

DENVER WATER LEAD REDUCTION PROGRAM PLAN

AMENDMENT TO ORIGINAL PLAN – 2023

Version 2.0: July 17, 2023

Presented by: Denver Water



ISSUE AND REVISION RECORD

Version	Date	Originator	Checker	Approver	Description
1.0	05/05/23	LRP Team	Erika Bender	Alexis Woodrow	Draft Submission
1.1	06/16/23	LRP Team	Erika Bender	Alexis Woodrow	Draft Submission
2.0	07/17/23	LRP Team	Erika Bender	Alexis Woodrow	Draft Submission

Document ID: DWLRP-1621808796-1348

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Appendix 1 – LSLI Improvements

LIST OF ACRONYMS

ALSLR	Accelerated lead service line replacement
CCT	Corrosion control treatment
CDPHE	Colorado Department of Public Health and Environment
COE	Communications, Outreach and Education
EPA	Environmental Protection Agency
HE&EJ	Health equity and environmental justice
LBD	Learn by Doing
LCR	Lead and Copper Rule
LCRR	Lead and Copper Rule Revisions
LRP	Lead Reduction Program
LRPP	Lead Reduction Program Plan
LSL	Lead service line
LSLI	Lead service line inventory
LSLR	Lead service line replacement
mg/L	Milligram per liter
OCCT	Optimal corrosion control treatment
µg/L	Microgram per liter
Variance	Variance Order

EXECUTIVE SUMMARY

Denver Water is committed to reducing the lead exposure levels to customers from lead service lines and plumbing. The Lead Reduction Program (LRP) provides a holistic and permanent lead reduction approach that will significantly reduce lead exposure to our customers and be less harmful to the environment than orthophosphate treatment.

The LRP consists of five key elements: 1) the development of a lead service line (LSL) inventory; 2) the replacement of all LSLs within our service area within fifteen years at a 7% cumulative annual replacement rate; 3) a filter distribution program to customers who may have an LSL; 4) a comprehensive communications outreach and education (COE) effort; and 5) the incorporation of health equity and environmental justice principles (HE&EJ) in all aspects of the program to focus on disproportionately impacted communities.

In 2012, at the end of Denver Water's annual lead and copper monitoring period, the 90th percentile value for sample results of lead levels in tap water was 17 micrograms per liter ($\mu\text{g/L}$), exceeding the Lead and Copper Rule (LCR) action level of 15 $\mu\text{g/L}$. There have been no exceedances of the 90th percentile calculation under the LCR since 2012.

From 2013 through 2017, Denver Water completed several corrosion control studies and adjusted treatment to optimize pH/alkalinity control. Based upon these studies, on March 20, 2018, the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division designated phosphate-based corrosion inhibitor addition (orthophosphate) as the optimal corrosion control treatment (OCCT) and ordered Denver Water to install and operate the designated corrosion control treatment (CCT) by March 20, 2020.

The designation of orthophosphate raised concerns among regional stakeholders, including the City of Aurora, The Greenway Foundation, Metro Water Recovery, Denver Water, and others, that increased loads of phosphorous from orthophosphate treatment would adversely impact Colorado's streams and rivers, which were already nutrient-stressed, as well as regional wastewater treatment operations, and drinking water treatment supplies. Denver Water was also concerned that orthophosphate treatment would not solve the ultimate public health issue of tackling lead at its source through removal of LSLs.

To request approval of a variance to OCCT, Denver Water developed a Lead Reduction Program Plan (LRPP) that described how Denver Water planned to implement the LRP if it were approved.¹ The program components include:

- A pH/alkalinity adjustment to reduce corrosivity;

¹ See Denver Water's [lead webpage](#) for more information on how the LRP is currently implemented and the [resource page](#) for all supporting documentation of the LRP.

- A fifteen-year accelerated LSL replacement program to replace an estimated 64,000-84,000 LSLs in Denver Water’s system within 15 years;
- A filter distribution program to provide added protection for our customers until their LSLs can be replaced;
- Development of an LSL inventory;
- Implementation of a comprehensive COE plan; and
- A focus on health equity and environmental justice (HE&EJ) principles in the prioritization of LSL replacements as well as COE activities.

To demonstrate that the LRP is projected to be “more efficient” than the current treatment technique authorized under the LCR, Denver Water developed an equivalency model, which the Environmental Protection Agency (EPA) determined is based upon a reasonable methodology. The model compared the projected results of the LRP to the results that could be achieved through implementation of orthophosphate with Denver Water’s then-current replacement rate of 1,200 LSLs per year. As discussed in the Technical Evaluation of the Denver Water Lead Reduction Program Plan, attached as Appendix A to the Variance, the model showed that the LRP “is expected to achieve greater lead reductions than orthophosphate treatment beginning in year one of the variance, assuming 7% of LSLs are removed annually, filters are widely used and remove lead, and the pH and alkalinity CCT performs as indicated by Denver Water.” The model is run at the end of each Program Year to prove the LRP’s efficiency compared to OCCT.

On November 15, 2019, CDPHE granted Denver Water’s request to modify the OCCT designated for Denver Water in accordance with § 11.26(3)(d)(iii) of the Colorado Primary Drinking Water Regulations, 5 CCR §§ 1002-11, et seq., subject to EPA’s approval of Denver Water’s variance request. Subsequently, on December 16, 2019, EPA granted the Variance to Denver Water from OCCT pursuant to § 1415(a)(3) of the SDWA, 42 U.S.C. § 300g-4, and 40 C.F.R. § 142.46 for a three-year term beginning January 1, 2020.

The LRPP and its described activities began on Jan. 1, 2020, when the LRP officially launched. In January 2021, the EPA published the Lead and Copper Rule Revisions (LCRR), with a compliance date of Oct. 16, 2024.² To comply with the LCRR, Denver Water worked with CDPHE and EPA to develop and approve a new variance to the LCRR to replace the existing variance from the LCR. The Dec. 16, 2019, Variance Order (LCR Variance) therefore expired in 2023 and was replaced by the Nov. 30, 2022, Variance Order (LCRR Variance).^{3,4} Since Jan. 1, 2020, there have been lessons learned, clarifications and minor deviations from the original LRPP. This LRPP technical amendment presents the changes within the LRP since its inception.

² See EPA’s [publication](#) for additional details on the regulation.

³ See the [original Variance](#) posted on Denver Water’s website for more details.

⁴ See the [new Variance](#), along with its [letter](#), [appendix](#), and [responsiveness summary](#).

Denver Water demonstrated, in the first three years of the program, that the holistic approach of the LRP is more efficient than orthophosphate treatment.⁵ All performance metrics required in the LCR Variance have been achieved and/or exceeded in the first three years of the program:

- Results from lead sampling indicate that lead levels continue to decline.
- The 90th percentile lead levels have continuously been measured less than 4.5 µg/L since CCT implementation.
- By the end of 2022, over 15,000 lead service lines have been replaced, nearly 10,000 of which were in areas designated as having HE&EJ concerns.
- As part of the Filter Program, all customers who may have an LSL are provided with a pitcher filter and continue to be supplied with replacement cartridges, per the manufacturer's requirement.
- Consistently, the filter adoption survey has shown an over 80% adoption rate.

The purpose of the original LRPP was to supplement the variance request and state Denver Water's intended plan if the variance were approved. Commitments made within the LRPP are included in Denver Water's required reporting and are updated, as needed, on Denver Water's website. To adjust to the LCRR Variance requirements and improve program efficiencies, Denver Water is making minor changes to its original LRPP, including:

CCT

- Lowering the threshold indicator of a lead release from a service line from 5 µg/L to 3 µg/L in investigative samples as a result of reduced lead levels based on pH performance and corrosion control improvements.
- Implementing a one-bottle sampling technique for water quality sampling at multi-family and commercial properties in place of the three-bottle technique.
- Removing monthly CCT water quality parameter reports, as directed in the LCRR Variance.

LSL Inventory

- Changing the terminology used for the service line material designations in the public map to conform with the requirements of the revised LCR and LCRR Variance.

LSL Investigations

- Maintaining the use of the three-bottle test for customer-requested and investigation water quality sampling under the LCRR Variance for consistency with past practices, as the three-bottle technique is a very effective sampling method for finding service line material. This would make the customer-requested samples ineligible as compliance samples.

⁵ See [2019 LRPP, pages 37 and 38](#), for more details on how this is calculated.

- Clarifying which investigations count toward the 1.4% investigation metric.
- Shifting to a cumulative annual average for investigation rate calculations, as directed in the LCRR Variance.

Accelerated LSL Replacement

- Shifting to a cumulative annual average for replacement rate calculations, as directed in the LCRR Variance.
- Revisiting properties where consent was not given to perform an LSL replacement and deploying additional tactics to require a customer to replace their service line.

Filter Program

- Omitting incomplete survey responses from the calculation of the filter adoption rate.
 - Reducing the filter adoption survey frequency from every year to every other year, as directed in the LCRR Variance.
 - Streamlining the post-replacement filter cartridge distribution, regardless of where the customer is at in their cartridge life.
 - Defining measurable lead in post-filter samples as greater than 1 µg/L.⁶
 - Simplifying the filter testing procedures when new filter manufacturers or models are introduced to the program.
 - Defining the actions taken if the filter adoption rate falls below the minimum when shifting to a biannual survey frequency.
 - Adjusting the minimum survey response requirement from a static number (1,059 responses) to a response rate that is consistent with a 95% confidence level and 3% margin of error for the remaining program participants.
- COE
 - Providing up-to-date educational, online resources on sources of lead in drinking water, particularly for 1983-1987 homes rather than conducting outreach through direct mail to select households, as directed in the LCRR Variance. Information includes how to request a water quality test kit and outlines that if the results of the test are over 3 µg/L, and there is a formula-fed infant in the home, how customers will be offered a water pitcher and filters to use until the infant reaches 24 months.
 - Allowing more flexibility in methods used to obtain customer consent for service line replacements, as directed in the LCRR Variance.

⁶ See CDPHE Requirements Change Notice on established water quality parameters for corrosion control treatment, dated June 9, 2021.

- Removing the detailed reporting requirement for informal filter adoption surveying via phone calls, as directed in the LCRR Variance.
- Automatically enrolling customers that may have a lead service line in the Filter Program, rather than requiring the customer to fill out an online request.
- HE&EJ
 - Modifying how HE&EJ impacts from the LRP are measured by implementing the new HE&EJ metric under the LCRR Variance.

This document presents the metrics achieved within the LRP for the first three years of the program, an assessment of the program changes under the LCRR Variance and describes deviations or clarifications from the original 2019 LRPP. Denver Water remains committed to the Learn by Doing approach as part of the original LRPP.⁷ Since 2019, Denver Water has documented over 500 improvements using the Learn by Doing approach with all program elements. This approach provides important flexibility, allowing Denver Water to adapt for greater program performance and efficiencies to achieve program goals. Learn by Doing improvements are documented and reported on as part of regular compliance reporting.

⁷ See Learn by Doing reports for [2020](#), [2021](#), and [2022](#).
DENVER WATER
Lead Reduction Program Plan Amendment 2023

INTRODUCTION

Denver Water began implementing the Lead Reduction Program Plan (LRPP) under the Dec. 16, 2019, Variance Order (LCR Variance) on Jan. 1, 2020. Elements of the original LRPP have been incorporated into Denver Water’s website, where customers can view answers to FAQs, navigate through different elements of the program (e.g., filters, water quality testing, replacements), view videos explaining various aspects of the program and recordings of virtual community meetings, review previous regulatory reports, view the lead service line (LSL) inventory and LSL replacement work area maps, and more, in both English and Spanish.⁸ The website is regularly updated to ensure the most up-to-date information. Throughout the first three program years, Denver Water remained faithful to the LRPP and the 2019 Variance, with only minor deviations and clarifications, which were communicated to and approved or provided by Colorado Department of Public Health and Environment (CDPHE) and the Environmental Protection Agency (EPA). Clarifications and deviations from the LCR Variance since the start of the program are noted below in Table 1.

The LCR Variance was a variance to the 1991 Lead and Copper Rule (LCR) and was approved for an initial three-year period with a potential extension for an additional 12 years. In recognition of the 2021 Lead and Copper Rule Revisions (LCRR), Denver Water worked with CDPHE and EPA to approve a new variance under the LCRR. The new variance (LCRR Variance) was approved Nov. 30, 2022, and Denver Water began operating under the LCRR Variance Jan. 1, 2023. In comparison with the LCR Variance, the major changes made in the LCRR Variance are described below in Table 2.

Under the LCRR Variance, Denver Water must submit an update to the 2019 LRPP by July 1, 2023. The purpose of this document is to summarize the success of the LRPP in the first three years of the program and communicate changes to the 2019 LRPP that will govern the LRP under the LCRR Variance.

TABLE 1. CLARIFICATIONS AND DEVIATIONS FROM THE LCR VARIANCE ORDER

Description of Deviation or Clarification from the LCR Variance (Dec. 16, 2019)	Reference	Date of Communication with EPA / CDPHE	Impacts on the LCRR Variance (Nov. 30, 2022)
Deviation: Change terminology used in the inventory map posted to the website from “lead, copper, or unknown” to “confirmed lead service line, likely lead service line, unlikely lead service line or no lead service line.”	2020 Annual Report	Jan. 24, 2020	By Oct. 16, 2024, the inventory map will need to use terminology from the LCRR: Confirmed Lead, Non-Lead, Galvanized Requiring

⁸ See Denver Water’s [Lead Reduction Program webpage](#) to navigate through all publicly available information.

Description of Deviation or Clarification from the LCR Variance (Dec. 16, 2019)	Reference	Date of Communication with EPA / CDPHE	Impacts on the LCRR Variance (Nov. 30, 2022)
			Replacement, Unknown Lead Status (likely or unlikely). ⁹
Deviation: Allow use of other methods to investigate lead at multi-family dwellings and commercial properties as the 3 L sample is ineffective.	2020 Annual Report	July 17, 2020	5 th L sampling is required by the LCRR, but multi-family and commercial properties are not prioritized in the LCRR's revised tiered sample site selection criteria and there are not considered tier 1 sites.
Deviation: Use a single bottle sampling procedure (i.e., 1 st draw, 1-liter) for post-LSLR sampling at multi-family and commercial properties.	2020 Annual Report	July 17, 2020	None.
Clarification: Measurable lead in samples obtained from filter testing in the field defined as greater than 1 µg/L.	2020 Annual Report	Sept. 16, 2020	N/A
Clarification: Remove and provide new pitcher filter if lead is measured ≥ 10 µg/L at LCR sites included in confirmation of filter performance and usage in the field.	CCT Implementation Plan	June 6, 2020	N/A
Deviation: Modify the schedule to report filter survey health equity and environmental justice (HE&EJ) indicators from semi-annual reporting to annual reporting.	2021 Annual Report	Jan. 28, 2022	N/A, HE&EJ results from the filter survey were removed from the reporting requirements.
Clarification: Adjust submission protocols from a single email submittal to both EPA and CDPHE to direct submittals provided separately to CDPHE (via secure portal) and EPA (via secure email) for routine reporting.	2021 Annual Report	Jan. 28, 2022	None.
Deviation: Modify protocols to offer post-LSL replacement sampling to customers that seek reimbursement for replacements by third parties. The	2022 Annual Report	Feb. 10, 2023	N/A

⁹ The [Lead and Copper Rule Revisions Guidance Manual](#) encourages water systems to provide an indication of likely or unlikely lead for unknown lead status service lines.

Description of Deviation or Clarification from the LCR Variance (Dec. 16, 2019)	Reference	Date of Communication with EPA / CDPHE	Impacts on the LCRR Variance (Nov. 30, 2022)
<p>duration between completing the work to replace the service line and seeking reimbursement can exceed the six-month time frame to offer post-LSL replacement sampling. Offer letters continue to be provided to these customers, based on the date that Denver water is notified of the request for reimbursement.</p>			
<p>Clarification: An investigation that confirms the current status of the service line without resulting in a change in its p-value can be counted as an investigation, as the information is used to support the determination of the service line material.</p>	2021 Annual Report	Jan. 5, 2022	The investigation rate is calculated using all unknowns in the inventory, increasing the 1.4% target to 2,421 service lines.

TABLE 2. REPORTING CHANGES UNDER LCRR VARIANCE (NOV. 30, 2022)

Reference Paragraph	Dec. 16, 2019, LCR Variance	Nov. 30, 2022, LCRR Variance
3.D	Required annually completing investigation at 1.4% of all properties designated as possible and suspected lead service lines in the baseline LSL inventory.	Requires a <u>cumulative</u> average 1.4% investigation rate based on the number of unknown service lines (likely LSL or unlikely LSL) in the baseline LSL inventory.
4.A	Required a 7% LSL replacement rate each year.	Requires a 7% <u>cumulative</u> average LSL replacement rate throughout the duration of the program.
6.C	No HE&EJ metric, but 7.B.vii required an annual qualitative analysis of efforts within the LRP that focused on HE&EJ principles.	Requires that the cumulative program year LSL replacement rate each year in HE&EJ areas of concern must be greater than or equal to the total LSL replacement rate.
5.G, 7.B.iv	Required submission of detailed address lists in semi-annual and annual reports for: <ol style="list-style-type: none"> 1. Filter distribution addresses. 2. Cartridge distribution addresses. 3. Proof of 95% outreach to customers. 	Does not require the submission of detailed address lists with semi-annual or annual reports. Address lists are to be maintained and made available to CDPHE and EPA, if requested.
7.B	Required two semi-annual reports and one annual report.	Merges the second semi-annual report with the annual report, requiring only two reports each year.
1.C, 1.I, 1.P, 1.X	Terminology used: <ul style="list-style-type: none"> - Known lead - Suspected lead - Possible lead - Unlikely lead - Non-lead 	Introduces new terminology: <ul style="list-style-type: none"> - Confirmed LSL - Unknown lead status (likely and unlikely) - Non-lead - Galvanized requiring replacement

OVERVIEW OF METRICS ACHIEVED

Corrosion Control Treatment

Corrosion control treatment (CCT) with pH adjustment is used to manage lead release from lead service lines as well as homes with copper plumbing with lead solder. Homes with an LSL that opt out of the LRP are also offered some protection from pH adjustment. Denver Water’s LRP webpage has a page dedicated to pH adjustment.¹⁰ The page describes the reasoning of the pH adjustment and how it benefits customers with an LSL or lead in their premise plumbing, answering FAQs and describing any downstream effects.

Treatment to adjust pH above 8.5 (required by the LCR Variance) was initiated at the Marston and Foothills Water Treatment Plants on March 3, 2020; treatment was initiated at the Moffat Water Treatment Plant when it was returned to service on May 1, 2020. The positive impact of a higher and more consistent pH in treated water to reduce lead levels measured at customers’ tap is shown in Figure 1 and Figure 2. These results are based on compliance samples and customer-requested samples.

The cumulative 90th percentile lead level in the system before the pH change on March 3, 2020, was approximately 13 micrograms per liter (µg/L).¹¹ After the pH stabilized at 8.8, the lead levels started to decline, eventually stabilizing by August of that same year to a 90th percentile lead concentration below 5 µg/L.¹² The 90th percentile lead levels represent a greater than a 60% decrease in lead levels.

The calculated 90th percentile lead concentrations for all sampling periods since 2019 are shown in Table 3. Data for 2019 represents conditions before operating with pH greater than 8.5, 2020 represents a period of transition to the higher setpoint for pH adjustment, and 2021 and 2022 represent full years with pH adjustment of treated water to 8.8 (±2 S.U.). A decrease in lead release is observed in the metric used as a basis of compliance with the LCRR.

TABLE 3. CCT PERFORMANCE BASED ON THE SAMPLING PERIOD 90TH PERCENTILE LEAD CONCENTRATION

LCR Six Month Sampling Period	2019	2020	2021	2022
Spring Overall 90 th Percentile Lead Concentration	10.0 µg/L	6.7 µg/L	4.1 µg/L	3.9 µg/L
Fall Overall 90 th Percentile Lead Concentration	11.0 µg/L	4.4 µg/L	4.4 µg/L	3.8 µg/L

Over the past several years, Denver Water has seen an increased LSL to copper plumbing lead solder (CPLS) ratio in the LCR sampling pool, which may explain a small increase

¹⁰ See Denver Water’s LRP [pH Adjustment](#) webpage.

¹¹ Note that the 90th percentiles provided in Table 3 are for a sampling period, and not cumulative.

¹² As seen in Table 3 for 2020.

in the overall Fall 90th percentile from 2017 to 2019. The Spring and Fall 2022 90th percentile concentrations of lead decreased to record lows, as shown in Table 4. This is likely due to the implementation of Denver Water’s CCT Plan to increase the pH in the distribution system. There will also be more LCR customers with lead service lines added to the LCR study over the next few compliance periods in preparation for the LCRR. A noticeable drop in the 2020 cumulative 90th percentile lead concentrations occurred after the pH adjustment period in March 2020.

TABLE 4. LCR LEAD CONCENTRATIONS FOR LSL AND CPLS HOMES

Historical Cumulative LCR Lead Concentrations	2019		2020		2021		2022	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Overall 90th Percentile	10	11.8	6.7	4.1	4.1	4.3	3.9	3.8
LSL 90th Percentile	10	12.4	6.7	4.3	4.1	4.5	4.0	3.9
CPLS 90th Percentile	7.8	5.1	4.8	2.9	3.4	2.3	1.2	1.7

FIGURE 1. CCT PERFORMANCE AT LSL PROPERTIES

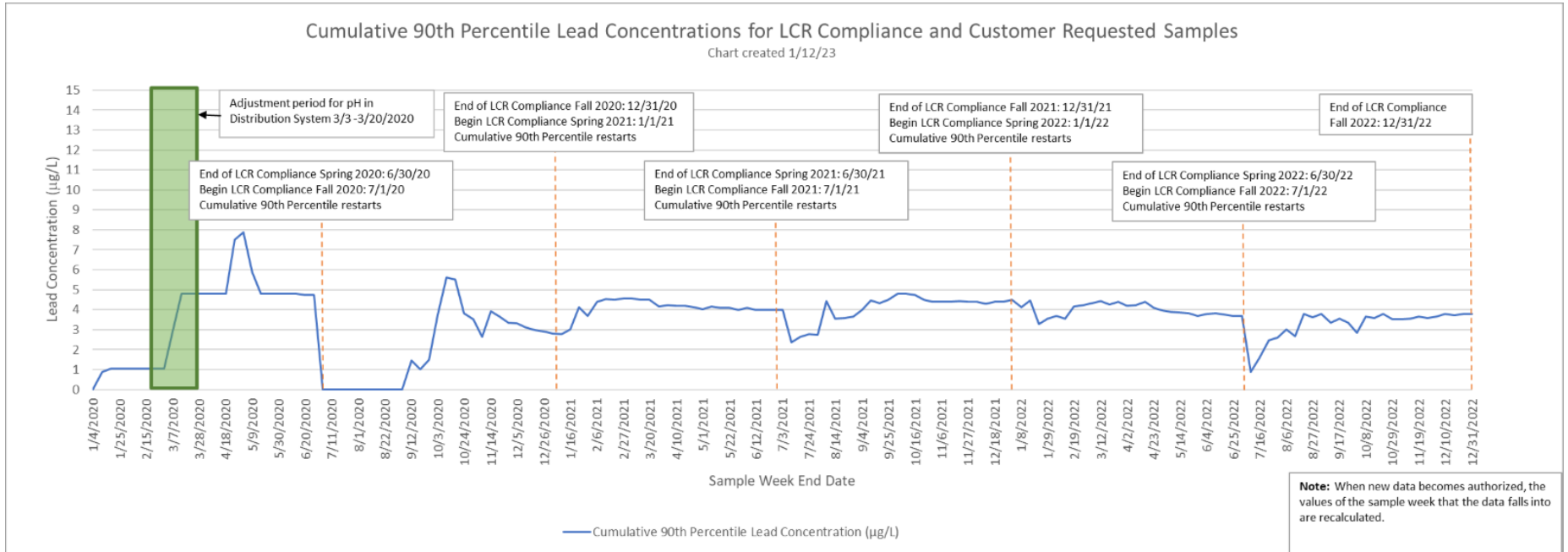
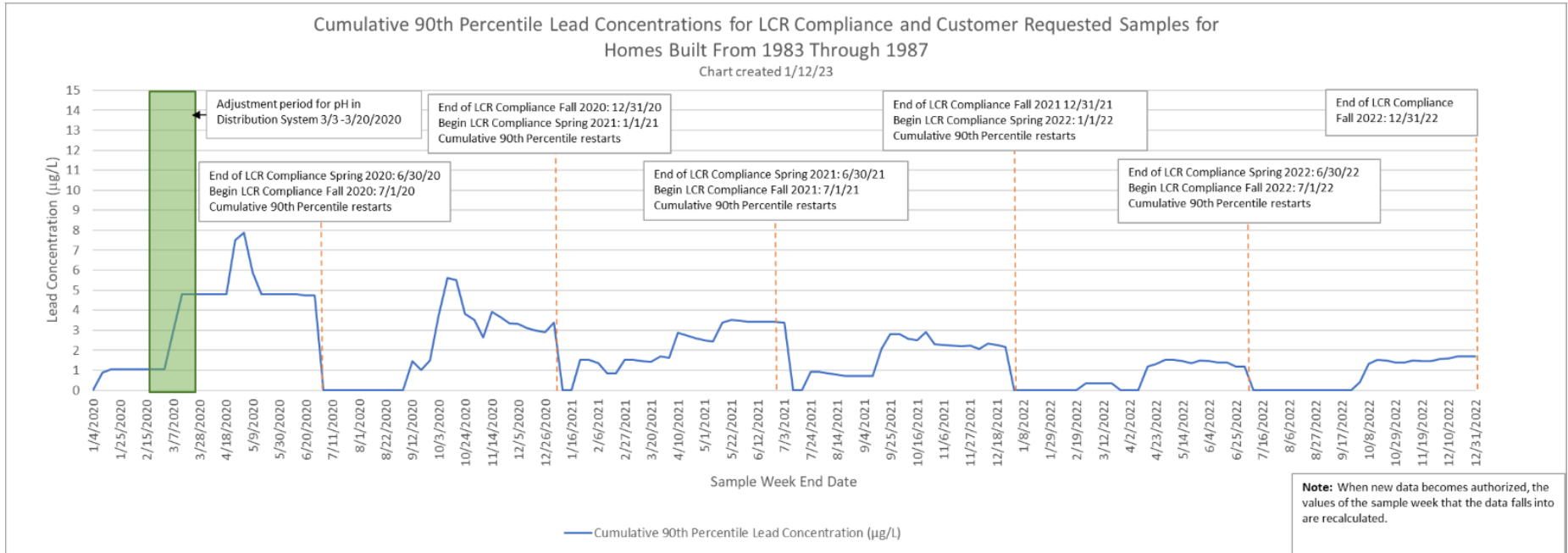


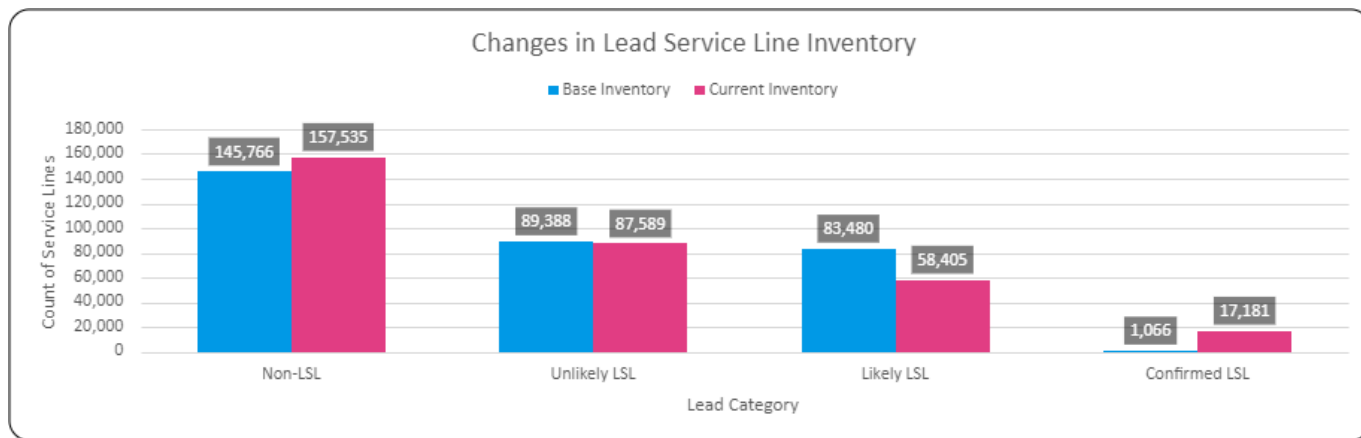
FIGURE 2. CCT PERFORMANCE AT CPLS PROPERTIES



LSL Inventory

On March 5, 2020, Denver Water published an online, publicly accessible map of all confirmed and likely LSLs, as well as lines that are unlikely LSLs and non-lead in our service area. Denver Water’s LSL inventory is updated at least twice a year on the website.¹³ An overview of the changes to the LSL Inventory for the first three years of the program is provided in Figure 3.

FIGURE 3. CHANGES IN THE BASE AND CURRENT INVENTORY (DEC. 31, 2022)



¹ The inventory count for “confirmed lead” include properties with either confirmed lead or that have had the LSL replaced.

LSL Investigations

Section 3.D of the LCR Variance requires that “Denver Water . . . [i]nvestigate a minimum of 1.4% of the total estimated number of suspected and possible LSLs in the LSL inventory each Program Year. . . .”

Investigations of service lines refine Denver Water’s LSL inventory. Investigations used at a given property include desktop reviews, water quality sampling, potholing and/or visual inspection of the service line. The annual number of investigations completed in each program year is shown in Table 5.¹⁴

TABLE 5. NUMBER OF INVESTIGATIONS COMPLETED

Number of Properties Investigated ¹	2020	2021	2022
Required Number of Investigations per Year	1,169 (1.4% of suspected and possible lead services from the baseline September 2019 inventory)		
Number of Investigations Completed per Year	3,326	4,562	4,918

¹ Number meeting criteria of “investigation,” i.e., independent of the 2020, 2021, or 2022 accelerated lead service line replacement (ALSLR) Programs.

¹³ See Denver Water’s [public lead map](#).

¹⁴ See Appendix 1 – LSLI Improvements for a description of how Denver Water conducts investigations to determine a service line’s material.

Accelerated LSL Replacement

Section 4.A of the LCR Variance provides that “[e]ach Program Year, Denver Water shall replace at least 7.0% of the estimated number of LSLs in its distribution system.” The overall intent of this requirement is to ensure that all lead service lines and galvanized lines requiring replacement (GRRs) are replaced within 15 years following the effective date of the LCR Variance.

From January 2020 through December 2022, Denver Water fully replaced more than 15,400 customer-owned LSLs. Replacements are performed at no out-of-pocket costs to customers and are prioritized in areas where our most vulnerable populations and disproportionately impacted communities are found. The required 7% replacement rate was surpassed in all three years.

Denver Water’s lead service line replacement program webpage allows customers to learn more about getting their service line replaced, through frequently asked questions (FAQs), videos detailing what to expect during construction, and describing the process through which Denver Water prioritizes replacements throughout the city.¹⁵ Table 6 provides the annual replacements for the first three years of the program.

TABLE 6. YEAR OVER YEAR COMPARISON OF LSL REPLACEMENTS

	2020	2021	2022
Total Number of Replacements Each Year	5,514	4,814	5,119
Annual Replacement Rate at End of Program Year	8.6%	7.5%	8.0%

Filter Program

Denver Water provides pitcher filters and filter cartridges to all customers within the service area that have the potential for a lead service line. Every six months, per the manufacturer’s recommendations, customers receive filter cartridge replacements. The initial pitcher filter distribution was launched in 2020, and any customers that are added to the program are promptly sent a filter pitcher and cartridge. Customers can request a pitcher or cartridge replacement, read about the Filter Program, and watch a video on proper filter usage through Denver Water’s filter webpage.¹⁶

Per paragraph 5.E.i of the LCR Variance, Denver Water “must conduct a survey each program year of randomly selected customers enrolled in the filter program to receive a minimum of 1,059 responses.” In addition, the original LRPP commits to maintaining at least a 65% filter adoption rate. Definitions are provided in Table 7 to describe the consistent application of the data from the filter adoption survey when measuring the filter adoption rate. The percentage filter

¹⁵ See Denver Water’s [Lead Service Line Replacement Program](#) webpage.

¹⁶ See Denver Water’s [Using Filters webpage](#).

adoption for drinking and/or cooking and infant formula is used as a single input in the equivalency model. In accordance with paragraph 5.E.ii of the LCR Variance, each program year’s total filter adoption rate is shown in Table 7. The filter adoption rates for drinking, cooking and infant formula preparation are provided in Table 9.

TABLE 7. DEFINITIONS FOR FILTER ADOPTION RATE AS USED IN THE EQUIVALENCY MODEL

YES to filter use for drinking water	= Q1 yes pitcher filter + Q1 alternative filter/bottled water
YES to filter use for cooking	= Q2 yes + [Q2 no <u>and one of</u> Q2a bottled water + Q2a alternative filter + Q2a do not cook + applicable Q2a other]
YES to formula-fed infant¹	= Q2 yes + [<u>and one or more of</u> Q3a N/A + Q3a pitcher filter + Q3a bottled + Q3a alternative filter]
TOTAL Filter Adoption Rate	= 1 x (yes drinking, yes cooking, yes formula-fed infant) (as defined in the Order) + 0.5 x (yes drinking, yes formula-fed infant only) ÷ total eligible responses
Percent filter adoption for drinking	= (YES to filter use for drinking water) ÷ total eligible responses
Percent filter adoption for cooking	= (YES to filter use for cooking) ÷ total eligible responses
Where total eligible responses = mailed responses with answers to Q1, Q2 and Q3 + electronic responses using the “submit” button	

¹ Includes customers that responded that they do not have a formula-fed infant in their household and customers that are not expecting.

TABLE 8. YEAR OVER YEAR COMPARISON OF FORMAL FILTER ADOPTION SURVEY

	2020	2021	2022
Number of OMB Approved Filter Surveys Mailed per Year	20,000	15,000	15,000
Number of OMB Approved Filter Surveys Received per Year	3,987	2,116	1,512
Filter Adoption Rate used in the Equivalency Model	80%	81%	83%

TABLE 9. YEAR OVER YEAR COMPARISON OF FILTER ADOPTION RATE ESTIMATES

Question	Percent 2020	Percent 2021	Percent 2022
Q1. Filtered or bottled water used for drinking water	93%	94%	93%
Q2. Filtered or bottled water used for cooking ¹	68%	71%	73%
Q3. Filtered or bottled water used for formula-fed infant in households that self-identify as an existing or expecting family	97%	93%	94%
Total Filter Adoption Rate as used in the equivalency model²	80%	81%	83%

¹ Includes those customers that responded that they do not cook.

² As described in paragraph 5.E.ii of the LCR Variance and the number used in the equivalency model.

Section 5.F.ii of the LCR Variance requires that Denver Water “confirm performance of filters in use at Customer Premise.” To confirm that customers enrolled in the Filter Program are effectively using filters to reduce lead exposure, the LCR Variance requires that “Denver Water must collect samples from filters in at least 50 locations in use by customers enrolled in the Filter Program who are also enrolled in Denver Water's compliance tap sampling program.”¹⁷

Results from post-filter water quality testing can be used to identify poor-performing filters if lead breakthrough is measured. In 2020, 72% of post-filter results were non-detect, with 10% of results above 3 µg/L lead. In 2021, 89% of post-filter results were non-detect, with 2% of results above 3 µg/L lead. In 2022, 87% of post-filter results were non-detect, with 3% of results above 3 µg/L. Overall, field testing of pitcher filters has shown high degrees of lead control.

TABLE 10. POST-FILTER LEAD RESULTS

Post Filter Lead Results	2020	2021	2022
Non-detect	78	99	90
Lead < 2.5 µg/L	19	11	10
Lead ≥ 2.5 µg/L	11	2	3

Communications Outreach and Education

Denver Water is committed to its public outreach and education efforts, strategies described in the annual COE Plan.¹⁸ Activities include community meetings and events, holding a Stakeholder Advisory Committee, developing materials to obtain customer consent for replacements, and other COE-specific efforts that relate to each element of the LRP. Denver Water’s LRP website has webpages specific to community partners and events and resource

¹⁷ Note the filter manufacturer thresholds and ANSI/NSF 53 standards were set to 10 µg/L, but have been updated to 5 µg/L per the 2019 ANSI/NSF 53 update.

¹⁸ See the [2022 Annual Report](#), Appendix COE-17, for the 2023 COE Plan.

materials to offer customers online educational materials and opportunities to learn more about the LRP in their community.^{19,20}

Section 7.B.vi of the LCR Variance requires that Denver Water report and maintain records for COE activities. Since the inception of the program, the COE program has achieved:

- Annual direct contact with at least 95% of Filter Program participants.
- Outreach to obtain consent for service line replacement within 91 days of all changes in ownership for a property on the Service Line Refusal List.

Denver Water continues to submit an annual COE Plan to outline the upcoming year's planned efforts.

Health Equity and Environmental Justice

HE&EJ serves as a foundational component of the LRP. Through this lens, Denver Water has actively worked for inclusive access and participation for everyone that is enrolled in or impacted by the LRP. Denver Water provides water pitcher filters (along with replacement cartridges) and fully replaces customer owned lead service lines with no out-of-pocket costs incurred by the customer, which helps ensure all customers have an opportunity to participate. The annual filter survey insights reveal broad participation across the diverse demographics within the program area, and we continue to build, strengthen, and expand our efforts to reach communities where they live. As a result of our focus on applying HE&EJ principles to all our work, the LRP has created a strong network of positive relationships between Denver Water and our customers, their families, neighbors, and communities throughout the program area.

HE&EJ principles have been integrated into every aspect of the LRP, including COE activities. This commitment created a holistic mindset that allowed HE&EJ principles to shape when and how Denver Water invited and involved community members in the program.

Denver Water met the following metrics in the first three years of the program.

1. Prioritization of replacements and filter distribution in areas of high HE&EJ concern.
2. Focus on replacement of LSLs at schools and childcare centers.
3. Denver Water's Ambassador Program is a partnership with community organizations to educate customers in harder to reach communities about the LRP. These partners often are in or serve a disproportionately impacted geographic community or support distinct cultural communities. These customized collaboration efforts use HE&EJ principles to expand the LRP's reach, build awareness of program requirements and create momentum for behavior change in the appropriate language and culture most valued in those communities.

¹⁹ See Denver Water's [Community Partners and Events](#) webpage.

²⁰ See Denver Water's [Resource Materials](#) webpage.

Equivalency Model

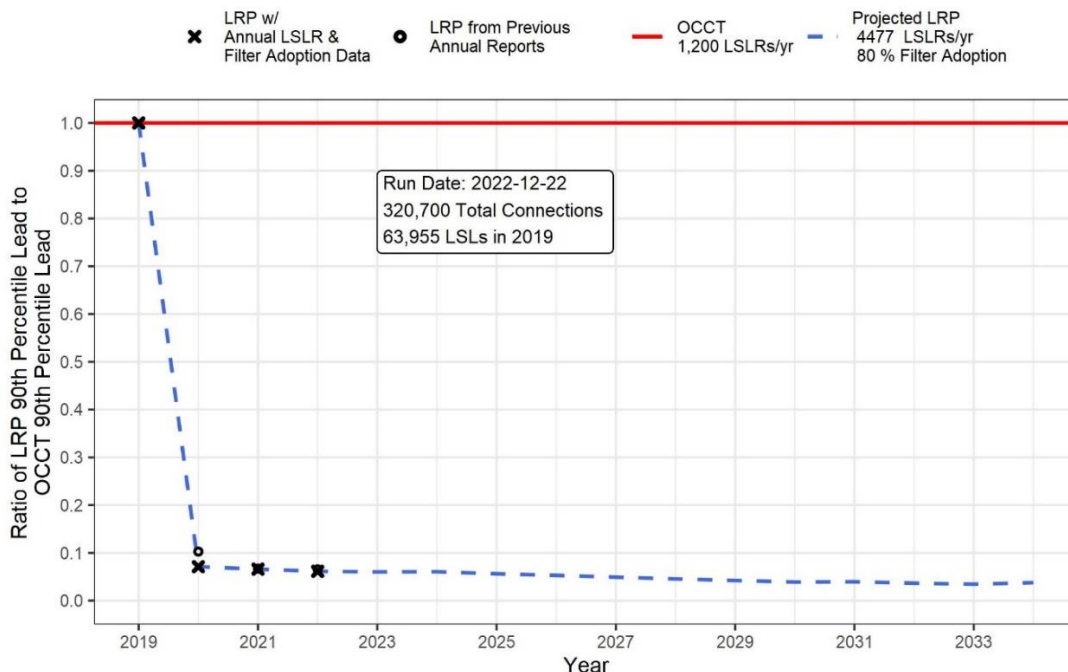
Section 7.C of the LCR Variance requires Denver Water perform a “comprehensive evaluation of the LRPP performance to date using the equivalency model described in the LRPP with updated inputs based on actual LRPP implementation for: 90th percentile lead levels at LSL and copper with lead solder sites after operation of increased pH and alkalinity adjustment as CCT, number of LSL replacements conducted, filter adoption rate, and filter performance in the field.” The metric is calculated or generated using actual performance data for various elements of the LRP to show the program “as implemented continues to be ‘at least as efficient as’ orthophosphate treatment in reducing lead exposure on an annual basis.”

The inventory and replacement data are collected for the same period to integrate comparable data into the model and to avoid any data gaps.

The primary output of the model is an indexed performance of the LRP to the presumed optimal corrosion control treatment (OCCT) conditions for each year, as shown in Figure 4. Results less than or equal to 1.0 demonstrate the LRP is “at least as efficient as” OCCT and in compliance with the LCR Variance. The points in Figure 4 reflect actual conditions each year (shown as a black X), the lines reflect projected numbers for future years (shown in solid red for the OCCT condition and dashed blue for the LRP condition).

The results of Figure 4 indicate that system-wide lead concentrations are significantly lower than they would have been under OCCT conditions. Thus, Denver Water has demonstrated better performance of the LRP compared with OCCT for every program year.

FIGURE 4. EQUIVALENCY MODEL OUTPUT FOR 2022



ASSESSMENT OF PROGRAM CHANGES NEEDED TO COMPLY WITH LCRR VARIANCE

Compliance Metrics per LCRR Variance

A summary of the required performance metrics from the LCRR Variance is provided in Table 11, with changes from the LCR Variance highlighted.

TABLE 11. SUMMARY OF COMPLIANCE METRICS EFFECTIVE WITH LCRR VARIANCE

Paragraph	Description in the LCRR Variance	Changes
2.C	For the entry points to the distribution system, pH must fall within a range of 8.6 to 9.0 and a minimum alkalinity of 20 milligrams per liter (mg/L) as CaCO ₃ ; for distribution system location, pH must fall within a range of 8.5 to 9.1 and a minimum alkalinity of 20 mg/L as CaCO ₃ .	Specifies the pH range and minimum setpoint for alkalinity rather than minimum targets for pH as directed by CDPHE.
3.D	Investigate a cumulative average of 1.4% of the total estimated number of unknown service lines in the inventory each Program Year from January 1, 2020, to the Variance End Date	Now calculated using a cumulative annual average.
4.I	Annually achieve at least a 7.0% cumulative average Program Year LSL replacement rate	Now calculated using a cumulative annual average. ²¹
5.G	Make direct contact with lead outreach and education materials to 95% of all customers enrolled in the filter program in every Program Year.	No change. See 6.C of LCRR Variance.
6.B	Demonstrate, using the updated equivalency model results, that the combined actual performance of the LRPP as implemented continues to be “at least as efficient as” OCCT in reducing lead exposure on an annual basis.	Previously referred to orthophosphate; the LCRR Variance now refers to OCCT. Provides more clarity on the definition of OCCT and allows EPA to request a new OCCT study if compliance metrics are not met, consistent with the LCRR.
6.C	Annually achieve a cumulative Program Year LSL replacement rate in areas with HE&EJ concern that is equal to or greater than the total replacement rate. Make direct contact with lead outreach and education materials to more than 95% of customers as identified in areas with HE&EJ concerns enrolled in the filter program in every Program Year.	New quantitative metric to focus outreach, identification and ultimately replacements within areas with HE&EJ concerns.

²¹ Refer to [2022 Annual Report, page 49](#), for details on how the cumulative average annual replacement rate is calculated.

AMENDED LEAD REDUCTION PROGRAM PLAN

The purpose of this technical amendment is to discuss the changes from the original 2019 LRPP during the first three years of the program as well as any changes necessary to comply with the new terms and conditions of the LCRR Variance (the LCR Variance Order is no longer in effect and is replaced by the LCRR Variance Order). These deviations were previously communicated, approved, and acknowledged by CDPHE and EPA. In this section, these deviations are described for each element of the program to reflect changes already approved and to communicate changes to accommodate the LCRR Variance.

Deviations from Original LRPP

Corrosion Control Treatment

- In March 2020, Denver Water began CCT by adjusting the pH and alkalinity of treated water to meet water quality setpoints at the point of entry and across the distribution system. The pH adjustment caused observable lead levels to decrease. To reflect the observed impact of CCT on lead release measured in water quality samples, the threshold used as an indicator of a lead service line was reduced from 5 µg/L to 3 µg/L.²² Samples collected on May 1, 2020, and after with lead measured above 3 µg/L are considered lead. Samples collected prior to May 1, 2020, are assessed using the original threshold of 5 µg/L.
- Section 7 of the LCRR Variance (Nov. 30, 2022) does not require monthly reporting.²³ Data originally included within monthly reports required under the LCR Variance (Dec. 16, 2019) will be summarized in the semi-annual reports required under the LCRR Variance and additional information can be provided, if requested. Note that, per CDPHE's Regulation 11, reports with lead and copper sampling results will continue to be submitted after each monitoring period (semi-annually).
- Section 2.C of the LCR Variance (Dec. 16, 2019) required compliance with CDPHE's set pH range and alkalinity minimum targets. These were subsequently revised to include a range for pH and minimum for alkalinity at the point of entry (pH range of 8.6 to 9.0, minimum alkalinity of 20 mg/L as CaCO₃) and the distribution system (pH range of 8.5 to 9.1, minimum alkalinity of 20 mg/L as CaCO₃) as directed by CDPHE in 2021 and adopted in the LCRR Variance (Nov. 30, 2022).²⁴

LSL Inventory

- On Jan. 24, 2020, Denver Water changed the terminology used in the public inventory map posted to the website from "lead, copper or unknown" to "confirmed lead service line, likely lead service line, unlikely lead service line or no lead service line," as communicated

²² See the [First Semi-Annual Report for 2021](#), page 17, for documentation of the change.

²³ See [LCRR Variance](#), dated Nov. 30, 2022, Section 7, pages 18 through 20 for reporting requirements.

²⁴ See letter from CDPHE, titled "Requirements Change Notice Water Quality Parameters for Corrosion Control Treatment", dated June 9, 2021.

in writing to CDPHE and EPA.²⁵ Beginning in 2024, Denver Water plans to modify the terminology to reflect what is used in the LCRR: lead, non-lead, unknown (likely and unlikely lead), galvanized requiring replacement.

LSL Investigations²⁶

- During the First Program Year, the three-bottle water quality test was found to be ineffective at schools, multi-unit properties and commercial properties due to the complexity of the premise plumbing.²⁷ For investigative purposes at these types of properties, other methods are used, such as potholing and visual inspections, in place of water quality sampling. To meet the Section 4.E LCR Variance requirement to offer post-LSLR water quality sampling, a single bottle sampling procedure is used to identify potential lead sources within premise plumbing.²⁸ Single bottle sampling is also used for pre-LSLR water quality sampling to maintain consistency for the customer. This practice is continued under the same section of the LCRR Variance; however, Denver Water will shift to new sampling techniques if a more effective methodology is determined.
- The original LRPP states that all residents in a multi-family property added to the refusal list for service line replacement will be enrolled in the Filter Program and receive educational materials and a water quality sampling kit.²⁹ However, all customers at multi-family properties were previously enrolled in the Filter Program at the start of the LRP and therefore continue to receive filter replacements and educational materials. Duplicate materials or water quality kits are not distributed in these instances. Rather, these customers continue to receive filter replacements and ongoing educational materials on the regular schedule and can request a water quality test kit if desired.
- Under the LCRR, the 5th L sample is required for compliance lead sampling. Customer-requested and investigative water quality sampling performed under the LRP will continue to use the three-bottle sampling method.³⁰ Second and third-liter water quality sampling results are good indicators for LSLs in single-family homes and maintaining this sampling method will allow consistency in data, helping the LRP Team detect trends and changes over the duration of the program. Additionally, maintaining the three-bottle sampling method will allow for straightforward communication with customers, as all sampling protocols will be the same. Denver Water will continue to submit all sampling results in the semi-annual and annual reports, but the LCRR compliance samples will not include most customer-requested samples unless they meet Tier I sampling requirements. Denver Water will shift practices, as needed, once the Lead and Copper Rule Improvements (LCRI) are announced.

²⁵ See letter to CDPHE and EPA, titled “Notice Concerning Publication of Inventory”, dated Jan. 24, 2020.

²⁶ Refer to the CCT section of this report for additional water quality-related items.

²⁷ See the [2019 LRPP, page 33](#), and Denver Water’s [online lead sampling instructions](#) for more details on the methodology.

²⁸ See [2020 Annual Report](#), page 26.

²⁹ See [2019 LRPP](#), page 62 and 63.

³⁰ See the [2019 LRPP, page 33](#), for more details on the methodology.

- Per Section 3.B of the LCR Variance (and maintained in the LCRR Variance), investigations can be performed using water quality sampling, potholing, visual inspections, or other means to support the determination of the service line material. Denver Water requested clarification that an investigation to confirm the current status of the service line without resulting in a change in its material designation of lead (i.e., the p-value) can be counted as an investigation to support the determination of the service line material. This request for clarification was confirmed Jan. 5, 2022, and therefore all investigations, whether or not they result in a change to the material designation (i.e., p-value), are counted toward the compliance metric for the number of investigations performed each year.
- Section 3.D of the LCR Variance required investigations to be undertaken at 1.4% of properties designated as possible and suspected lead service lines in the inventory, or about 1,169 service lines per year. Section 3.D of the LCRR Variance requires investigations to be performed at a cumulative annual average of 1.4% of all unknown service lines identified in the inventory, or 2,420 per year. Denver Water continues to focus on the use of desktop reviews, potholing, water quality tests, a predictive model, and interior inspections to meet the required metric.^{31,32,33,34}

Accelerated LSL Replacement

- Section 4.A of the LCR Variance required the replacement of 7.0% of lead service lines in the inventory, or about 4,477 service lines per year.³⁵ Section 4.A of the LCRR Variance requires the replacement at a cumulative annual average of 7.0%. This means that if the annual replacement rate falls below 7.0%, it does not require a public notice unless the cumulative annual average falls below 7.0%. Denver Water continues to replace lead service lines to meet, if not exceed, the 7.0% cumulative average annual replacement rate.
- Section 4.H of the LCRR Variance that no properties are to remain on the Service Line Refusal List by the Variance End Date. In order to ensure this requirement is met, Denver Water will need to revisit properties where consent was not given to perform an LSL replacement. This may involve the use of additional measures to ensure the LSL replacement is made, such as a requirement to replace.

³¹ See [2022 Annual Report](#), pages 36 through 42, for more information on how investigations are conducted and how they count towards the 1.4% requirement.

³² Refer to Appendix III.B.3 (pages 300 through 319) of the 2019 LRPP for more details on the implementation of the predictive model.

³³ See Appendix 1 – LSLI Improvements for more details.

³⁴ The predictive model is updated monthly based on the latest data set of field findings to refine predictions. As more data become available, the ability of the model to differentiate lead from non-lead services is improved and the estimate of the total number of lead services in the water system is refined.

³⁵ This is based off of the base inventory lead service line estimate of 63,955. See [LCR Variance](#), dated Dec. 16, 2019, page 11, for more details.

Filter Program

- Section 5.E.ii of the LCR Variance and the LCRR Variance require that all survey responses be used to calculate the filter adoption rate. As was the practice under the LCR Variance, there are two cases when a filter survey response is removed from the calculation. Filter adoption survey participants who do not respond to survey questions 1, 2 and 3 are not included in the filter adoption calculation. Online filter survey participants who fill out but do not select the “submit” button on their online survey are also not included in the calculation.
- Lead service lines are replaced at any point in the service life of the customer's current pitcher filter. To streamline the process and to provide a filter cartridge for the required six months post-replacement, the customer is provided with a new replacement filter cartridge when the lead service line is replaced, regardless of where they are in their current filter cartridge service life.
- Measurable lead in samples obtained from filter testing in the field is defined as greater than 1 µg/L as clarified in email correspondence from EPA on Sept. 16, 2020.
- If lead is measured ≥ 10 µg/L at LCR compliance sites included in filter performance testing in the field, the pitcher filter is removed, and the customer is provided a new pitcher filter.³⁶
- Section 5.E.i of the LCRR Variance removes the requirement to conduct a filter adoption survey every year and instead requires the survey be conducted every other year. The first survey under the LCRR Variance will be conducted in the latter half of 2023, using the survey questions approved by EPA on Sept. 10, 2020. Proposed minor updates to the survey questions for 2025 and 2027 were submitted to EPA for review on Feb. 7, 2023.
- From time to time, the filter manufacturer may change the filter design or model number as was the case in early 2021, when a change in filter cartridge model was made by the filter manufacturer.³⁷ The new testing procedure simplifies the previous protocol³⁸ and only tests pH and alkalinity from Denver Water’s distribution system. The new model of filter cartridges was distributed to customers in the Filter Program starting in February 2021.
- Per the original LRPP, if the filter adoption rate is calculated less than 65% in a year, a commitment was made to increase outreach and education efforts to improve filter use and a notice would be made to customers of the corrective actions taking place. The LRPP included a clause that failure to achieve a 65% adoption rate for three years would result in termination of the LCR Variance and a public notice would be issued to all customers. Under the LCRR Variance, the frequency of filter surveys is reduced to every other year. In addition to increasing outreach efforts, corrective action will include increasing the survey frequency back to every year. If the cumulative adoption rate drops

³⁶ Refer to the CCT Implementation Plan submitted on June 6, 2020, and approved by EPA on July 17, 2020, for a description of this process.

³⁷ See letter to CDPHE and EPA, titled “Notice of Filter Change and Testing”, dated Jan. 11, 2021.

³⁸ See technical memorandum prepared by Corona Environmental Consulting, dated Dec. 13, 2019.

below 65% for three consecutive years Denver Water must follow Section 8.E. of the LCRR Variance and may result in revocation of the Variance.³⁹

- Per Section 5.E.i.b of the LCRR Variance, Denver Water no longer needs to meet a static minimum survey response (1,059 responses) and rather is required to receive the minimum responses from the remaining program participants that is consistent with a 95% confidence level and 3% margin of error.

Communications Outreach and Education

- Under Section 5.D of the LCRR Variance, COE efforts related to the 1983-1987 Homes Program will focus on maintaining accessible online information for 1983-1987 homes and the opportunity to request a water quality test kit, rather than focusing on proactive outreach.
- A variety of outreach methods are available to encourage customers to sign the consent form for service line replacement. Under Section 4.G of the LCR Variance, two mailed and one door-knocking attempts were required. As of 2023, methods such as phone calls or emails may be used in lieu of mailings or door-knocking, if appropriate. This revised approach was adopted in Section 4.G of the LCRR Variance.
- The original LRPP mentions several surveys on filter use that would be completed throughout each year.⁴⁰ Instead, in the first three years of the program, the LRP implemented four channels for surveys focused on filter use:
 - The annual filter adoption survey, requirements for which are outlined in the LCRR Variance.
 - Informal surveys conducted in the field by crews as they visit customer properties to discuss the construction of the service line replacement process.
 - Informal surveys conducted during community meetings and/or by community partners engaging with community members who are in the LRP.
 - Surveys conducted in the field during filter performance testing.

Health Equity and Environmental Justice

- A new quantitative metric related to HE&EJ was incorporated into Section 6.C of the LCRR Variance, requiring that the cumulative average annual replacement rate within areas of HE&EJ concern be greater than or equal to the overall cumulative average annual replacement rate.⁴¹ An area of HE&EJ concern for the purpose of this metric is defined using the supplemental indices of EPA's EJScreen mapping tool.⁴²
- Denver Water uses a prioritization model to identify work areas that may be of HE&EJ concern for the upcoming year.⁴³

³⁹ See [LCRR Variance](#).

⁴⁰ See [2019 LRPP](#), page 55.

⁴¹ See pages 77 through 79 of the [2022 Annual Report](#) for more details.

⁴² Refer to EPA's [EJScreen](#) for a list of supplemental indices.

⁴³ See pages 80 and 81 of the [2022 Annual Report](#) for more details.

Learn by Doing

Denver Water continues to incorporate Learn by Doing (LBD) evaluations to improve outcomes during the life of the LRP and presents LBD items in the semi-annual and annual reports as well as the annual LBD summary report.⁴⁴ Since the inception of the program, Denver Water has documented over 500 improvements using the LBD approach with all program elements. Some examples of these improvements include:

- Risk Registry, which identifies potential risks and mitigation steps for the LRP.
 - o Example log entry: Additional work related to federal funding may overburden the team without additional help and/or planning.
- Decisions Log documents decisions made to implement the LRP consistently and effectively.
 - o Example decision: The most recent filter adoption rate will be used for the equivalency model now that surveys are conducted every other year.
- Assumptions Log details the programmatic approach to implementation, which allows for better planning and program execution.
 - o Example assumption: For annual replacement planning, it is assumed that the percentage of premises within a geographic task order that are expected to have a lead service line is 70%, or the historical replacement rate within that work area, whichever is higher.
- LBD Log details examples throughout the LRP that the team was able to learn from and improve practices.
 - o Examples can be found in the annual LBD reports.
- Contractor LBD Sessions are held bi-annually in order to obtain feedback and improvements from the accelerated lead service line replacement (ALSLR) contractors.
 - o Example: Contractors perform internal flush post replacement and also provide customer with a pre-construction checklist.
- Material Designation Log is a matrix that identifies different service line investigation scenarios and aggregated data collected and allows the LRP to make final determinations on the service line material.
 - o Example: A property with four potholes (two main to meter and two meter to building) showing copper is designated as a non-lead service line.

LRP Performance using the Equivalency Model

There have been no major deviations to the assumptions and application of the equivalency model since the presentation in the LRPP, however, the impact of federal funding will influence annual performance.⁴⁵ With federal funding, Denver Water expects the equivalency model curve to change as a function of a) the progress achieved to complete the inventory (identifying lead) and b) the number of replacements completed each year, which is expected to

⁴⁴ See Learn by Doing reports for [2020](#), [2021](#), and [2022](#) for more details.

⁴⁵ See Appendix II.A (pages 168 through 208) of the [original LRPP](#) for more details on how the equivalency model is implemented.

almost double with federal funding. The basis for comparison (OCCT with orthophosphate) does not change.

Under the LCRR Variance, the filter adoption survey is conducted every other year. For the purposes of the equivalency model and dashboard reporting, the previous year's adoption rate is used during the years in which the survey is not conducted,. For example, in 2024 Denver Water will not be conducting a survey and therefore will use survey results from 2023 for the 2024 equivalency modeling input.

CONCLUSION

The original LRPP submitted to EPA and CDPHE in 2019 was to support the proposal for a variance to orthophosphate treatment. As a result, the LRPP was used as guidance to the methodology in which the program would meet public health needs. It has been over three years since the inception of the LRP, which now operates under an updated Variance, dated Nov. 30, 2022, and the program has evolved. As the program incorporates minor updates to the LRPP, they are cataloged and reported to EPA and CDPHE. The purpose of this LRPP technical amendment is to summarize those changes. Denver Water continues to implement the LRPP faithfully and will continue to report any adaptations when the LCRR goes into effect. The LCRR Variance will expire when the LCRI goes into effect, and Denver Water will work closely with CDPHE and EPA to develop a new Variance under the LCRI, and any adaptations will be communicated, as necessary.

APPENDIX 1 – LEAD SERVICE LINE INVENTORY IMPROVEMENTS

Version 2.0: July 17, 2023

Presented by: Denver Water



OVERVIEW

In the original Lead Reduction Program Plan submitted Sept. 6, 2019, Denver Water detailed i) the preliminary identification of lead service lines, based on historical data, and ii) the preliminary development of the predictive and prioritization model to sequence the work areas.¹ As the LRP progressed and more field data became available, service line materials were updated in the lead service line inventory, and the predictive model was used to identify trends in the field data to improve the model's accuracy of predictions.

Denver Water uses a combination of desktop reviews, investigations and replacements of service lines, and a predictive model to drive changes in the lead service line inventory. The ultimate goal of refining the lead service line inventory (LSLI) is to designate all services lines in the water system as either confirmed lead, galvanized service lines requiring replacement (GRRs), or non-lead.

Our most recent inventory was shared in the 2022 Annual Report submitted Feb. 10, 2023.

DESKTOP REVIEW

Desktop reviews of historical data were first used in 2014 to establish high-level estimates of lead service lines. These desktop review efforts expanded further in 2019 to build the initial lead inventory to determine a property's service line material. A desktop review is used to collect, organize, and combine available data for a given property using methodologies that do not require a field investigation. Datasets, such as plumbing permits, tap permits, work orders, field notes, and customer-supplied information, typically support a desktop review.

The desktop review process consists of a review of existing documentation pertaining to a specific property and its service line. Typically, the purpose of the review is to determine if there is sufficient supporting evidence to indicate if a service line is non-lead, commonly due to a replacement conducted prior to the Lead Reduction Program (LRP) (pre-2020).

Desktop reviews support lead service line (LSL) replacement activities and investigations to advance the inventory and contribute toward the compliance metric defined in the Lead and Copper Rule Revisions (LCRR) Variance.

The supporting evidence used in a desktop review varies, as does the information available for each individual property. Generally, supporting evidence consists of construction and plumbing permits, Denver Water work orders (housed in Maximo, Denver Water's Computerized Maintenance Management System that tracks work orders and Denver Water assets), customer submitted proof of replacement or other field notes. Records indicating a

¹ See Appendix III.B.2 (pages 272 through 299) and Appendix III.B.3 (pages 300 through 319) of the [2019 LRPP](#) for more details.

partial service line replacement require additional verification, either through desktop or field investigation, to confirm that the entire service line is non-lead following the partial replacement.

Most desktop reviews are property-specific and are tracked in the LRP database as such, clearly defining the address, the reason for the review and the resulting action. Larger scale desktop reviews are also performed to focus on a particular set of records with specific attributes in common. The material designation of a property (and its associate p-value) is updated in the LSLI as a result of the desktop reviews with records resulting in a confirmation of service line material.

PREDICTIVE MODEL

A predictive model (also known as machine learning) is used in the LRP to locate and assign a confidence to service line material. The predictive model is:

- A tool that looks for patterns in the data to predict material designations (non-lead or lead).
- Statistically driven.
- Used to refine the inventory and prioritize replacements based on health equity and environmental justice (HE&EJ) concerns and construction opportunities.
- Able to learn from existing work to designate a service line as confirmed lead or non-lead. The confidence is improved each time the model is trained on additional data generated by desktop reviews or field work.
- Based on principles of machine learning to fill in the gaps in information from existing records rather than undertaking labor-intensive excavation at every property.
- Applied to estimate the confidence in the assigned service line material category where information gaps exist.
- Updated using validated data to describe the service line material based on desktop reviews and field work.
- Tested for accuracy when applied to other records for service line material.

How the Predictive Model Works

The predictive model assigns each service line a score representing the probability of lead being present. This expands the p-value score from the 11 discrete values (e.g., 0, 0.5, 1) in the LSLI to a continuous range from 0 to 1 in the predictive model. The predictive model advances the decision logic developed for the LSLI by using input data based on a set of observed outcomes for lead or non-lead service lines and a series of variables that contain information characterizing properties, such as year built, year tapped, main install year and service line size.

The LRP replacements, field investigations, water quality sampling results and material verification data are incorporated into the model data set.

The training of the predictive model involves validation and testing. Every time the model is trained on new data, a subset of the training data set is set aside to validate the model and measure the performance and gauge how it will generalize the new data. Test data derived from

verifications in the field since the last model run (e.g., the previous month) are used to test previously trained and validated models. These test data include results from field investigations, water quality data, desktop investigations, and service line replacements and provide another independent check on performance. The major phases of the predictive model development and updates in an iterative process are as follows:

1. Update the confirmed service line material data set to include new field information from investigations, pre-construction verifications, and results from lead service line replacements.
2. Use the previous iteration of the predictive model on the new field data to understand prediction performance on this new, independent data, termed the test data set. Evaluate the model output probabilities based on the test data set and compare performance to previous iterations of the model.
3. Following the evaluation of the previous model output on the new field data, combine these data with all previous data to make a new training set. The training data are split according to industry best practices into new training and test data sets (75% and 25%, respectively) and the model is trained and tested. This grouping of data was determined to best balance training and verification of results in order to provide certainty in the model results and performance.
4. Run the predictive model over all service lines in the water system to generate new predictions. Quality Assure/Quality Check (QA/QC) the results against service line material designations.
5. Define actions based on the model output, such as recommendations for additional record reviews, field investigations and where to replace lead services.
6. Support planning and LRP execution with model output.

The predictive model is updated (re-trained) monthly based on the latest data set of aggregated field findings for training, validation, evaluation of performance and refinement of predictions. As more data become available, the ability of the model to differentiate lead from non-lead services is improved and the estimate of the total number of lead services in the water system is refined. The data inputs, the model itself, and the outputs (i.e., the probability of finding an LSL) are assessed at each training iteration. The predictive model accuracy is calculated based on the process of splitting the data for training (75%) and testing (25%) of the current training data.²

Application of the Predictive Model

During the first three years of the LRP, the LSLI served as the foundation of the LRP, with the predictive model evaluated against the LSLI. The two approaches to develop the inventory (desktop and predictive model) are used differently for decision-making and action: the LSLI is

² Predictive model accuracy will be discussed in further detail in the Predictive Model Technical Memorandum, to be submitted in late 2023.

used to manage properties categorized as either lead or non-lead, the predictive model assigns a probability of finding lead at a property and these probabilities are used to guide actions.

The LSLI is distinctly organized and managed: all properties designed as likely lead (i.e., with a p-value greater than or equal to 0.5) are included in the Filter Program, are provided with communication, outreach and education (COE) materials, and are subsequently managed by this designation. The predictive model confirms the service line material designation when there is agreement with the LSLI material designation at a property and provides opportunities to better understand material designations (and thus act) when there is less certainty or disagreement with an LSLI material designation. Such properties can be examined for corrections to the underlying assumptions or decisions of the LSLI as well.

Thus far, the predictive model has been used to prioritize enrollment in the Filter Program, prioritize replacement of lead service lines, and focus investigations around the uncertainty in the model to improve model performance. The predictive model will be used to designate the material of the service line (i.e., make p-value changes) to the LSLI, thus removing unknowns in preparation for the LCRR inventory due date.

INVESTIGATIONS

Investigations of service lines are carried out to refine the LSLI to improve the assumptions used to develop the LSLI.³ Investigations used at a given property include desktop reviews, water quality sampling, potholing and/or visual investigation. After 15 years of the LRP, there should be no remaining properties in the LSL Inventory categorized as unknown lead status (likely or unlikely), all confirmed lead should be replaced, and all properties in the LSLI should be designated as non-lead.

Per the LCRR Variance, Denver Water must investigate 1.4% of all unknown service lines in the initial LSLI. An unknown service line is defined as any service line that does not have a p-value of 0 (non-lead) or 1 (known lead). Denver Water considers four types of investigations that can be performed on service lines:

- 1) Potholing,
- 2) Desktop reviews,
- 3) Interior inspections, and
- 4) Water quality sampling.

A property can be counted towards an investigation up to four times (one time per category). An investigation does not need to result in a p-value change.

An investigation is counted as part of the LCRR Variance if all the following conditions apply:

³ Refer to the latest semi-annual report for the most up-to-date investigation practices.

- 1) The property is originally classified as a service line with unknown lead status, and specifically as likely lead.
- 2) The investigation was performed independently of LSL replacements.^{4,5}
- 3) The investigation was not the result of a customer-requested water quality sample.

Potholing can be used in combination with other investigation methods to determine that a property is designated “lead” or “non-lead” (i.e., p-value of 1 or 0, respectively). To confirm “non-lead,” there can be no lead or galvanized visually observed from potholing and interior inspections and there can be no contradictions with the desktop records review and/or water quality sampling results.

Investigation practices are continuously improved and/or made more efficient through learning by doing. The outcomes from investigations continue to refine both the predictive model and LSLI.

NEXT STEPS

The combined efforts of desktop reviews, predictive modeling and ongoing investigations serves to update the knowledge of lead use in the water system. Terminology used to design the material of a service line has been adjusted to comply with the Lead and Copper Rule Revisions. Inventory updates will continue to be provided in semi-annual and annual reporting.

⁴ Verification potholing that results in a copper material designation, and therefore does not result in a replacement, is counted as an investigation.

⁵ If Denver Water includes an investigation in the first semi-annual report and later replaces said LSL even though it was not originally planned, that investigation will still count towards the 1.4% metric and will not be removed from the investigation metric total.