considered further in the analysis based on other data. This data field is considered to be known when complete.

3. Filtered by “CCB.Service.Line.Type” for “COPPCOPP”.

p-value	Category	Basis	No. Records
0	Not lead	Direct Evidence	10,189

   These records were not considered further in the analysis based on other data. This data field is considered to be known when complete.

Incorporate the pool of LCR monitoring sites which have had a materials survey.

4. Filtered by “PBCU_SERVICE” for “PB”.

p-value	Category	Basis	No. Records
1	Known LSL	Direct Evidence	142

   These records were not considered further in the analysis based on other data. This data field is considered to be known when complete.

5. Filtered by “PBCU_SERVICE” for “CU”.

p-value	Category	Basis	No. Records
0	Not Lead	Direct Evidence	117

   These records were not considered further in the analysis based on other data. This data field is considered to be known when complete.

Use ARG records next because they are direct evidence, but tend to be not as accurate as CCB records because the recordkeeping shifted from ARG to CCB a few years ago and may be dated.

6. Filtered by "ARG_FullPartial" for "Partial".

p-value	Category	Basis	No. Records
1	Known LSL	Direct Evidence	146

These records were not considered further in the analysis based on other data. This data field is considered to be known when complete, but "CCB.Service.Line.Type" takes precedence. "Full" was not used because the definition of a "full replacement" has changed over time. At times in the past, "full replacement" may have referred to meter to main only.

Incorporate records from retail customers.

7. Filtered by "D_Confirmed_Copper" for "Y". This column was added to the database to reflect results of the ISA survey conducted by Denver Water. Records were assigned "Y" when distributors verified the line was copper based on visual inspection, detailed records, or distributor policies.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	447

8. Filtered by "DistributorContractDesc" for North Washington, City of Edgewater, and Crestview. These distributors have verified that there are no LSLs in their service areas. North Washington and Crestview first installed water service lines in 1954; the lines were required to be copper. In addition, both areas have completed extensive main replacements recently and did not discover lead services. Edgewater completed potholing of all lines and replaced lead lines in 2014.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	9,898

9. Filtered by "DistributorContractDesc" for City of Glendale and "TappedYear">1952. Glendale was incorporated in 1952 and has never allowed LSLs.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	260

10. Filtered by "DistributorContractDesc" for Cherry Creek Valley and "TappedYear">1961. Cherry Creek Valley was formed in 1961 and has never allowed LSLs.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	2,486

11. Filtered by "DistributorContractDesc" for North Pecos and "TappedYear">=1967. North Pecos was formed in the mid-1960s and has used only copper lines.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	463

12. Filtered by "DistributorContractDesc" for Valley Water District and "TappedYear">1957. The District was connected in 1957 and has no known lead.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	1,842

13. Filtered by “DistributorContractDesc” for Southgate Water District and “TappedYear”>1961. Southgate formed in 1961 and all records indicate that lines are copper or poly.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	11,356

14. Filtered by “DistributorContractDesc” for Meadowbrook and Willowbrook and “TappedYear”>=1964. Neither district allowed lead from 1964 forward. DW tap dates on older homes in the area were checked against tap permit records by the Districts and found to be matching.

p-value	Category	Basis	No. Records
0	Not Lead	Distributor Evidence	5,242

Identify service lines first installed after lead was prohibited. Records in this category with a water quality sample result indicative of an LSL is considered to be a positive identification.

15. Filtered by “ParcelYearBuilt” for years 1972 to present and “TappedYear” for years 1972 to present.

p-value	Category	Basis	No. Records
0	Not Lead	Post No Lead	108,676

16. Filtered by “ParcelYearBuilt” & “TappedYear” for years 1951 and earlier. Filtered by for those with 3 or more lead samples. Considered an average lead concentration >=5 ppb conclusive evidence of an LSL.

p-value	Category	Basis	No. Records
1	Known LSL	pre 1952, WQ results	604

To this point, the information used is considered as an inventory. 151,902of the 335,457 services under consideration have been assigned (45%). 926 LSLs, 150,976non-LSLs.

The following steps have two recorded dates <=1951 and 1/2” or 5/8” service line sizes. Services lines in these sizes during this time period are indicative of lead; however, evidence shows that size records are less likely to be updated when lines are replaced.

17. Sort for records with “ParcelYearBuilt” and “TappedYear” <=1951 and “ServiceLineSize” of 1/2 or 5/8.

p-value	Category	Basis	No. Records
0.9	Suspected Lead	5/8 or 1/2 Service, pre 1952	28,329

18. Sort for records with no “ParcelYearBuilt” and “TappedYear” <=1951, “GISAbanMainInstallYear”<=1951 and “ServiceLineSize” of 1/2 or 5/8.

p-value	Category	Basis	No. Records
0.9	Suspected Lead	5/8 or 1/2 Service, pre 1952	13

19. Sort for records with no “ParcelYearBuilt” and “TappedYear” <=1951 , “GISMainInstallYear”<=1951, no “GISAbanMainInstallYear” and “ServiceLineSize” of 1/2 or 5/8.

p-value	Category	Basis	No. Records

0.9	Suspected Lead	5/8 or 1/2 Service, pre 1952	163

20. Sort for records with no “TappedYear” and “ParcelYearBuilt” <=1951 , “GISAbanMainInstallYear”<=1951 and “ServiceLineSize” of 1/2 or 5/8.

p-value	Category	Basis	No. Records
0.9	Suspected Lead	5/8 or 1/2 Service, pre 1952	0

21. Sort for records with no “TappedYear” and “ParcelYearBuilt”<=1951 , “GISMainInstallYear” <=1951, no “GISAbanMainInstallYear” and “ServiceLineSize” of 1/2 or 5/8.

p-value	Category	Basis	No. Records
0.9	Suspected Lead	5/8 or 1/2 Service, pre 1952	4

The following steps have two recorded dates <=1951. Denver Water required lead service lines until 1951 but does not have records of all service line replacements.

22. Filtered by “ParcelYearBuilt” for <=1951, and “TappedYear” for <=1951.

p-value	Category	Basis	No. Records
0.8	Suspected Lead	Build & Tap Date	33,750

23. Filtered by no “ParcelYearBuilt”, “TappedYear” for <=1951, and “GISAbanMainInstallYear” <=1951. The abandoned main install likely reflects the year the service line was installed, given that it is the date of the original main install.

p-value	Category	Basis	No. Records
0.8	Suspected Lead	Build & Tap Date	12

24. Filtered by no “ParcelYearBuilt”, “TappedYear” for <=1951, “GISMainInstallYear” <=1951, and no “GISAbanMainInstallYear”. For records that do not have an abandoned main install date, the main install year is the original install date.

p-value	Category	Basis	No. Records
0.8	Suspected Lead	Build & Tap Date	137

25. Filtered by no “TappedYear”, “ParcelYearBuilt” for <=1951, and “GISAbanMainInstallYear” <=1951.

p-value	Category	Basis	No. Records
0.8	Suspected Lead	Build & Tap Date	4

26. Filtered by no “TappedYear”, “ParcelYearBuilt” for <=1951, “GISMainInstallYear”<=1951, and no “GISAbanMainInstallYear”.

p-value	Category	Basis	No. Records
0.8	Suspected Lead	Build & Tap Date	22

The following steps have two recorded dates >=1972. Unlike the subset included in the inventory, the following records are missing either “ParcelYearBuilt” or “TappedYear” data and are therefore considered to be less certain.

27. Sort for records with no “ParcelYearBuilt” and “TappedYear” >=1972 and “GISAbanMainInstallYear” >= 1972

p-value	Category	Basis	No. Records
0.01	Unlikely Lead	Tap & Main Install Date	72

28. Sort for records with no “ParcelYearBuilt” and “TappedYear” >=1972 and “GISMainInstallYear”>= 1972 with no “GISAbanMainInstallYear”

p-value	Category	Basis	No. Records
0.01	Unlikely Lead	Tap & Main Install Date	3,317

29. Sort for records with no “TappedYear” and “ParcelYearBuilt”>=1972 and “GISAbanMainInstallYear” >= 1972

p-value	Category	Basis	No. Records
0.01	Unlikely Lead	Build & Main Install Date	20

30. Sort for records with no “TappedYear” and “ParcelYearBuilt”>=1972 and “GISMainInstallYear”>= 1972 with no “GISAbanMainInstallYear”

p-value	Category	Basis	No. Records
0.01	Unlikely Lead	Build & Main Install Date	434

The following steps have either “TappedYear” or “ParcelYearBuilt” information. Since fewer data are available, less certainty is applied than in previous steps.

31. Filtered by “TappedYear”<=1951 and no other dates. Later dates in other date categories indicate uncertainty as to when the current service line was installed.

p-value	Category	Basis	No. Records
0.7	Suspected Lead	Tap Date	277

32. Sort for records with “TappedYear”>=1972 and no “ParcelYearBuilt”. An early parcel build date could indicate that a new tap was installed without completely replacing the service line material.

p-value	Category	Basis	No. Records
0.03	Unlikely Lead	Date and Distributor	2,734

33. Filtered by ParcelYearBuilt<=1951 and no other dates. Later dates in other date categories indicate uncertainty as to when the current service line was installed.

p-value	Category	Basis	No. Records
0.7	Suspected Lead	Date and Distributor	323

The following steps work with the records that are between the last required lead year, 1951, and the first no lead year, 1972. During this time, lead was not commonly used. For this analysis, it is divided into two bins, surrounding the year 1958. 1958 was chosen based on the latest build date associated with a known LSL of 1956.

34. Filtered by “ParcelYearBuilt” for >1951 and <=1958, and “TappedYear” for >1951 and <=1958.

p-value	Category	Basis	No. Records
0.03	Unlikely Lead	Build & Tap Date	28,872

35. Filtered by “ParcelYearBuilt” for >1958, and “TappedYear” for >1958.

p-value	Category	Basis	No. Records
0.02	Unlikely Lead	Build & Tap Date	47,286

36. Filtered by “TappedYear” >1951 and <=1958 and no other dates

p-value	Category	Basis	No. Records
0.05	Unlikely Lead	Date and Distributor	237

37. Filtered by “TappedYear” >1958 and no other dates

p-value	Category	Basis	No. Records
0.04	Unlikely Lead	Date and Distributor	680

38. Unassigned records at this point consist of conflicting date ranges between threshold dates.

p-value	Category	Basis	No. Records
0.5	Possible Lead	Build & Tap Date	36,869

Adjust assigned values by removing the large diameters and main replacements.

39. Filter for “ServiceLineSize” & “TapSize” = 3 or 4 inches with an existing p-value > 0.05. Large diameters are rarely lead; however, LSLs up to 4 inches have been found.

p-value	Category	Basis	No. Records
0.05	Unlikely Lead	Build & Tap Date + Size	419

40. Filter for “ServiceLineSize” & “TapSize” >= 3 inches excluding records above.

p-value	Category	Basis	No. Records
0	Not Lead	Size	1,039

41. Filter for “GISMainInstallYear” after 1/1/2016 with p-value >0.5. Denver Water policy requires any LSL found during a main replacement after 1/1/2016 should be replaced to the first fitting in the building. However, Denver Water records and interviews indicate that the policy was not fully employed.
https://www.denverwater.org/project-updates/pipe-replacement

p-value	Category	Basis	No. Records
0.05	Unlikely Lead	Presumed replacement at scrape	133

Results

The results have been mapped by Denver Water GIS and the results are consistent with our expectations based on areas where LSLs are known to occur. The following table summarizes the number of taps in each category:

Service Type	Services
Known LSL	926
Suspected LSL	62,816
Possible LSL	36,388
Unlikely LSL	83,312
Not LSL	152,015

An estimate of the total number of lead service lines can be made by summing of the p-values greater than 0.5. This would indicate 72,158 LSLs in the Denver Water service area. However, it should be noted that the p-values assigned were based on consensus and judgment and not actual data. As the data becomes available, this estimate may be refined.

	Basis	LSLs	Non-LSLs	Total
Census	Direct Evidence	322	10,306	10,628
	Distributor Evidence	0	31,994	31,994
	Post No Lead	0	108,676	108,676
	Pre 1952 + WQ	604	0	604
Estimate	Build & Tap Dates	71,232	110,732	181,964
	Service Size	0	1,458	1,458
	Presumed Replacement	0	133	133
	Totals	**72,158**	**263,299**	**335,457**

Most of the probable LSLs are located in the core Denver Water service area. The Table below summarizes the occurrence of LSLs by service area.

Service Area	LSLs	Total	% LSL
Inside City	61,596	172,499	36%
Littleton	2,413	10,622	23%
SE Englewood	378	11,797	3%
Berkeley	369	1,336	28%
Sheridan	235	1,566	15%
Wheat Ridge	2,409	6,310	38%
South Sheridan	76	1,084	7%
Southgate	26	11,644	0.2%
Holly Hills	51	853	0.6%

Next Steps

Denver Water is currently undertaking a field verification effort of potholing as many service lines as possible. These will be used to verify the logic used in the development. This will also supplement existing data to be able to base p-values on actual occurrence data. The estimate will continue to improve as data begins to come in when the ALSLR program begins. Denver Water also continues to refine methods in being able to identify service lines from water quality sampling.

The full-scale lead service line replacement program will include an identification component consisting of a combination of replacement, water quality testing, potholing, and potentially other technologies. Also, customers will be asked to help in identifying lead services lines by providing proof of replacement, pictures of the first fitting in the house, and requesting a lead sample kit.

APPENDIX III.B.3 - PREDICTIVE MODEL AND PRIORITIZATION

September 2019

DENVER WATER

AECOM
1600 S Quebec Street
Greenwood Village, CO 80111
aecom.com

Project name: Accelerated Lead Service Line Replacement Plan

To: Denver Water

Project ref: Denver Water Lead Reduction Plan

From: AECOM

CC:

Date:
August 20, 2019

Appendix III.B.3 Predictive Model and Prioritization

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Acronyms

p-value	Predictive Model Probability of Lead Score
ACR	American Census Record
ALSLR	Accelerated Lead Service Line Replacement
CDPHE	Colorado Department of Public Health and Environment
COE Program	Communications, Outreach, and Education Program
EPA	Environmental Protection Agency
LRP	Lead Reduction Plan
LRP Plan	Lead Reduction Program Plan
O&M	Operation and Maintenance
PPB	Parts Per Billion
RF	Random Forest
WM	Water main

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Background and Purpose

The Lead Reduction Program Plan (LRP Plan) is supported by an Accelerated Lead Service Line Replacement (ALSLR) Program (see Appendix III.D). Properties with known and suspected lead service lines are enrolled in the ALSLR Program and Denver Water will replace the service lines within its service area (including distributor areas) within 15 years of the approved variance.

The ALSLR Plan details the process and resource estimates to replace the estimated 63,955 lead service lines at a minimum cumulative program year average replacement rate of 7.0%. Of interest is the number of total lead services estimated in the Denver Water service area: not only will this serve as the basis for the target for annual replacements, but it also serves as the basis for developing the ALSLR Plan. To efficiently identify the number of lead services that exist in the Denver Water service area, a predictive model will be used with the lead service line inventory to strategically perform explorations.

This technical memorandum (TM) describes the development of the predictive model. The predictive model will be used to generalize the results of explorations completed to date and to guide subsequent explorations in the future, without having to undertake an excavation at every property. Once developed, the predictive model will be applied to the Denver Water Lead Service Line Inventory to prioritize enrollment in the Filter Program and prioritize the replacement of lead service lines. The TM defines data sources used to populate the predictive model and its application toward prioritization regarding those efforts.

Predictive Model Implementation

Introduction

Denver Water's lead service line Inventory was developed to identify lead service line within Denver Water's service area and surrounding communities (see Appendix III.B.2, Preliminary Identification of Lead Service Lines). A set of logic rules was applied to the data to sort service lines into groups based on the estimated probability that a lead service line is present. The probability represents the uncertainty in our knowledge of the service line material and is captured as a "p-value" that is assigned based on known construction practices, historical records, expert judgement, and data interpretation. The inventory assigns a p-value score to each property to guide Filter Program enrollment, service line material exploration, and lead service line replacement. The p-value score ranges from 0 to 1, with 0 being a known non-lead service and 1 being a known lead service line in the service line. The service connections are grouped into classes of likelihood based on p-value. Table 1 (Estimate of Service Materials Based on Probabilities of Lead) shows the estimated number of services in each class. The inventory currently contains a preliminary estimate of approximately 319,700 records and will be updated to incorporate additional information periodically.

Table III.B.3-1. Estimate of Services Based on Probabilities of Lead

Probability of Finding a Lead Service	p-Value	Estimated Number of Services
Known lead service line	p = 1	1,066
Suspected lead service line	0.8 ≤ p < 1	61,374
Possible lead service line	0.5 ≤ p < 0.8	22,106
Unlikely lead service line	0.01 ≤ p ≤ 0.05	89,388
Non-lead service line	p = 0	145,766
Numbers in the table are provisional, subject **to change will be updated by the August submission**		

The existing inventory (see Appendix III.B.2, Preliminary Identification of Lead Service Lines) was constructed based on data available from several sources. It includes apartments, schools and businesses. To date, some fieldwork has been performed to gain a better understanding of the estimated number of lead service lines. As additional data become available for a property, the p-value score for properties with similar characteristics will be adjusted accordingly to reflect the inventory updates. Enhancements to the inventory and predictive model are underway to support enrollment in the Filter Program and implementation of the ALSLR.

Using the Lead Service Inventory to Build the Predictive Model

A predictive model will be used throughout the ALSLR Program to take advantage of results from field investigation of service line type or service line material and service line replacements to better estimate the materials expected. This data-driven approach will permit the estimation of the possible presence of an lead service line based on observed property and other common characteristics. The recommended approach involves the use of a machine learning model known as a random forest (RF) (Breiman, 2001).

The RF can be set to include existing rules and has the capacity to generate new rules based on the discovery of relationships between input and output variables. In addition, this approach offers the means to audit and explain the decision-making process. Finally, the model can be used to address data inconsistencies, handling data measurements on a variety of scales, and categorical data.

The model will be used to build on the current lead service line inventory based on learning from the results of completed work. The model will make use of the results of field lead service line data collection indicating service line composition found, as well as potholing data collected to verify presence/absence of lead service lines in areas not participating in the ALSLRP. This data driven approach will permit the estimation of “p-value” scores based on observed direct evidence findings and other common characteristics incorporated into the model. These will include tap data as derived for the initial lead service line inventory (year installed, etc.) as well as possible additional variables (sewer age, median income levels, etc.). The model calibration and investigation of service line type or service line material process will identify variables that contribute significantly to the accurate identification of lead service line.

The RF model uses an ensemble of individual decision trees to assign a decision and a probability to observations. A simple decision tree is shown in **Figure III**.B.1 **Decision Tree Example**.

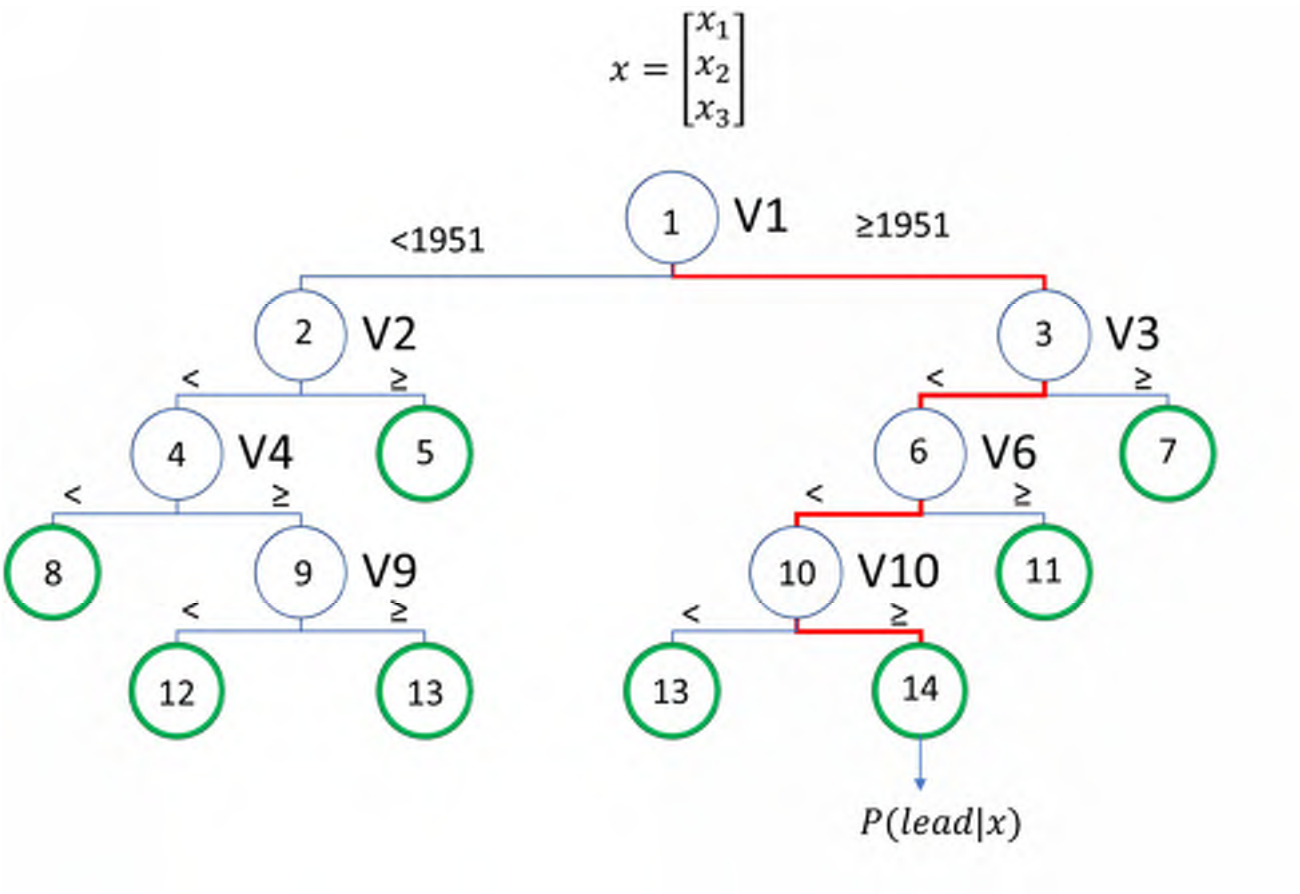


Figure III.B.1 Decision Tree Example

Figure III.B.1 **Decision Tree Example** has four layers of decision processing. The branching node labeled as 1 is where all properties enter the tree and are split according to a characteristic variable (V1). This variable could represent the tap year with the threshold of 1951 representing the year prior to which service lines are most likely lead (the algorithm uses statistical methods to decide on the variables and thresholds to be used). In this example, properties will be split to node 2 or 3 based on the year and a probability of lead being present assigned based on this variable alone. If this split perfectly distinguished lead services from non-lead services in the data, we could stop there, but this will not be the case. The next layer of decisions at nodes 2 and 3 will use two additional variables (V2 and V3) to further split the property services, such as tap size, and assign probabilities for the presence of lead at the child nodes. This process continues using different thresholds of different variables until the algorithm decides to terminate the branching process. These terminal nodes (known as leaf nodes, in green) contain all the property services. Each leaf node classifies the services that fall into it based on the suite of variables expressed in the rules necessary to reach it. A prediction for a property service based on this tree simply considers all relevant variables starting at node 1 and splits through each node until it lands in a leaf node.

The RF algorithm uses many individual trees (as described above) that are randomized both in terms of the data sampled for training (known as "Bagging" (Breiman 1996) and the variables used at each split in the decision tree. Each tree provides a prediction that are on average close to the true mean (low bias), but inherently noisy and sensitive to changes in the data (high variance). When the "forest" of many low bias and high variance trees are averaged for the final model, each tree contributes a vote, thereby reducing the variance and retaining a low bias (Hastie et al. 2009:588). Figure III.B.2 shows a schematic representation of how the ensemble method works. This example shows individual trees (1 through b), which can number as computer resources allow, although there is a point of dimensioning returns.

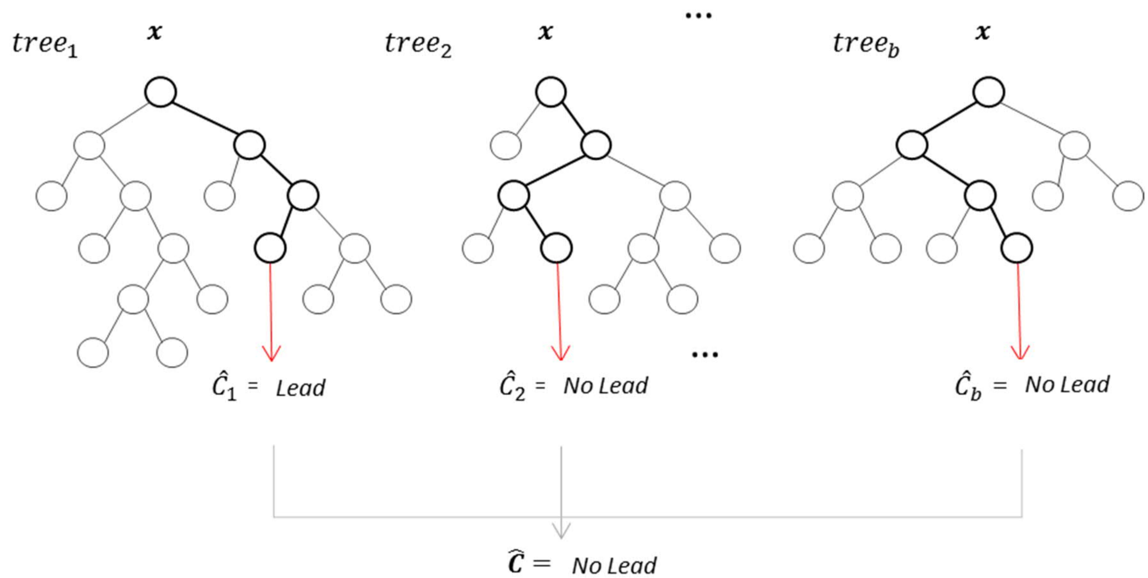


Figure III.B.2 Schematic of Prediction Based on a Decision Tree Ensemble

As a new property observation (x) is sent though each tree, it is split at each node according to the splitting criterion established when the tree was fit to field inspection data that is essential for project delivery. This follows the track of the bolded branches and nodes depicted in **Figure III**.B.2 **Schematic of Prediction Based on a Decision Tree Ensemble**. Even though the property data x are the same, each tree sends it along a different path because each tree was built with a randomized sample and randomly selected variables at each node. For each tree, the property is split until it reaches a leaf node and its service is then assigned a classification and probability. This can be represented as $\hat{C}_b(x)$ where C-hat is the predicted class of x for the b^{th} tree.

The final prediction, represented as $\hat{C}_{rf}^{B}(x)$, is simply the class that the majority of trees agree on, in this case two out of three trees predicted that x is not lead. The algorithm also provides a final probability that property x service line is lead, expressed as $P\left(\hat{C}_{rf}^{B} \mid x\right)$.

An algorithm incorporating the RF model based on decision trees was selected because it is a natural extension of the decision logic developed for the initial lead service line inventory. Further, there is a precedent for incorporating RF as part of lead service line models as discussed by Abernethy et al. (2018), Chojnacki et al. (2017), and Goovaerts (2019) for Flint, Michigan; Gurewitsch (2019) for Pittsburgh, Pennsylvania; and Ardila et al. (2016) for Chicago, Illinois. The approach has the capacity to give priority to existing classification rules, to generate new rules based on the discovery of relationships between input and output variables, and weight specific observations. Furthermore, this approach offers the means to audit and explain the decision-making process through machine learning explanation tools (Biecek and Burzykowski 2019). Finally, is robust to data on different scales of measurements as well as categorical data.

The RF algorithm is a non-parametric tree-based estimator focused on reducing prediction variance through the use of randomization (bagging) and the majority-votes principle of an ensemble (Breiman 1996).; as discussed in the text above. The assumptions of this approach are like other parametric and non-parametric classification models. Namely that the input data consist of a set of observed outcomes in specific classes and a series of variables that lend to the discrimination of the observed classes. It is assumed that the observed classes are *exchangeable*, meaning that the reordering of each observation does not change the outcome (i.e. the data do not represent a time series or possess some other inherent ordering). It is also assumed the explanatory variables are not highly correlated, however RF is less affected by this property compared to other models. Finally, for the purposes of model diagnostics and scoring, it is assumed that the model residuals are normally distributed (violations of this assumptions can be verified, and appropriate action taken to control for this). It is acknowledged that spatial correlation will lead to bias in the assumptions of exchangeability and residual distribution. For these reasons' additional steps for spatially valid cross-validation and neighborhood random effects are being explored.

Model Updates

The model enhancements will change the approach from inventory to prediction, based on field validated results. The predictive model will support decisions regarding the location of future construction activities, will provide support for long-term strategies to maintain the 7.0% target for lead service line replacements, and will be referenced by the Communications, Outreach, and Education Program (COE Program). This will be completed by transforming estimates of the presence of lead service lines into actionable items and developing a better understanding of the likelihood (or not) of finding a lead service line.

The predictive model will support Denver Water's annual ALSLR Plan by allowing Denver Water to focus efforts on the areas with a higher likelihood of lead. It will also be used by Denver Water to determine where additional investigation of service line type or service line material activities are needed, particularly at properties enrolled in the Filter Program (i.e., possible lead service). It is anticipated that this model will be updated when field results are available from the previous year's activities. Both the model data inputs, the model itself, and the output property lead service line probabilities will be assessed after each update to support the development and prioritization of construction work areas. It is currently projected that the model will be run twice a year to include probability and consequence updates to support enrollment in the Filter Program and construction sequencing of the ALSLR Program.

Model Performance Analysis

Model performance assessment involves several approaches and metrics. The area under the receiver operator characteristic (ROC) curve is computed. The area under the curve (AUC) is a measure of the probability that the model will assign a higher probability to a randomly selected lead tap versus a randomly selected non-lead tap. A value of 50% means the model is no better than random guessing. Residuals (errors between predictions and outcomes) also can be examined for patterns. Additionally, several metrics capturing different aspects of classification accuracy can be computed for different threshold p-values. These include: sensitivity (true positive rate, i.e. the fraction of lead taps correctly identified); specificity (fraction of non-lead taps correctly identified); accuracy (fraction of positives and negatives together correctly identified over all taps); precision (the fraction of predicted positive taps that turn out to be positive); F1 score (the harmonic mean between precision and sensitivity); and the false negative rate (fraction of lead taps predicted to be non-lead) among others.

In addition to model performance metric, structural aspects of the model and data will be considered. Independent variables will be examined for the strength of their contribution to the p-value. This can include an assessment of the loss in predictive capability when a variable of interest is resampled randomly (i.e. its value is selected randomly from existing values), and plots of p-values as a function of the value of a particular variable (all others held constant). These methods allow one to simplify the model or otherwise take into account information in the data. For example, identification of correlations between independent variables can be useful to model development.

Prioritization

Properties with a known, suspected or possible lead service will be prioritized for i) Filter Program enrollment and ii) ALSLR implementation. The results of the prioritization analysis will be used to identify areas having the greater potential to benefit from the ALSLR Plan while considering logistical needs.

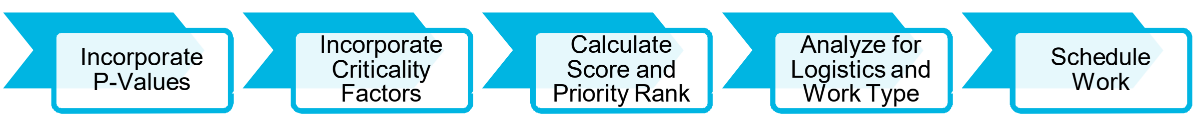
Prioritization involves developing a risk-based approach for long-term construction activity planning that accounts for impacts to public health, equity and environmental justice as well as logistical issues related to other planned capital improvements. The prioritization evaluation will be completed by integrating the p-value from the lead service line Inventory with a measure of consequence.

There are three primary factors that are used to develop a prioritization. These include i) a probability of having a lead service, ii) considerations that affect the consequence of lead exposure, and iii) logistical constraints that need evaluation to turn planning into work activities. Each of these individual components are incorporated into an analytical process for evaluation.

The analytical process consists of gathering the datasets from the respective sources and compiling them into a Geographic Information Systems (GIS) centric environment. Once all the datasets are obtained, they are combined with the lead service line inventory data to create one source of information. The information is then used to calculate the resulting likelihood and criticality scores which are computed from each individual service line location represented in the lead service line inventory. Upon completion of the individual risk calculations, the scores are totalized to the census tract area for normalization analysis

the results of this analysis are incorporated into a multistep process that incorporates logistical constraints and then be administered for construction activities as shown in Figure III.B.3-3 (Prioritization Process).

Figure III.B.3-3. Prioritization Process



Prioritization and Confirming a Lead Service

Under the current Lead Service Line Inventory, properties with known, suspected or possible Lead Service Lines will be included in the Filter Program and be placed in the ALSLR Program. In order to implement the ALSLR Program prioritized sets of actionable properties must be extracted from the Lead Service Line Inventory based on risk and placed into contracting groups (see below and in Appendix III.D.1). Actions taken on properties within these groups will be based on the group type and their lead service lines status. These are presented in Table III.B.3-2 (Lead Service Line Status Cohorts and Actions).

Table III.B.3-2 Service Line Category and Actions

Group	Service Line Category	ACTION AND RESPONSES		
		Filter Program	Lead Inventory	ALSLR Program
A	Known lead service line	Provide Filter	Add to lead inventory as confirmed lead	1. Add to list for replacement 2. Remove from inventory / Filter Program through replacement
B**	Suspected and possible lead service line	Provide Filter	Confirm materials (per Table III.D-6)	1. Add to list for replacement 2. Remove from inventory / Filter Program through replacement
C	Unlikely lead service line	Desk-top review / COE as necessary. Review predictive model output regularly for change in service line material assumption		
D	Confirmed to be lead-free	COE Program		
E***	Other (fire lines, recycled water taps, consecutive system)	No Action / COE Program		

*Table was developed using information in Appendix III.B.2 (Preliminary Identification of Lead Service Lines).

**Water Quality sampling will be limited to clusters or groups of properties in Group B.

*** Inclusion in Group E is based on application process, not likelihood of lead. Service lines will be maintained in the inventory, should the application change in the future. Provide COE that indicates the water supply is not a suitable source of drinking water.

The preliminary set of service line category and actions shown in Table III.B.3-2 (Service Line Category and Actions) are based on the current lead service line inventory predictions. This approach is conservative in the sense that properties with a possible lead service line status are included in the Filter Program. The predictive model that is under development will reduce this uncertainty and refine the inventory lead service line status and allow for refinement of the target properties over time.

Revisions to the inventory lead service line status based on future updates and learning by doing will allow action levels to be refined as needed to assess the estimated number of lead services and how this is reported.

Properties classed as having a known or suspected lead service will be visited and subject to an investigation with the lead service replacement performed as necessary. Properties identified as possible lead service lines will be investigated by either water quality sampling, and/or potholing as necessary (in that order) to confirm service line material. Those properties found to have a lead service will have it replaced. Properties confirmed to have no lead will be taken off the Filter Program. Properties unlikely to have a lead service will be given a record review, customer outreach and or visual inspections, water quality as necessary (in that order) to confirm service line material. The results of these investigations will provide data to verify the results of the model and improve its predictive power.

Probability Factors

The probability of the presence of a lead service is determined primarily through the lead service line inventory p-values (see Appendix III.B.2, Preliminary Identification of Lead Service Lines), and through the predictive model p-values in future updates. Subsequent actions can be taken to revise these numbers. These include:

- Digging or potholing
- Water quality sampling
- Visual inspections (by field crews)
- Customer outreach
- Additional and/or more detailed records review

Digging and potholing is considered definitive confirmation of service line material. The validity of the remaining methods in assigning service line status will be evaluated as part of the ALSLR, and where appropriate such information integrated into the predictive model.

Criticality Factors

The criticality factors are used to describe the potential impact of lead exposure, based on features unique to a property such as water quality sampling results or the demographics of the occupants. These factors are selected to consider the health consequences of lead exposure in the larger context of health equity and environmental justice (HE&EJ).

The consequence of lead exposure provides a priority categorization separate from the likelihood of lead. It provides additional justification for selecting work locations on a yearly basis. Each property of the Lead Service Line Inventory will be evaluated based on health impacts of lead exposure, equity and environmental justice. Criticality factors associated with each property will be identified and weighted. The criticality factors and weights can be defined by analysis tools and/or stakeholder consensus agreement. The process to develop the criticality score is presented in Figure III.B.3- 4 (Criticality Weighting Process).

Figure III.B.3-4 Criticality Weighting Process

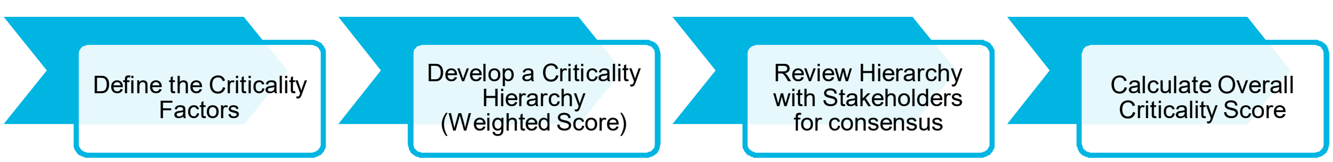


Table III.B.3-3 A list of proposed criticality factors and their weights developed in consultation with EPA and CDPHE presented in Table III.B.3-3 (Proposed Criticality Factors and Weighting). Each factor's values are expressed as a score on a scale of zero (0) to one (1) and a weighted combination computed as shown below. Values for factors will be determined based on the best available data. In some cases, estimates will need to be substituted for missing values (e.g. using an average age for a missing age attribute).

Table III.B.3-3 Proposed Criticality Factors and Weightings

Criticality Factor* (Cf)	Description	Criticality Co-efficient*	Criticality Weight*(%) (Cw)
Public Health Consideration	Odds Ratio (OR) Contours from the Spatial Confounder-Adjusted Spatial Risk Model (Berg, et al, 2017)	Spatial risk odds ratio for elevated childhood blood lead level	0.2
Filter Adoption Rate**	Areas where filter adoption is low.	Non-successful filter adoption X 1) / total number of customers per area	0
Critical Customers	Day care centers child care providers, schools, dialysis centers, formula fed infants	Count of critical customers	0.3
Age (Census Data)	Children	Population estimates of children under 5 years of age	0.4
	Expecting Families	Population estimates of existing families within XX-XX years of age***	
Socio-Economic Factors	Probability of being below the Federal Poverty Level	Population estimates of Residences that fall under the defined federal poverty level	0.1
	Median Income Level	Weighted Income Distribution	
		Criticality Weight Total:	1

* List of criticality weightings currently in use changes shall be based on learn by doing or coordination with CDPHE and EPA.

** To be incorporated in future model iterations

*** Based on available data from the 2010, 2013-2017 ACS data that encompasses medically derived age bearing years. Considerations from CDPHE and EPA are recommended.

The Odds Ratio from the Spatial Confounder data was converted to a score of zero (0) to one (1), with a ratio of 1 set to 0.5 (see Equation 1, where OR is the odds ratio). In addition, a default value of 0.5 was set for locations that were within the extent of the odds ratio data.

Equation 1 Odds Ratio Score Rescaling

$$\begin{Bmatrix} OR < 1 & \sqrt{\frac{OR}{\max(OR)}} + mult1 * \left(\frac{\sqrt{\frac{OR}{\max(OR)}}}{\sqrt{\frac{1}{\max(OR)}}} \right) \\ OR \geq 1 & \sqrt{\frac{OR}{\max(OR)}} + \frac{mult1}{mult2} * \left(1 - \sqrt{\frac{OR}{\max(OR)}} \right) \end{Bmatrix}$$

$$mult1 = 0.5 - \sqrt{\frac{1}{\max(OR)}}, \qquad mult2 = 1 - \sqrt{\frac{1}{\max(OR)}}$$

Other factors' values were split into five (5) groups using Jenks natural breaks, and a score assigned to each group (0, 0.2, 0.5, 0.8 and 1). With all criticality factors scored on a scale of zero (0) to one (1), the weighted criticality score (between 0 and 1) is calculated as follows:

Equation 2 Consequence of Lead

$$F_{LSL_C} = Tap\ Prioritization\ Ranking\ Value$$

$$F_{LSL_C} = (Cw1 * Cf1) + (Cw2 * Cf2) + (Cw3 * Cf3) \ldots$$

The list of criticality factors has gone through an analysis to evaluate the data usage and their alignment with HE&EJ and program goals. Each one of the criticality factors was given different weights and run through the prioritization model to better understand the sensitivity of the criticality factor as it relates to output and the performance to meet the objectives of the LRP Program. This sensitivity analysis showed how adjustments to weights affected the outcome to guide the factors considered and their preferred weightings. For example, the dataset that included an older population category was removed to focus on customers more vulnerable to lead exposure. In coordination with CDPHE, review of the criticality model indicated that additional information, such as data from women, infant, and children (WIC), is most beneficial for inclusion as critical customers. The current weights as shown in Table III.B.3-3 (Proposed Criticality Factors and Weighting) were chosen to ensure the risk score is in alignment with HE&EJ and program goals and will continue to evolve in coordination with CDPHE and EPA.

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Risk Factors

Once the individual likelihood (probability of lead, p-value) and criticality scores are generated for each property, a risk score is then calculated for the property to establish the individual risk score (Equation 3 Individual Risk Score).

Equation 3 Individual Risk Score

$$Risk = Probability\ of\ lead\ x\ Criticality\ of\ lead$$

Individual risk scores are totalized to a common spatial boundary (i.e., the 2010, 2013-2017 Census Neighborhood Blocks / American Census Survey records (ACS)) to establish an overall risk score. The result of this is the aggregate risk over an area that is normalized to take into account density by summing over parcels with taps and dividing by the area of parcels with taps in each census area. (Equation 4 Normalized Risk Score).

Equation 4 Normalized Risk Score

$$Normalized\ Risk = \frac{\sum(Probability\ of\ lead\ x\ Criticality\ of\ lead)\ for\ parcels\ with\ tap}{\sum Area\ of\ Parcels\ with\ Tap}$$

This process allows for the control of differences in area/size between spatial units (larger areas tend to have more taps, while at the same time some areas have significant open spaces with no taps). The result of this analysis is that individual and accumulated risk scores can be assigned to a spatial feature based on occupied area rather than total area. Additional issues can then be considered in the prioritization process, including logistics and ALSLR contracting work development.

Using Risk Scores to Prioritize Construction and Filter Distribution

The process used for establishing priority ranked activities is based on the results of the probability and consequence evaluations. The goal is to take the risk scores from all the (census) areas and look at replacing lead services in a way that addresses both the (high) risk of lead exposure at a property and the efficiency of working through an area of properties to consider the risk to a broader portion of the community. This is considered a geographical construction area. Additionally, locations that are high risk that are not incorporated in a census area for production are also evaluated for sequence of constructions as part of individual construction activities. As a result, lead service replacements may be completed on an individual basis or as part of a larger grouping of properties.

Both the prioritization risk scores that are established for individual locations and grouped together in the Census survey areas are used to produce lists where both the greatest probability and the greatest consequence is considered. An example of how the individual and combined scores (from Equations 2 and 3) will be applied is described in Table III.B.3-4 (Applying Risk Scores for Prioritization).

Table III.B.3-4 Applying Risk Scores for Prioritization

Risk Score Types	Description
Individual	Individual scores are considered for properties defined as high consequence but are geographically isolated.
Geographic Area	Combined scores are considered for properties where the categories of known and possible lead scores define an area.

Evaluation of the two types of risk scores is the basis to prioritize i) enrollment in the Filter Program, ii) sequencing the ALSLR Program contracting needs, and iii) communication efforts. Additionally, the output from this analysis shows where additional investigative efforts are needed to drive the LRP and sustain the year-over-year annual targets for the number of lead service line replacements. As described above, all properties in a high-risk contractor group derived using census areas will be investigated.

The Predictive Model and Coordination with Other Capital Programs

The results from the predictive model in terms of prioritizing lead service line replacements will be evaluated with other activities within the Denver Water service area for scheduling and coordination of construction. Other considerations (mobilization, street repair, scheduled water main replacement, etc.) are necessary scheduling components to minimize repeat visits to the same street or block and to efficiently complete the necessary lead service line replacements. The logistical considerations (see Table III.B.3-5, Predictive Model and Coordination with Other Capital Programs) will influence the development of construction activities. Additionally, information related to current customers will be identified to ensure that work is performed at connected services.

Table III.B.3-5 Predictive Model and Coordination with Other Capital Programs

Coordination Item*	Description
Previously Completed Partial Replacements (where some portion of the service line is still lead)	Public to curb box previously completed; follow-up work outside of the full replacements
Water Main Replacement Program Schedule	ALSLR based on scheduled water main replacements
Long-term Roadway Full Depth Resurfacing Plan	Full depth or resurfacing roadway projects in areas susceptible to lead services
Leak Repairs and Operation and Maintenance Activities	ALSLR based on a response to reported leaks or necessary maintenance
Redevelopment Properties	City of Denver Development in areas susceptible to lead services
Archeological / Cultural / Historic Areas / Locations	Identification of areas requiring more sensitive construction coordination and approval
Property Type (Single Family Commercial / Industrial / Multi-dwelling units)	Building inventory of data regarding residential, commercial, and industrial units
Active Water Account	Identifies taps that have service agreements
Property Status	Identification of property status (occupied, abandoned, etc.)

Implementing the Predictive Model Outcomes

Upon completion of the analysis phase, information for i) individual and grouped risk scores and ii) logistical considerations that exist within the Denver Water service area will be available to support the annual planning cycle for the LRP. The next step is to apply the results to the Filter Program and ALSLR Program.

Filter Distribution Prioritization

Filter distribution will target the properties with a known, suspected, or possible lead service line under the current lead service line inventory. The predictive model will be used to identify the risk category for each census area to allow a sequence of distribution of the Filter Program based on starting at the highest risk areas and working down in priority.

ALSLR Prioritization

The process used to develop the ALSLR Program construction sequence is presented in Figure III.B.3-5 (The Role of the Prioritization Analysis for Annual Updates to the ALSLR Plan). This is based on taking the results from the predictive model and prioritization analysis to establish the annual ALSLR work activities.

Figure III.B.3-5 The Role of the Prioritization Analysis for Annual Updates to the ALSLR Plan

The predicative model and consequence data will be used to identify candidate properties for the different ALSLR contracting groups presented in Appendix III.D.1 (see Table III.D.8 Contracting Groups Summary). The contracting groups include:

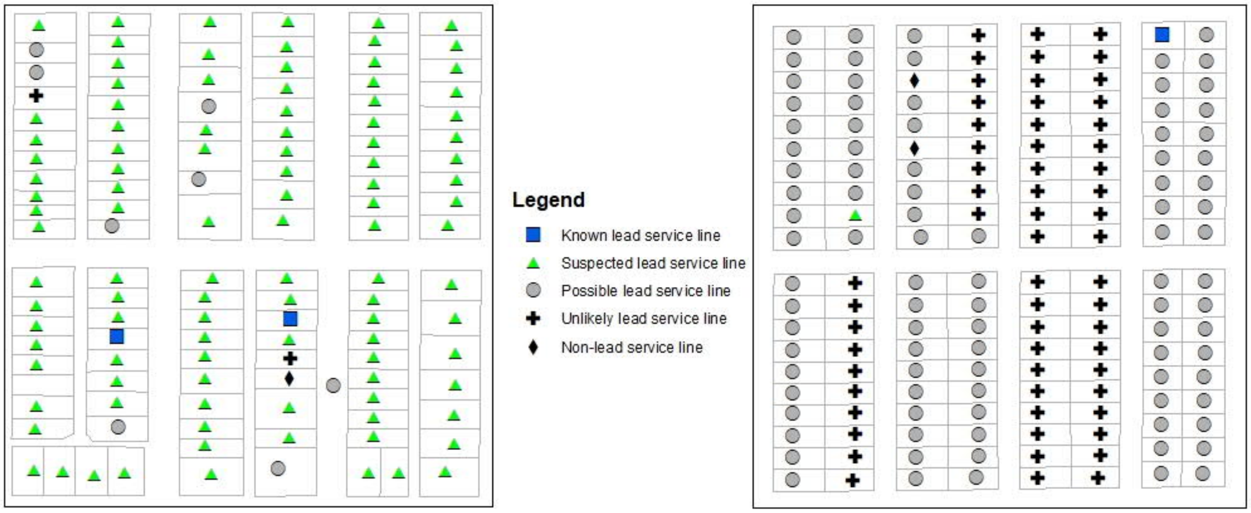
- Group A – Geographic Area ALSLR Type
- Group A – Individual ALSLR Type
- Group B – Investigation

The risk scores developed from the prioritization analysis will be used to further define the groups and sub-group categories that will comprise the yearly work plan.

Group A - Geographic Area ALSLR Work Type

The list of properties with a known lead service included in Group A – Geographic Area ALSLR will be generated from the output of the prioritization risk analysis. Grouped risk score areas will be reviewed to identify the highest priority areas for inclusion in the annual ALSR Program's scope of work. The properties associated with the identified areas will be collectively issued to contractors for replacement of lead service lines on blocks or streets as needed. Figure III.B.3- 4 (Geographic and Individual Area Visual Representation) shows an example of an area selected for the ALSLR Program. In this example, the results of normalized risk (Equation 3) were used to identify the work area. This geographical area shown below would hypothetically receive a high priority ranking and would incorporate all the properties within the boundary for the contract in accordance with the yearly construction goals. As described above, all properties in this group will be investigated using progressively more invasive methods based on p-values.

Figure III.B.3- 4 Geographic Area (left) and Individual Map (right) Visual Representation



Group A – Individual ALSLR Work Type

The properties with a known lead service included in Group A – Individual ALSLR are properties that were individually prioritized as "high" but are not in close enough proximity (geographically) for inclusion in the geographic lead service line replacement areas. This ASLR contracting strategy takes into consideration where critical properties would not typically rise to the top of the list from a grouped risk-based analysis. Figure III.B.3- 4 Geographic and Individual Area Visual Representation defines an area where the density of properties is low, but a select group of properties were defined to be critical for prioritized construction activities. In this situation the individual risk score (equation 3) was evaluated and the top ranked properties were identified in accordance with the yearly construction goals.

Group B – Investigation Work Type

The goal of investigation work areas is to gather more information where necessary to produce better predictive model results in areas where available information is limited and to provide a more representative sampling of data. Investigation type activities include detailed records review, non-intrusive inspections, water quality sampling and potholing to support the ALSLR construction and planning. In areas where there are groupings of similar properties with similar p-values, then a sample of the total group population will be investigated to evaluate the composition of taps at these properties.

Another example for where investigation is needed occurs at properties for which risk is high due to a high consequence of having a lead service, but the likelihood of lead is relatively low. In this case, investigations as described above will be performed to determine service line material and support better model prediction outcomes as new iterations of the predictive model are run.

APPENDIX III.C.1 - FILTER ADOPTION

September 2019

DENVER WATER

Appendix III.C.1

Lead Filter Program Sample Size Required for Determining Rate

Date:	Revised August 16, 2019 March 14, 2019
To:	Denver Water
From:	Corona Environmental Consulting, LLC

Executive Summary

The objective of this memorandum is to develop a statistical method to estimate the number of Denver Water customers that adopt a lead filter and therefore reduce their exposure to lead in their drinking water. To meet this objective, the memorandum answers the following question: "How many Denver Water customers must respond to the lead filter program survey to sufficiently estimate filter adoption rate for all customers provided a lead filter?" Survey responses from 1,059 or more randomly selected Denver Water customers that received lead filters are needed to estimate the filter adoption rate (p) with at least 95% confidence and no more than 5% error, based on an adoption rate greater than 60%. Distributing the survey to a group of 1,250 Denver Water customers that received a lead filter is recommended to achieve the requisite survey response from 1,059 random surveyed customers while limiting the self-selection bias.

Introduction

Corona prepared a statistical approach to support Denver Water's efforts in understanding the required number of customers to be surveyed to sufficiently estimate point of use filter device adoption rates. Denver Water is investigating a program to provide filter devices to customers to protect them from lead exposure. When used properly, filter devices are effective at removing dissolved and particulate lead from drinking water. Therefore, the effectiveness of the filter devices in protecting Denver Water customers from lead exposure relies on customers' adoption of the devices. Filter device adoption assumes customers are installing, using and maintaining the device properly, as well as replacing the filters at the appropriate time. Customers not using the filter device but relying on bottled water for drinking and cooking will also be considered an adoption. Corona's statistical approach described in this memorandum details the number of customers that received a filter device that need to be surveyed based on the acceptable confidence level and the error in the estimated filter device adoption rate.

Statistical Analysis

The objective of the statistical analysis is to estimate the number of Denver Water customers that adopt their lead filter and therefore reduce their exposure to lead in their drinking water. The total number of Denver Water customers that adopt their lead filter can be estimated using the total number of Denver Water customers that receive a lead filter and the filter adoption rate for this entire population. To avoid having to survey the entire population of customers receiving a lead filter, a statistical analysis can be used to estimate the filter adoption rate utilizing a subset of the population. To determine the subset sample size required, the adoption rate distribution, confidence level, and acceptable error must be considered.

Lead filter adoption takes on a binomial distribution of "adoption" or "lack of adoption" (e.g. 1 or 0), which gives a discrete probability distribution of Bernoulli trials. A Bernoulli trial is an event that has two possible outcomes, such as flipping a coin. Each filter adoption, or lack of adoption, can be described as a Bernoulli trial because there are only two possible outcomes: adoption ("success") or no adoption ("failure"). We assume each customer's lead filter adoption, or lack of adoption, is independent of other customers' filter device adoption, and therefore, each "trial" constitutes a random, independent experiment. This assumption that each customer's filter adoption is not dependent on any other's customer's filter adoption emphasizes the need for Denver Water to ensure that surveyed customers are randomly selected. More information on the recommended survey procedure to prevent sampling bias is provided in the following section. We also assume that the probability, p, of a success in each trial remains constant. This means that we assume the probability that each customer will adopt the lead filter is constant and equal to some value p. Because actual adoption may not be constant, we recommend Denver Water repeat the survey annually.

The binomial distribution has a mean np and variance $np(1-p)$ where n is number of Bernoulli trials. In the context of this memorandum, n is equal to the number of surveyed Denver Water customers offered lead filters. The number of surveyed customers who have adopted their filter are defined as X, where $X \leq n$. The quantity X/n is the point estimator ($\widehat{P}$) of the filter adoption rate (p) for all customers receiving a lead filter. The binomial distribution is described in further detail in the Appendix. The descriptions were developed utilizing Montgomery & Runger (2007)[1].

The size of the confidence interval, which can also be defined as the difference between the true proportion of all Denver Water customers' filter adoption rate, p, and the proportion of surveyed customers' lead filter adoption rate, $\hat{p}$, is dependent on both α, which defines the confidence level, and n, the sample size of surveyed customers[2]. By defining the error $E = \left|p - \widehat{P}\right|$ and selecting an acceptable error (i.e. 0.05) and an acceptable statistical power (i.e. 95%) that *E* is less than our acceptable error, we can determine the required sample size utilizing the statistical computing software R package Binomial Confidence Intervals For Several Parameterizations ("binom")[3]. The power of a statistical test is the probability of rejecting the null hypothesis H_0 when the alternative hypothesis is true, which can be interpreted as the probability of correctly rejecting the false null hypothesis. In this application, the alternative hypothesis is true if the true proportion of all Denver Water customers' adoption rate p is greater than the proportion of surveyed customers' adoption rate $\hat{p}$ minus the error E.

$$H_0: p = \hat{p} - E$$

$$H_0: p > \hat{p} - E$$

Figure 1 illustrates the relationship between the survey sample size of Denver Water customers needed to estimate the filter acceptance rate and the acceptable error and confidence level. Table 1 summarizes

[1] Montgomery, D.C. & Runger, G.C. 2007. Applied Statistics and Probability for Engineers: Fourth Edition. John Wiley & Sons, Inc. USA.

[2] Note that $\widehat{P}$is a random variable point estimator for the filter device adoption rate (p) and $\hat{p}$ is the filter device adoption rate for surveyed Denver Water customers.

[3] Dorai-Raj, S. 2015. Package 'binom'. "Binomial Confidence Intervals For Several Parameterizations. Accessed 5/8/2019. https://cran.r-project.org/web/packages/binom/binom.pdf

the required sample sizes for acceptable errors of 10%, 5%, and 1% and for filter adoption rates of 50%, 60%, 70%, 80%, 90%, and 95% assuming 95% statistical power. To ensure, with 95% statistical power, that the sample size filter device acceptance rate, of at least 60%, is within 5% of the entire customer population filter acceptance rate, responses would be required from 1,059 random surveyed customers. If the adoption rate falls to 60% with the sample size of 1,059 random surveyed customers, the error of the estimate increases by less than 1%. Therefore, we recommend a sample size of random surveyed customers of 1,059 to be both achievable and representative.

Figure 1 Survey sample size based on acceptable error and filter adoption rate using a binomial distribution assumption with 95% statistical power

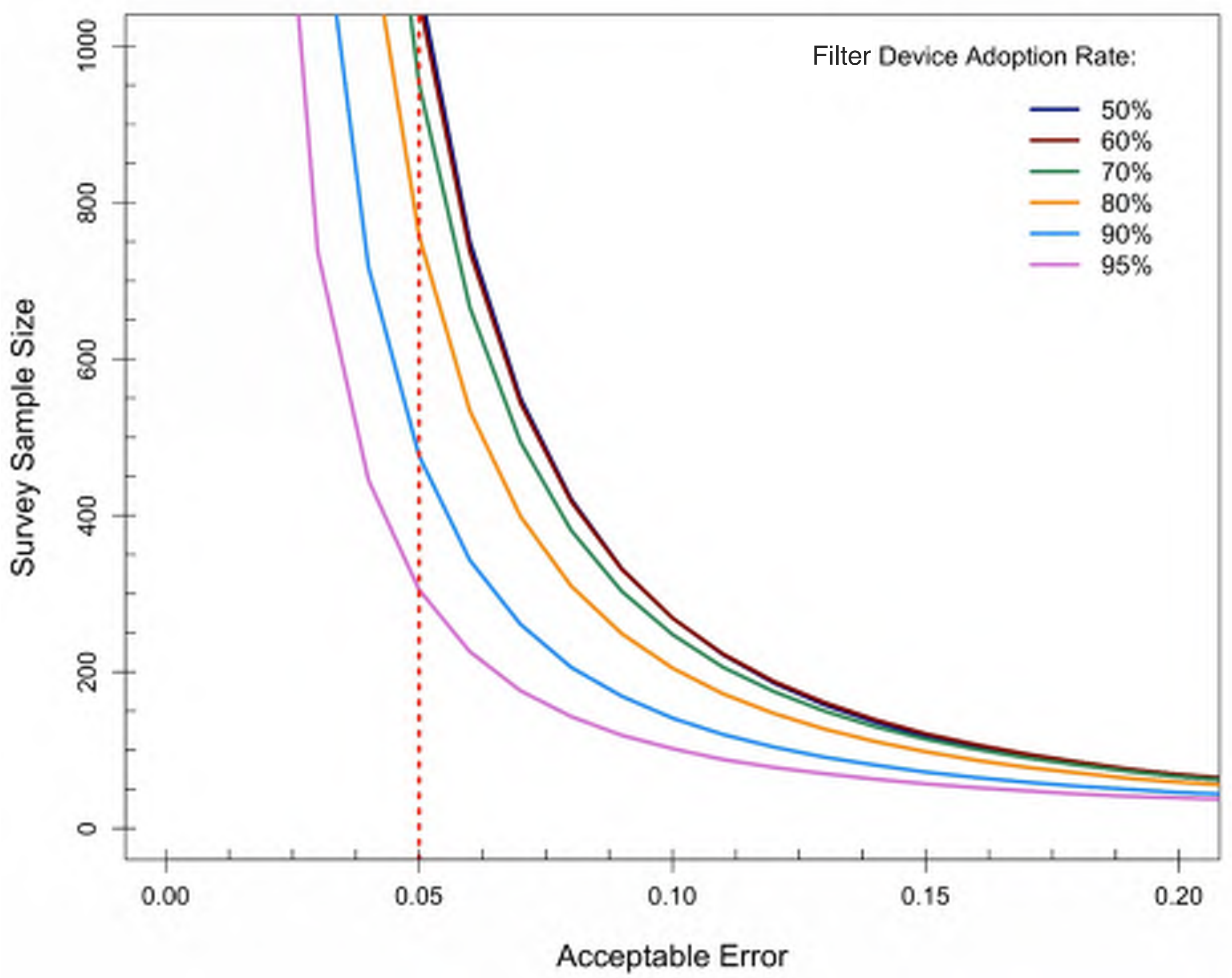


Table 1 Required sample size of surveyed customers based on acceptable error and filter adoption rate and 95% statistical power

Acceptable Error	**50% Adoption**	**60% Adoption**	**70% Adoption**	**80% Adoption**	**90% Adoption**	**95% Adoption**
10%	n=269	n=269	n=248	n=205	n =141	n=102
5%	n=1,081	n=1,059	n=951	n=757	n=476	n=305
1%	n=27,054	n=26,080	n=22,942	n=17,640	n=10,173	n=5,630

Alternatively, a normal approximation can be assumed for the point estimator $\hat{P}$ of the filter adoption rate (p) for all customers receiving a lead filter if the sample size (n) is sufficiently large and p is not too close to 0 or 1. To apply this approximation, we require that np and $n(1-p)$ are greater than or equal to 5. The normal distribution, standard normal distribution and the normal approximation and confidence interval for the probability p that each customer will adopt the filter are described in detail in the Appendix.

Using the normal approximation, the size of the confidence interval, which can also be defined as the difference between the true proportion of all Denver Water customers' filter adoption rate, p, and the proportion of surveyed customers' filter adoption rate, $\hat{p}$, is dependent on both α, which defines the confidence level, and n, the sample size of surveyed customers[4]. If we define the error $E = |p - \hat{P}|$, and we select an acceptable error (i.e. 0.05) and an acceptable confidence (95%) that *E* is less than our acceptable error, we can determine the required sample size as:

$$n = \left(\frac{z_{\alpha/2}}{E}\right)^2 p(1-p)$$ *Equation 1*

Using the exact binomial distribution results in a more conservative sample size requirement as compared with the normal approximation assumption. Therefore, if the surveyed customers' filter adoption rate is greater than 60% a sample size of 1,059 for survey responses from Denver Water customers is a sufficiently conservative requirement to determine that the filter adoption rate for all Denver Water customers receiving a lead filter is within 5% of the surveyed customers' filter adoption rate.

Sample Selection and Verification

A random selection of 1,250 customers from the group of all of the customers provided a filter should be performed each year. The customers selected and the corresponding surveys received should be randomized based on geography and demographics. Efforts to achieve the requisite response rates (e.g. at least 1,059 of 1,250) must be undertaken to prevent self-selection bias in the reporting group. These efforts may include mailings, phone calls, and site visits to the randomly selected customers. Community groups present an opportunity to leverage independent parties that might obtain higher response rates and a higher level of truthfulness in the responses.

Even though the number of respondents may approach a level of confidence and error that are acceptable, efforts should be continued to complete responses from all the customers selected for

[4] Note that $\hat{P}$is a random variable point estimator for the filter device adoption rate (p) and $\hat{p}$ is the filter adoption rate for surveyed Denver Water customers.

verification. A high response rate from the random selection ensures a full representation of the diversity of Denver Water's customer base.

Recommendation

For the lead filter program to be considered successful, the adoption rate needs to be greater than or equal to 60% for equivalence. However, Denver Water should continue efforts to maximize the adoption rate. Corona recommends obtaining responses from a minimum of 1,059 customers out of a randomly selected group of 1,250. The survey should be repeated on an annual basis to detect changes in adoption rate over time. Responses from 1,059 randomly selected customers would achieve 95% confidence that the true sample adoption is within 5% of the subsample adoption if the subsample adoption is above 60%. If the subsample adoption is greater than 60%, then the confidence is increased and/or the error is decreased. If the subsample adoption is lower, then Denver Water should take measures to increase the adoption rate.

Appendix

Binomial Distribution

A random experiment consists of n Bernoulli trials such that

(1) The trials are independent
(2) Each trial results in only two possible outcomes, labeled as "success" and "failure"
(3) The probability of a success in each trial, denoted as p, remains constant

The random variable X that equals the number of trials that result in a success has a binomial random variable with parameters $0 < p < 1$ and n = 1,2,…. The probability mass function X is:

$$f(x) = \binom{n}{x} p^x (1-p)^{n-x} \qquad \textit{Equation 2}$$

$\binom{n}{x}$ equals the total number of different sequences of trials that contain x successes and $n-x$ failures. The total number of different sequences that contain x successes and $n-x$ failures times the probability of each sequence equals $P(X=x)$.

If X is a binomial random variable with parameters p and n, the mean $\mu = E(X) = np$ and the variance $\sigma^2 = V(X) = np(1-p)$.

Normal and Standard Normal Distributions

A normal random variable X from a normal distribution with mean μ and variance σ^2 can be standardized by the following:

$$Z = \frac{\bar{X}-\mu}{\sigma} \qquad \textit{Equation 3}$$

Z is then a standard normal random variable with a standard normal distribution. A standard normal distribution is a normal distribution with mean μ=0 and variance σ^2=1. The standard normal distribution probability density function is described below by $P(x)$:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2)/(2\sigma^2)} = \frac{1}{\sqrt{2\pi}} e^{\left(-x^2/2\right)} \qquad \textit{Equation 4}$$

To determine the probability that the standard normal random variable Z is less than or equal to some value z, written as $P(Z \leq z)$, we can use the cumulative distribution function of a standard normal random variable, denoted as $\Phi(z)$, which is found by integrating the probability density function:

$$\Phi(z) = P(Z \leq z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{\left(-z^2/2\right)} dz \qquad \textit{Equation 5}$$

To determine the probability that Z is greater than some value z, $P(Z > z)$, we can utilize the fact that the integral of the probability density function taken from -∞ to ∞ is equal to 1:

$$P(Z > z) = 1 - P(Z \leq z) \qquad \textit{Equation 6}$$

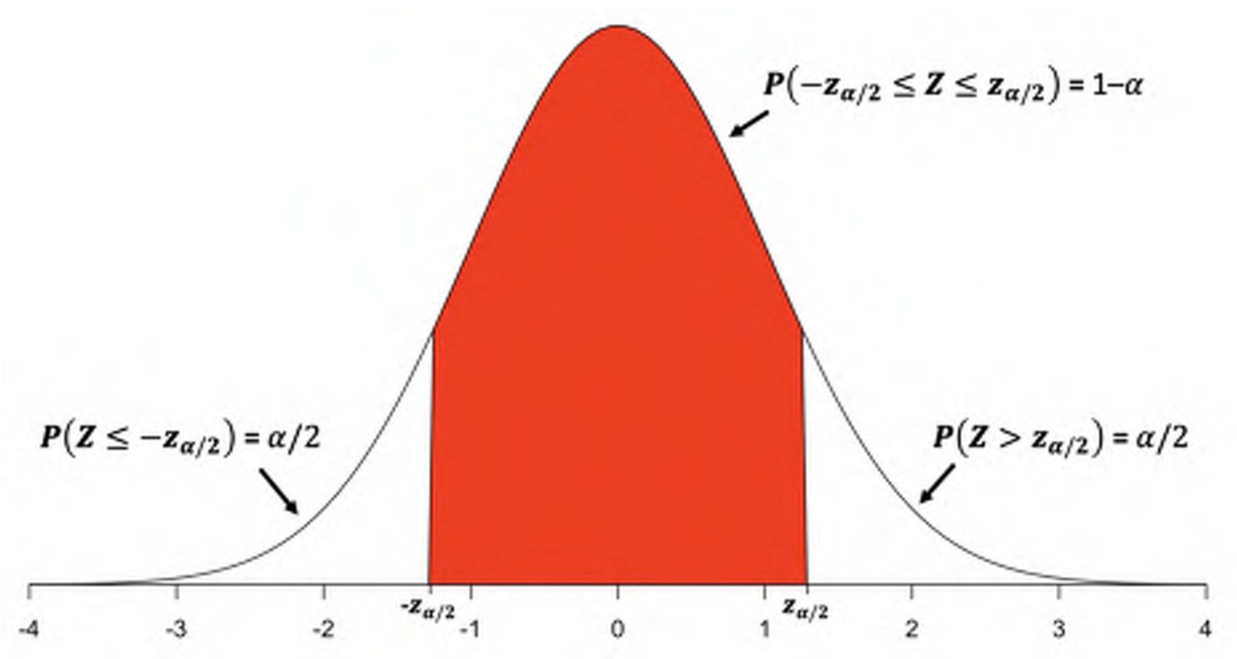
For a standard normal distribution, we can define the probability that Z is within a defined confidence interval with a confidence level of 100(1-α)% by:

$$P(-z_{\alpha/2} \leq Z \leq z_{\alpha/2}) \cong 1 - \alpha \qquad \textit{Equation 7}$$

where $z_{\alpha/2}$ is defined as the z value that corresponds with the upper $\alpha/2$ percentage point of the standard normal distribution (see Figure 2). Alternatively, we can say with 100(1-α)% confidence that:

$$-z_{\alpha/2} \leq Z \leq z_{\alpha/2} \qquad \textit{Equation 8}$$

Figure 2 Standard normal distribution showing confidence intervals for Z



Large Sample Confidence Intervals for the Mean of a Normal Distribution

In the case of sampling from a normally distributed population with an unknown mean and a known standard deviation σ with the objective to estimate the population mean, a large sample confidence interval for the mean μ can be determined if the sample size is sufficiently large. Given the assumption that the sample size is large, the central limit theorem can be applied such that the sample mean $\bar{X}$ has an approximate normal distribution with mean μ and variance ${\sigma^2}/{n}$. Therefore, for a normal distribution with a large sample size:

$$Z = \frac{\bar{X} - \mu}{S/\sqrt{n}} \qquad \textit{Equation 9}$$

where: $\bar{X}$ is the sample mean,

μ is the distribution mean,

S is the sample standard deviation, and

n is the sample size.

The large sample confidence interval for μ for a confidence level of approximately 100(1-α)% can then be described as:

$$\bar{x} - z_{\alpha/2}\frac{s}{\sqrt{n}} \leq x \leq \bar{x} + z_{\alpha/2}\frac{s}{\sqrt{n}}$$ *Equation 10*

Normal Approximation to the Binomial Proportion

Using the normal approximation, the sampling distribution of $\hat{P}$ is approximately normal with mean *p* and variance *p*(1-*p*)/n. If Denver Water uses a sufficiently large sample size n and *p* is not too close to 0 or 1, the normal approximation for *p*, the probability that each Denver Water customer who receives a lead filter will adopt the filter, is equal to the following:

$$Z = \frac{\hat{P} - p}{\sqrt{\frac{p(1-p)}{n}}}$$ *Equation 11*

where Z has an approximate standard normal distribution. Using the normal approximation of the binomial proportion, we can use the standard normal confidence intervals to determine the following approximate confidence interval for our binomial proportion, p:

$$\hat{p} - z_{\alpha/2}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \leq p \leq \hat{p} + z_{\alpha/2}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$ *Equation 12*

The error E between the true filter adoption rate among all Denver Water filter recipients p and the filter adoption rate among all surveyed Denver Water customers $\hat{p}$ can be defined as $E = |p - \hat{P}|$ where $\hat{P}$ is a random variable from a binomial distribution with mean *p* and variance *p*(1-*p*)/n. Thus, there is 100(1-α)% confidence that $E < z_{\alpha/2}\sqrt{p(1-p)/n}$. If we set $E = z_{\alpha/2}\sqrt{p(1-p)/n}$, we can solve for the sample size n.