OFFICIAL NOTICE & AGENDA
REGULAR MEETING

MEETING:	Wausau Water Works Commission	**MEMBERS:**	
DATE/TIME:	Wednesday, April 8, 2026 at 11:00 AM	Mayor Doug Diny (P)	Aaron Griner
LOCATION:	Wausau City Hall — Council Chambers 407 Grant Street, Wausau WI, 54403	Jim Force	Deb Hadley
		Peter Gelhar	

1 Consideration of the minutes of the preceding meeting(s).

March 3, 2026 Regular Wausau Water Works Commission Minutes.

2 Director's Reports.

- **a.** Capital Projects Planning and Initial Discussion
- **b.** Wastewater — Update on Headworks Screening Project, Cherry Street Lift Station Project, and Status of Class A Biosolids from WDNR.

3 Discussion.

- **a.** Discussion and Update on LSL Replacement Project for 2026 and related news on the nationwide cost of new regulations.
- **b.** Report for the Corrosion Control Treatment Optimization Study submitted to the WDNR.
- **c.** Discussion and Update on Influent, Effluent and Biosolids PFAS Testing.

4 Adjournment.

**Next meeting scheduled for May 5, 2026 @ 11:00 AM*

Mayor Doug Diny, President

NOTICE POSTED AT CITY HALL (407 GRANT STREET) AND TRANSMITTED TO THE OFFICIALLY DESIGNATED NEWSPAPER
DATE: 04/02/2026
TIME: 9:30 AM
POSTED BY: Wausau Water Works

This meeting can be viewed on
YouTube and Channel 981 on Cable TV

In accordance with the requirements of Title II of the Americans with Disabilities Act of 1990 (ADA), the City of Wausau will not discriminate against qualified individuals with disabilities on the basis of disability in its services, programs or activities. If you need assistance or reasonable accommodations in participating in this meeting or event due to a disability as defined under the ADA, please call the ADA Coordinator at (715) 261-6622 or ADAServices@wausauwi.gov to discuss your accessibility needs. We ask your request be provided a minimum of 72 hours before the scheduled event or meeting. If a request is made less than 72 hours before the event the City of Wausau will make a good faith effort to accommodate your request.

City of Wausau
(715) 261-6500 | clerk@wausauwi.gov
wausauwi.gov

OFFICIAL MINUTES
REGULAR MEETING

MEETING:	Wausau Water Works Commission	**MEMBERS:**	
DATE/TIME:	Tuesday, March 3, 2026 at 11:00 AM	Mayor Doug Diny (P)	Aaron Griner
LOCATION:	Wausau City Hall — Council Chambers 407 Grant Street, Wausau WI, 54403	Jim Force Peter Gelhar	Deb Hadley

Members Present: Doug Diny, Jim Force, Peter Gelhar, Aaron Griner
Members Not Present:
Members Excused: Deb Hadley
Present 4, Not Present 0, Excused 1

Noting the presence of a quorum, the Chairperson called the meeting to order at 11:03 AM.

1 Consideration of the minutes of the preceding meeting(s).

February 3, 2026 Regular Wausau Water Works Commission Minutes

- Motion to approve the minutes of February 3, 2026 by Griner. Seconded by Gelhar. Motion carried 4-0.

2 Director's Reports.

Report placed on file.

a. Lead and Copper Rule Improvements (LCRI) Compliance Date November 1, 2027.

Lindman reported that all lead service lines must be replaced by 2037 and noted Wausau Water Works Commission approved a mandatory LSL replacement ordinance and was sent but not approved by city council. Therefore, the city lacks an ordinance to require private-side replacements. EPA funding will likely end within one to two years, shifting costs to homeowners or the city. Diny added that 2026 may be the last year with full funding. Boers estimated about 3,000 city-side and 6,000–7,000 private-side lines. DNR inventory work continues, but principal forgiveness will drop to 50 percent after this year. New federal rules in 2027–2028 will require treating all unknowns as lead and increasing sampling. Lindman explained that meeting future replacement needs far exceeds current capacity. Force expressed disappointment with the program's limitations; Lindman agreed, citing statewide administrative challenges.

b. Corrosion Control Treatment Optimization Study Update and Timeline

Boers reported that the EPA-mandated study, started in 2022, is due to DNR by March 31, 2026. The likely recommendation is adding about 1 mg/L of polyphosphate, with final results pending additional lead samples and lead-loop testing. In response to Griner, Boers noted anticipated equipment needs may include a pump skid, day tank, and a dual pump skid system (estimated around $50,000), along with spill containment and piping, pending final results and available space.

c. Water Rate Increase History

Griner asked about remaining debt from the old facility. Lindman noted uncertainty regarding debt from the 1999–2001 for plant addition but confirmed state revolving loans utilized from 2015 to 2018 for capital projects. Groat added that only the 2017 and 2019 revenue bonds remain, with the 2017 bond nearing payoff. Force asked what a 3 percent rate increase would generate in revenue. Lindman said Ehlers would need to calculate that, and Diny noted fixed and meter charges would not increase at the same rate.

d. Updates on the Headworks Screening Project, Cherry St Lift Station Project and Status of

Approval for Class A Biosolids

Lindman summarized updates are in packet. We brought back the WPDES permit status for Class A Biosolids. Staff got in touch with Angela from WDNR updating Fred should be responding soon.

3 Discussion and Possible Action.

a. Approving Amendment #2 to the contract with Clark Dietz for the Cherry St and Crocker St Lift Stations.

Lindman reported that the amendment is needed due to added engineering time caused by contractor IGE's delays and submission of pumps that did not meet specifications. A compliant pump has since been selected. He noted the city will seek to have IGE cover most or all of the added costs and may pursue liquidated damages if necessary. In response to questions, Lindman stated the pumps were from Flygt and estimated the city's exposure could be up to half of the $25,000, though liquidated damages of up to $1,000 per day (and $500 after substantial completion) over 2–3 months would likely exceed that amount. An update will be provided once calculations are finalized if we have to follow through with litigation.

- Motion to approve amendment#2 to the contract with Clark Dietz for the Cherry Street and Crocker Street Lift Stations by Gelhar. Seconded by Griner. Motion carried 4-0.

b. Approving the Sole Source Purchase of a Backhoe for the Water Department.

Boers summarized the backhoe quotes are included and noted that the Fabick Cat model is preferable because existing attachments are compatible, avoiding the need for adapter plates or hydraulic retrofits. When Force asked about retrofit costs, Boers estimated roughly $5,000 for the hammer and $5,000 for the front-end attachment.

- Motion to approve the sole source purchase of a backhoe through FabickCat for Water Department by Force. Seconded by Gelhar. Motion carried 4-0.

4 Adjournment.

Next meeting scheduled for Wednesday, April 8th at 11:00 AM.

- Motion to adjourn by Griner. Seconded by Gelhar. Motion carried 4-0. Meeting adjourned at 11:33 AM.

The recording of this meeting may be viewed on YouTube @CityofWausauMeetings

Engineering
Eric Lindman, Public Works Director

DATE: April 8, 2026
TO: Wausau Water Works Commission
SUBJECT: Capital Projects Planning and Initial Discussion

PURPOSE

Initial discussion on the 5-year capital plan for Water and Wastewater.

BACKGROUND

Each year the Commission reviews and approves a 5-year capital projects plan. Attached is the 5-year capital plan that was approved last year. Staff has begun working on the updated plan and further discussions will come forward over the next couple of months for the Commission's approval. Since we have a couple new members on the Commission, I thought it beneficial to provide the summary of our current plan approved last year and have an initial discussion about the timeline for capital project plan approvals and the process. As part of this process we share our capital plan with our financial consultant, Ehler's and this is part of what they use to determine if our rate structure appears to be adequate for the proposed work. Ehler's will be presenting to the Commission at one of our meetings this summer, timing to be determined as we complete our proposed budget for the next five years.

RECOMMENDATION

None at this time.

Total Cost of Each Project by Year

Department - Project Name	Prior to2027	Current Year:2027	Year 1:2028	Year 2:2029	Year 3:2030	Year 4:2031	Unfunded	Total
Water Division								
2026 Lead Service Line Replacement	40,090,259	20,000,000	12,000,000	-	-	-	-	72,090,259
Asset Management Software	300,000	-	-	-	-	-	-	300,000
Asterra Leak Detection	45,000	-	-	-	-	-	-	45,000
Backhoe/ Excavator	180,000	-	350,000	-	-	-	-	530,000
Hydrovac Valve Turner	-	600,000	-	-	-	-	-	600,000
Meters and (Transmitters) Radios	200,000	100,000	100,000	100,000	100,000	-	-	600,000
Monroe Booster Reconstruction	60,000	-	500,000	-	-	-	-	560,000
New Well	-	-	-	700,000	-	-	-	700,000
Portable/On Site Generator	-	80,000	-	80,000	-	-	-	160,000
Reservoir Coatings and Maintenance	150,000	150,000	150,000	150,000	150,000	-	-	750,000
Reservoir Inspections	-	-	-	-	40,000	-	-	40,000
Vehicles	85,000	85,000	85,000	85,000	85,000	-	-	425,000
Water Main Looping	550,000	300,000	400,000	400,000	300,000	-	-	1,950,000
Water Main Replacement - 12th Street from Forest Street to Jackson Street	-	-	-	63,000	-	-	-	63,000
Water Main Replacement - 28th Avenue from Westhill Drive to West Wausau Avenue	100,000	-	-	-	-	-	-	100,000
Water Main Replacement - 2nd Street from Forest Street to Division Street	75,000	-	-	-	-	-	-	75,000
Water Main Replacement - 3rd Avenue from West Eldred Street to Randolph Street	-	-	160,000	-	-	-	-	160,000
Water Main Replacement - Brown Street from 5th Street to 13th Street	-	-	-	1,009,000	-	-	-	1,009,000
Water Main Replacement - Division Street from 2nd Street east to the dead end	-	-	-	-	-	-	-	-
Water Main Replacement - Ethel Street from Grand Avenue to Zimmerman Street	-	791,000	-	-	-	-	-	791,000
Water Main Replacement - Forest Street from Bellis Street to 12th Street	-	-	-	335,000	-	-	-	335,000
Water Main Replacement - Garfield Avenue from Marathon Park to 3rd Avenue	-	-	-	353,000	-	-	-	353,000
Water Main Replacement - North 11th Avenue from Elm Street to Cedar Street	-	-	-	-	412,000	-	-	412,000
Water Main Replacement - North 11th Street from East Crocker Street to Sylvan Street	-	-	264,000	-	-	-	-	264,000
Water Main Replacement - North 4th Avenue from Merrill Avenue to Randolph Street	-	-	-	-	395,000	-	-	395,000
Water Main Replacement - North 8th Avenue from Spruce Street to Bridge Street	400,000	-	-	-	-	-	-	400,000
Water Main Replacement - North 9th Avenue from Elm Street to Bridge Street	-	-	695,000	-	-	-	-	695,000
Water Main Replacement - Park Avenue from 2nd Street to 10th Street	-	-	-	-	798,000	-	-	798,000
Water Main Replacement - Plumer Street from Grand Avenue to Battery Street	-	-	-	-	434,000	-	-	434,000
Water Main Replacement - South 11th Avenue from West Thomas Street to Flieth Street	-	404,000	-	-	-	-	-	404,000
Water Main Replacement - South 17th Avenue from Sherman Street to Stewart Avenue	-	-	-	-	230,000	-	-	230,000
Water Main Replacement - Stark Street from 5th Street to 12th Street	775,000	-	-	-	-	-	-	775,000
Water Main Replacement - West Eldred Street from North 3rd Avenue to North 1st Avenue	-	-	136,000	-	-	-	-	136,000
Water Main Replacement - West Wausau Avenue from North 10th Avenue to Stevens Drive	242,000	-	-	-	-	-	-	242,000
Water Division Total	***43,252,259***	***22,510,000***	***14,840,000***	***3,275,000***	***2,944,000***	***-***	***-***	***86,821,259***

Total Cost of Each Project by Year

Department - Project Name	Prior to2027	Current Year:2027	Year 1:2028	Year 2:2029	Year 3:2030	Year 4:2031	Unfunded	Total
Wastewater Division								
Airport and 32nd Ave Lift Station Upgrades	-	1,320,000	-	-	-	-	-	1,320,000
Asset Management/Work Order Program	300,000	-	-	-	-	-	-	300,000
Automated Septage Receving Station	-	-	-	-	1,200,000	-	-	1,200,000
Biogas Conditioning Skid or New Microturbines and Gas Skid	-	-	1,309,000	-	-	-	-	1,309,000
Crocker St Lift Station	1,693,000	-	-	-	-	-	-	1,693,000
Forcemain Pigging and Cleaning	120,000	-	120,000	-	120,000	-	-	360,000
Interceptor Line H2S Repairs and Manhole Rehab	500,000	-	500,000	-	500,000	-	-	1,500,000
Lift Station Engineering Report & Design- 6 Lift Stations	100,000	100,000	-	-	-	-	-	200,000
New Lift Station Service Truck	-	-	200,000	-	-	-	-	200,000
New Sludge Truck	-	-	-	-	250,000	-	-	250,000
New Vactor Truck	-	-	800,000	-	-	-	-	800,000
Radio or Cellular Communications Upgrade at Lift Stations	83,500	90,000	-	-	-	-	-	173,500
Sanitary Sewer Replacement - 2nd Street from Forest Street to Division Street	75,000	-	-	-	-	-	-	75,000
Sanitary Sewer Replacement - Garfield Avenue from Marathon Park to 3rd Avenue	-	-	-	487,000	-	-	-	487,000
Sanitary Sewer Replacement - 12th Street from Forest Street to Jackson Street	-	-	-	42,000	-	-	-	42,000
Sanitary Sewer Replacement - 28th Avenue from Westhill Drive to West Wausau Avenue	100,000	-	-	-	-	-	-	100,000
Sanitary Sewer Replacement - 3rd Avenue from West Eldred Street to Randolph Street	-	-	82,000	-	-	-	-	82,000
Sanitary Sewer Replacement - Brown Street from 5th Street to 13th Street	-	-	-	705,000	-	-	-	705,000
Sanitary Sewer Replacement - Division Street from 2nd Street east to the dead end	-	-	-	-	-	-	-	-
Sanitary Sewer Replacement - Ethel Street from Grand Avenue to Zimmerman Street	-	530,000	-	-	-	-	-	530,000
Sanitary Sewer Replacement - Forest Street from Bellis Street to 12th Street	-	-	-	209,000	-	-	-	209,000
Sanitary Sewer Replacement - North 11th Avenue from Elm Street to Cedar Street	-	-	-	-	288,000	-	-	288,000
Sanitary Sewer Replacement - North 11th Street from East Crocker Street to Sylvan Street	-	-	194,000	-	-	-	-	194,000
Sanitary Sewer Replacement - North 4th Avenue from Merrill Avenue to Randolph Street	-	-	-	-	327,000	-	-	327,000
Sanitary Sewer Replacement - North 8th Avenue from Spring Street to Bridge Street	300,000	-	-	-	-	-	-	300,000
Sanitary Sewer Replacement - North 9th Avenue from Elm Street to Bridge Street	-	-	328,000	-	-	-	-	328,000
Sanitary Sewer Replacement - Park Avenue from 2nd Street to 10th Street	-	-	-	-	671,000	-	-	671,000
Sanitary Sewer Replacement - Plumer Street from Grand Avenue to Battery Street	-	-	-	-	271,000	-	-	271,000
Sanitary Sewer Replacement - South 11th Avenue from West Thomas Street to Flieth Street	-	380,000	-	-	-	-	-	380,000
Sanitary Sewer Replacement - South 17th Avenue from Sherman Street to Stewart Avenue	-	-	-	-	498,000	-	-	498,000
Sanitary Sewer Replacement - Stark Street from 5th Street to 12th Street	625,000	-	-	-	-	-	-	625,000
Sanitary Sewer Replacement - West Wausau Avenue from North 10th Avenue to Stevens Drive	176,000	-	-	-	-	-	-	176,000
Sewer Capacity Study of Wausau's Collections System	159,000	-	-	-	-	-	-	159,000
Slipline Sewers (Cured in Place & I&I Repairs)	-	525,000	525,000	525,000	525,000	-	-	2,100,000
Sludge Loadout Bldg. Addition, Class B Sludge Automatic Diversion and Concrete between STR. 770 & STR. 540	-	-	-	781,000	-	-	-	781,000
Str. 110 (Parking Garage) Roofing	-	-	-	-	282,000	-	-	282,000
Str. 115 (Cold Storage Bldg.) Remodel	-	-	-	312,000	-	-	-	312,000
West Eldred Street from 3rd Avenue to 1st Avenue	-	-	48,000	-	-	-	-	48,000
Wastewater Division Total	***4,231,500***	***2,945,000***	***4,106,000***	***3,061,000***	***4,932,000***	***-***	***-***	***19,275,500***

Wausau Water Works
Ben Brooks, Wastewater Superintendent

DATE: April 8, 2026
TO: Wausau Water Works Commission
SUBJECT: Wastewater — Update on Headworks Screening Project, Cherry Street Lift Station Project, and Status of Class A Biosolids from WDNR.

PURPOSE

Provide an Update on the Headworks Screening Project, Cherry Street Lift Station and Status of Class A Biosolids from WDNR.

BACKGROUND

Headworks Screening Project Update:
- Ahern & subcontractors mobilized: 06/16/2025.
- Substantial Completion Date: 10/15/2026.
- Final Completion Date: 11/15/2026.
- Installation of the West screen is in progress currently with a start-up date scheduled for 04/01/2026. Both new Headworks screens are installed now.

Cherry St. Lift Station Project Update:
- Integrity mobilized on site: 09/08/2025.
- Substantial Completion Date: 01/31/2026.
  (new lift station operating with demo work completed)
- Final Completion Date: 05/15/2026.
  (all work complete, with grass actively growing)
- Final start up training of the new lift station and generator occurred on April 1, 2026. Demolition of the old lift station building, lawn restoration and final punch list items remain.

Update from WDNR on Status of Class A Biosolids:
- The March 2026 update concluded that the WDNR would provide final Class A Biosolids designation approval in a few weeks per Angela Parkhurst.
- Current update from WDNR Basin Engineer Katie Jo Jerzak. Wausau Class A designation approval has been reassigned to a different WDNR Engineer, no name was provided at this time. It was also mentioned that other utilities around the State have also been experiencing long delays in the approval process and were told the same thing in that the approval process has been reassigned to someone else within the WDNR.
- Update to follow at May 2026 Commission Meeting.

RECOMMENDATION

Engineering
Eric Lindman, Public Works Director

DATE: April 8, 2026
TO: Wausau Water Works Commission
SUBJECT: Discussion and Update on LSL Replacement Project for 2026 and related news on the nationwide cost of new regulations.

PURPOSE

Better understand the financial burdens left on utilities related to the extensive regulations established over the past 5 years.

BACKGROUND

We have begun our 3rd year of LSL replacements. Each year, with changing requirements related to the funding, we have had to make changes to the project delivery program. Some of the challenges with the WDNR funding each year are the lateness of when we receive the final award amounts and how the WDNR is calculating its allocations as it relates to census tracts and census data. This year, one of the census tracts we have had a significant number of LSL's in changed with the new census data, it went from a 100% Principal Forgiveness (PF) allocation census tract to 75% PF allocation census tract. This tract allowed us to use 100% PF in 2024 and 2025, but now in 2026, this tract is only eligible for 75% of PF funding based on new census data. This change increased the amount of the subsidized loan required on the private side and decreased the amount of PF. CIP has run several different scenarios to try and maximize PF funding for 2026 and this scenario presented below maximizes the number of LSL's we can replace with the highest amount of PF. The funding allocations are shown below, and you can see the difference from last fall to this year. It is important to note that all loan funds shown below are the WDNR subsidized loans at 0.25%. There is not expected to be any additional borrowing in 2026 like there was in 2024 and 2025.

2026 Budget Request vs Funding Award			
2026 Budget Request — Nov 2025		**2026 Funding Award — Jan/Feb 2026**	
Private Side Replacements		**Private Side Replacements**	
Private Side (PF estimate)	$12,394,268.00	Private Side (PF estimate)	$7,580,832
Private Side (Loan 0.25%) — G.O. Borrow	$1,751,969.70	Private Side (Loan 0.25%) — G.O. Borrow	$3,367,709
Private Side Total =	**$14,146,237.70**	**Private Side Total =**	**$10,948,541**

Public Side Replacements		**Public Side Replacements**	
Public Side (PF)	$0.00	Public Side (PF)	$0
Public Side (Loan 0.25%) — Revenue Bond	$6,062,673.30	Public Side (Loan 0.25%) — Revenue Bond	$3,376,810
Public Side Total =	**$6,062,673.30**	**Public Side Total =**	**$3,376,810**

Wausau residents and the water rate payers have felt the full weight of the regulatory burdens the state and federal regulatory agencies have placed on local utilities. With the new regulations, the state and federal regulators have not provided near enough funding to support utilities/municipalities to keep up with the regulations and maintain compliance. Lack of financial support from regulators places the financial burden on rate payers and city taxpayers. This burden will continue over the next several years with these regulations being implemented and Wausau Water Works needing to meet compliance deadlines with these new regulations.

The Lead Service Line Replacement (LSLR) project, which is now required by the USEPA Lead and Copper Rule Improvements (LCRI), has some funding available but is billions of dollars short to even replace half the LSL's in the country. This means rate payers and/or taxpayers need to pay for the remainder to meet compliance; replacing these lines now with the funding available is the least expensive time to complete this work. The funding that has been made available here in WI is further burdened by the WDNR putting more restrictions on the funding, limiting how Wausau is able to use the funding. WDNR has significantly restricted the use of funding for public outreach, planning and homeowner engagement; a critical piece of the project to conduct replacements. The additional costs of the project will need to be taken on by rate payers. As you recall, the Commission passed a Mandatory Lead Service Line Replacement Ordinance. This ordinance was presented to the City Council and they did not approve the ordinance. The result is, all LSL's to be replaced with the USEPA/WDNR funding, require full replacement, and no partial replacements are allowed. Any private side costs not covered by the funding or eligible to be paid by rate revenue need to be paid by the city. Without an ordinance in place, the utility has no authority to require the replacement of the private side and no way to charge the homeowner back the cost of replacement. All LSL's must be replaced by the end of 2037, meaning an average 10% of LSL's need to be replaced each year. This will equal about 500–600 replacements each year. The cost of these replacements will have to be paid by the municipality/utility. The more LSL's we replace with available funding, the less expensive it will be for the utility, municipality and the rate payer. Funding is expected to run out in 2028.

Over the past 5–6 years, I have stated many times that the high number of new regulations being placed on utilities is historic. Each of these regulations comes with a cost and those costs are passed along to the users. Attached you will find an updated AWWA published document that looks at the significant number of new regulations and how this affects household affordability. The cost of these regulations is significant with a lack of funding to support their implementation. In this profession, we call these unfunded mandates.

There are groups/associations who work with municipalities and utilities to support mitigating some of this over regulation and impractical regulations. Through our membership, we support these groups, and they have been good advocates on behalf of municipalities. A couple of them are the American Water Works Association (AWWA), American Public Works Association (APWA), Municipal Environmental Group (MEG) and Water Research Foundation (WRF).

The attached document is lengthy and outlines many of the regulations and safeguards the utility.

RECOMMENDATION

NA

American
Water Works
Association

Beyond the Replacement Era:

Balancing Compounding Infrastructure Needs With Household Affordability

ONEWATER ECON

RAFTELIS

FOREWORD

Beyond the Replacement Era

Strong, reliable drinking water infrastructure underpins the health and economic vitality of our communities—but the cost of sustaining it is rising rapidly and straining household affordability.
Over the past quarter-century, the American Water Works Association (AWWA) has actively raised the conversation about buried water infrastructure above ground, defining the challenge, informing policymakers, and advancing solutions to assist communities and address affordability. Still, respondents to AWWA's 2026 State of the Water Industry survey name water infrastructure renewal and replacement as the top concern in the sector – as they do most every year -- followed closely behind by how to finance those improvements.

This new report verifies their deep-seated concerns. *Beyond the Replacement Era* provides an unprecedented assessment of the headwinds facing communities as they seek to provide robust, sustainable water services through the year 2050.

Key Takeaways from *Beyond the Replacement Era* include:

1. The Water Sector Has Entered a New Cost Era

Drinking water utilities are no longer facing just an asset-replacement challenge; they are confronting a compounding set of cost drivers that include regulatory compliance, climate resilience, cybersecurity, and treating more complex sources. Over the next 25 years (2026–2050), total drinking water infrastructure needs are projected at $2.1–$2.4 trillion (2025 dollars), far exceeding earlier estimates tied solely to buried infrastructure. These pressures signal a structural shift in the cost of providing safe drinking water, not a temporary spike.

2. There Is a Persistent and Growing Funding Gap

Current capital spending by drinking water utilities averages about $33.6 billion per year, while the annual investment needed to meet projected requirements is approximately $90.2 billion. This leaves an annual funding gap of roughly $56.6 billion, requiring a 168% increase in capital investment to close it. With a few exceptions (such as the Infrastructure Investment & Jobs Act (IIJA)), federal contributions have been limited — about 3.9% of total public infrastructure sector spending is on all water sector utilities, far below levels provided to other infrastructure sectors.

3. Household Drinking Water Bills Are Likely to More Than Double

If communities rely exclusively on revenue from water bills to close the funding gap, average annual household drinking water bills would rise from $429 in 2025 to $969 by 2050 (2025 dollars) — more than doubling in real terms. Even under a baseline spending scenario, bills are projected to increase to $685, reflecting rising operating and maintenance costs.

4. Affordability is at a Tipping Point

If the funding gap is addressed entirely through increases in household water rates, an estimated 30.4 million households (21.5%) would spend more than 2.5% of their income on drinking water, and 53.5 million households (37.8%) would exceed a 1.5% income threshold. The report estimates that $13.6 billion per year in assistance by 2050 would be needed to keep water bills below commonly cited affordability benchmarks. These impacts would disproportionately affect low-income households and small-system communities.

5. Core Federal Infrastructure Loan Programs are Critical

The IIJA provided a historic and much needed infusion of funding that expires after FY2026. However, it cannot fully solve the long-term gap. With total annual capital and O&M needs projected to reach $200.3 billion by 2050, temporary programs will not fully stabilize the sector. Core funding programs like the State Revolving Loan Funds (SRF) and the Water Infrastructure Finance and Innovation Act (WIFIA) remain critical, helping water utilities access low-cost loans with extended repayment periods and customizable terms. Reductions in financing costs can moderate rate increases and help keep water affordable.

AWWA's Infrastructure and Affordability Work in the 21st Century

Beyond the Replacement Era extends a series of AWWA reports that have characterized the U.S. water infrastructure challenge over the past 25 years. *Dawn of the Replacement Era* in 2001 introduced the reality that buried infrastructure, primarily the millions of miles of water mains across the United States, was entering a time where increased investment would be critical. Many of the findings from that report ring true today:

Pipes are expensive, but invisible
Pipes are hearty, but ultimately mortal
Increased expenditure is needed to climb the ramp and avoid a gap
Addressing affordability is at the heart of the challenge

In 2006, AWWA published *Water Infrastructure at a Turning Point*, which encouraged utilities to adopt asset management strategies to drive the systematic renewal of our water infrastructure. Using the metaphor of a well-maintained car to explain the need for proactive investment, the guide explained that utilities face a choice — the turning point—to either to adopt strategies that will lead to the systematic renewal of our water infrastructure or accept the erosion over time of reliable water service, public health, and environmental quality.

Buried No Longer: Confronting America's Water Infrastructure Challenge (2012) explored the drinking water infrastructure challenge in unprecedented depth, revealing the timing of water main installation and life expectancy, materials used, replacement costs and shifting demographics. It found investment needs for buried drinking water infrastructure alone would total more than $1 trillion nationwide over the 25 years (between 2011 and 2035). It determined needs would exceed $1.7 trillion through 2050, split roughly between replacement and expansion. The report noted the cost of these investments would be borne mostly by consumers through higher water rates.

Concurrently, AWWA advocated for a new federal loan program, culminating in 2014 with the passage of WIFIA. WIFIA has since served as an important complement to the critical SRF loans, which help water systems reduce the cost of infrastructure projects and moderate rate increases for consumers.

The Ides of Affordability

Throughout the infrastructure conversation, affordability concerns have steadily risen. In 2004, AWWA published the first of three editions of *Thinking Outside the Bill*, elevating the fact that water and wastewater rates in many communities were rising faster than inflation and low-income wages, leading households to spend an increasing percentage of their income on water and wastewater bills. The third edition (2022) provided new metrics for assessing affordability and an actionable guide to walk utility leaders through diagnosing the problem and identifying solutions.

As affordability concerns swelled, AWWA advocated for increased federal support through the Low-Income Water Assistance Program (LIHWAP). At the same time, it partnered with the National Association of Clean Water Agencies (NACWA) and the Water Environment Federation (WEF) on *Developing a Water and Wastewater Utility Assistance Program* to help utilities design comprehensive assistance programs for households struggling to meet essential needs.

Recognizing the potential for a significant affordability challenge related to federal regulations, AWWA organized an expert panel that created a report in 2021 titled *Improving the Evaluation of Household-Level Affordability in SDWA Rulemaking: New Approaches.* The project aimed to help regulators better understand affordability at a household level. As communities work to replace lead service lines and address PFAS contamination under new regulations, rising water rates will further stress households with lower incomes.

A Water 2050 Challenge

Beyond the Replacement Era for the first time captures the scope of the drinking water infrastructure alongside other critical pressure points impacting affordability. Its reckonings extend to the year 2050, providing a timely challenge for AWWA's Water 2050 visioning initiative. The Water 2050 vision strives for a secure, sustainable, affordable, resilient, and innovative water future.

One of the core principles of Water 2050 is that just waiting for change is not a strategy. *Beyond the Replacement Era* lays out the realities confronting our water systems, and it also makes clear that the future is not predetermined. If we move forward collaboratively and with clear intent, we can transform today's realities into a stronger, more resilient water future.

Sincerely,

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List of Acronyms

ACS	American Community Survey
ALICE	Asset Limited, Income Constrained, Employed
ASCE	American Society of Civil Engineers
AWIA	America’s Water Infrastructure Act
AWWA	American Water Works Association
BLS	Bureau of Labor Statistics
CBO	Congressional Budget Office
CDBG	Community Development Block Grant
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CEX	Consumer Expenditure Survey
CPI	Consumer Price Index
CWS	Community Water Systems
DWINSA	Drinking Water Infrastructure Needs Survey and Assessment
DWSRF	Drinking Water State Revolving Loan Fund
FPL	Federal Poverty Level
FRED	Federal Reserve Economic Data
GAC	Granular Activated Carbon
GASB	Governmental Accounting Standards Board
GPCD	Gallons per Capita per Day
HBI	Household Burden Indicator
IIJA	Infrastructure Investment and Jobs Act
IOU	Investor-Owned Utility
IPR	Indirect Potable Reuse
IT	Information Technology
IX	Ion Exchange
LACSD	Los Angeles County Sanitation Districts
LCR	Lead and Copper Rule
LIHWAP	Low Income Household Water Assistance Program
LIWCAP	Low Income Water Customer Assistance Program
LQI	Lowest Quintile Income
LQPI	Lowest Quintile Poverty Indicator
LRP	Lead Reduction Program
LSLs	Lead Service Lines
MCL	Maximum Contaminant Level
MGD	Million Gallons per Day
MHI	Median Household Income
MWD	Metropolitan Water District of Southern California
NACWA	National Association of Clean Water Agencies
NCEI	National Centers for Environmental Information
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration

NPDWR	National Primary Drinking Water Regulation
NRW	Non-Revenue Water
O&M	Operations and Maintenance
OBMUA	Old Bridge Municipal Utilities Authority
OCCT	Optimal Corrosion Control Treatment
OT	Operational Technology
PFAS	Perfluoroalkyl and poly fluoroalkyl substances
PPI	Poverty Prevalence Indicator
PUMS	Public Use Microdata Sample
PWSC	Pure Water Southern California
R&R	Rehabilitation and Replacement
RI	Residential Indicator
RPPs	Regional Price Parities
SDWA	Safe Drinking Water Act
TOC	Total Organic Carbon
U.S.	United States
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
WEP	Rural Development Water and Environmental Programs
WIFIA	Water Infrastructure Finance and Innovation Act
WPAFB	Wright-Patterson Air Force Base
ZLD	Zero-Liquid Discharge

Executive Summary

The American Water Works Association ("AWWA") has repeatedly highlighted the critical need for investment in drinking water system infrastructure, with prior assessments estimating more than $1 trillion nationwide over 25 years (2011-2035) to replace and expand aging drinking water systems.[1] Yet, these needs continue to escalate nationally as significant challenges and obligations on drinking water utilities compound. Beyond the ongoing costs to replace, repair, and expand infrastructure, drinking water utilities now face additional cost drivers associated with compliance with major federal regulations, the treatment of complex water sources, and essential resilience measures to protect against natural hazards and other threats. The research team evaluated projected capital and operating costs required to meet new regulatory requirements and to maintain and expand the nation's drinking water infrastructure.

This assessment examined existing data sources and recent regulatory impact analyses which contained cost data associated with these stressors and compared these against the current drinking water utility funding levels and household income trends. Based on this analysis, several key findings emerged regarding the drinking water utility funding gap and resulting affordability implications.

Infrastructure Investment Needs and Costs are Growing

The total cost to address the need for investment in drinking water infrastructure over the next 25 years (2026–2050) is estimated to be between $2.1 trillion and $2.4 trillion (in 2025 dollars). Replacement and rehabilitation of existing assets account for a significant portion of this total, but new cost drivers add hundreds of billions of dollars to the national tab of drinking water utility investment needs. These drivers include regulatory compliance for perfluoroalkyl and polyfluoroalkyl substances ("PFAS") treatment, lead service line replacement, and hardening systems against natural hazards. Still other drivers, such as the need to address cybersecurity and to develop alternative water supplies to improve resiliency and accommodate growth are known but do not currently have data to fully quantify.

Water Utility Capital Infrastructure Needs – 25-Year Costs

Cost Driver	25-Year Cost (in 2025 $ Billions)
Infrastructure Replacement, Rehabilitation, and Expansion	$1,728.4 - $1,757.1
Regulatory Compliance (PFAS and Lead Service Lines)	$94.1 - $105.8
Risk and Resilience	$263.6 - $561.1
Total	**$2,086.1 - $2,424.0**

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[1] American Water Works Association, *Buried No Longer: Confronting America's Water Infrastructure Challenge*, Denver, CO, 2012; https://www.awwa.org/wp-content/uploads/Buried-No-Longer-Report.pdf.

Infrastructure Funding Gap

Current capital spending by drinking water utilities averages approximately $33.6 billion annually whereas the identified need averages $90.2 billion per year. To meet the identified needs, capital investment must increase by approximately 168%, corresponding to an annual infrastructure funding gap of $56.6 billion. Under current funding models, the federal government provides approximately 3.9% of total public spending on drinking water utilities, a significantly lower federal contribution than those to other infrastructure sectors such as highways (22.5%). Furthermore, while the Infrastructure Investment and Jobs Act ("IIJA") provided a temporary influx of capital funding support, these funds are scheduled to expire after FY2026 and prior appropriations will be expended over a few years, while drinking water utility operations and maintenance ("O&M") costs continue to rise at a rate exceeding inflation.

Projected Impact on Household Costs

If the identified funding gap is addressed entirely through increases in local household water rates, the financial burden on households will increase substantially. Under a baseline scenario, comprised of continued historical national spending trends, the average annual household drinking water bill is projected to rise from $429 in 2025 to $685 by 2050 (in 2025 dollars). However, if the entire funding gap is met by increasing local utility rates the average annual bill would then be projected to reach $969 by 2050. This represents an increase of roughly 126% - more than doubling the average household bill - over current levels (in 2025 dollars).

Affordability Analysis

The projected increase in water service costs significantly expands the segment of the population facing water affordability challenges. If the identified funding gap is closed entirely by increases in utility rates:

- Approximately 30.4 million households (21.5% of the U.S. total) would spend more than 2.5% of their income on drinking water services.
- Approximately 53.5 million households (37.8% of the U.S. total) would spend more than 1.5% of their income on drinking water services.

An estimated $13.6 billion in annual assistance from federal, state, or other sources (in 2025 dollars) would be required by 2050 to support these households to ensure water bills remain below the 2.5% affordability threshold. Recognizing that 2.5% of household income is not a perfect threshold for gauging affordability, its use allows us to quantify the scope of the affordability challenge. These projected impacts on affordability pertain only to drinking water. In many cases, the same water utility ratepayer will also need to absorb the escalating cost of other water sector utilities, such as wastewater and stormwater.

Conclusion

The investment needs for drinking water infrastructure are estimated to exceed $2.1-2.4 trillion for 2026-2050. If drinking water infrastructure needs are met through local rates alone, drinking water bills will more than double by 2050, posing much greater water affordability challenges and impacting many more households than today. Recognizing the need for utilities and the local communities they serve to do their part to invest towards addressing these challenges, the size of the challenge to close the infrastructure gap while maintaining affordability, will also require a significant, sustained federal investment in infrastructure and affordability.

1. Introduction

The American Water Works Association ("AWWA") has been a leader in highlighting the critical need for investment in drinking water infrastructure in the United States ("U.S.") and throughout North America. The *Dawn of the Replacement Era* (2001)[2] demonstrated that large portions of water mains were aging and in need of replacement; *Buried No Longer: Confronting America's Water Infrastructure Challenge* (2012)[3] revealed that more than $1 trillion would be required over 25 years to replace and expand drinking water infrastructure. However, drinking water utilities are now entering a new era where these foundational needs are no longer the primary drivers of investment.

Today's drinking water utilities face compounding challenges that extend beyond the traditional repair of aging assets and new construction to accommodate growth. While the need to replace, rehabilitate, and expand infrastructure remains critical, utilities must also contend with an additional set of financial stressors that were not fully captured in previous eras. These pressures are driving up costs at an unprecedented rate and include the following:

- Major changes to regulatory landscape: Simultaneous compliance with existing, along with new and evolving, federal and state regulations, particularly those requiring advanced treatment for per- and polyfluoroalkyl substances ("PFAS") and the replacement of lead service lines.
- Source water complexity: The need to develop and utilize alternative water supplies that are more difficult and costly to treat as population growth and climate stressors limit the availability of existing, high-quality sources of water.
- Risk and Resilience: Urgent requirements to harden infrastructure against observed and reasonably anticipated natural and manmade hazards, along with the critical need to implement robust cybersecurity measures to protect essential systems.
- Operational Realities: Escalating costs associated with complex waste disposal requirements, advanced drinking water treatment, and inflationary pressures on utility operations and maintenance ("O&M") costs. Although beyond the scope of this report to fully assess, operational considerations may necessitate greater cooperation and economy of scale amongst utilities in the future.

This report brings together these interconnected stressors to update and reframe AWWA's previous estimate of the total investment required to sustain the nation's drinking water systems. It aims to provide policy makers and stakeholders with a clear understanding of the scope of necessary investment and the cumulative financial impact these drivers will have on households and communities.

Furthermore, this analysis addresses the growing affordability challenge. As costs rise to meet these needs, the financial burden on customers increases, necessitating a re-evaluation of how these needs are funded. This report highlights that while recent federal funding measures like the Infrastructure Investment and Jobs Act ("IIJA") provide a welcome funding source, they are time-limited and insufficient to close the widening gap. By estimating the costs of these drivers, this report underscores the risks of inaction: delaying these investments or forgoing necessary maintenance will stifle economic growth and could lead to compliance failures and compromise public health protections that remain drinking water utilities' highest priority.

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[2] American Water Works Association. *Dawn of the Replacement Era: Reinvesting in Drinking Water Infrastructure*, Denver, CO, May 2001.

[3] American Water Works Association. *Buried No Longer: Confronting America's Water Infrastructure Challenge*, https://www.awwa.org/resource/water-infrastructure-funding/.

2. Cost Drivers of Infrastructure Needs

The total investment required to sustain the nation’s drinking water infrastructure in the future is driven by aging assets, expansion needs, and emerging financial stressors. To capture the full scope of this challenge, this analysis aggregates projected expenditure needs across three primary categories: the replacement and expansion of physical assets, the compliance with evolving federal regulations, and the critical hardening of facilities against natural hazards. These estimates reflect the cumulative investment necessary to help ensure the long-term service reliability and public health protection over the 25-year period spanning from 2026 through 2050.

Major cost drivers were segregated into the following categories and evaluated based on existing federal data, regulatory impact analyses, and supplemental industry research:

1. Infrastructure Replacement, Rehabilitation, and Expansion
2. Regulatory Compliance
3. System Resilience and Operational Risk

Other drivers, such as the need to address cybersecurity threats and the need to treat more challenging water supplies to meet demand growth, will further increase costs but do not currently have robust data to fully quantify, and are discussed separately.

2.1. Infrastructure Replacement, Rehabilitation, and Expansion

U.S. drinking water utilities are inherently capital intensive, relying heavily on physical infrastructure to provide their service, requiring significant and sustained investment, which is a baseline financial requirement. This category includes the costs associated with rehabilitation and replacement of aging infrastructure, as well as necessary capacity expansion to support growth.

2.1.1. Infrastructure Replacement and Rehabilitation

There is already a well-established understanding of the need for significant investment in water infrastructure throughout the U.S. The U.S. Environmental Protection Agency (“USEPA”) regularly surveys drinking water utilities nationwide to assess the capital costs they anticipate over the next 20 years. The USEPA released The *Drinking Water Infrastructure Needs Survey and Assessment, Seventh Report to Congress* (“DWINSA”) in 2023, demonstrating the scale of the reinvestment needs facing water systems.[4] USEPA indicates that “comprehensive infrastructure costs, including engineering and design, raw materials and equipment purchases, and construction labor” are captured in the DWINSA. This widely accepted, though inherently conservative, assessment estimated that drinking water systems will need more than $625 billion in investment between 2021 and 2040 (in 2021 dollars). This figure includes costs associated with infrastructure replacement and rehabilitation of sources of supply infrastructure, water transmission and distribution mains, water treatment plants, and storage facilities.

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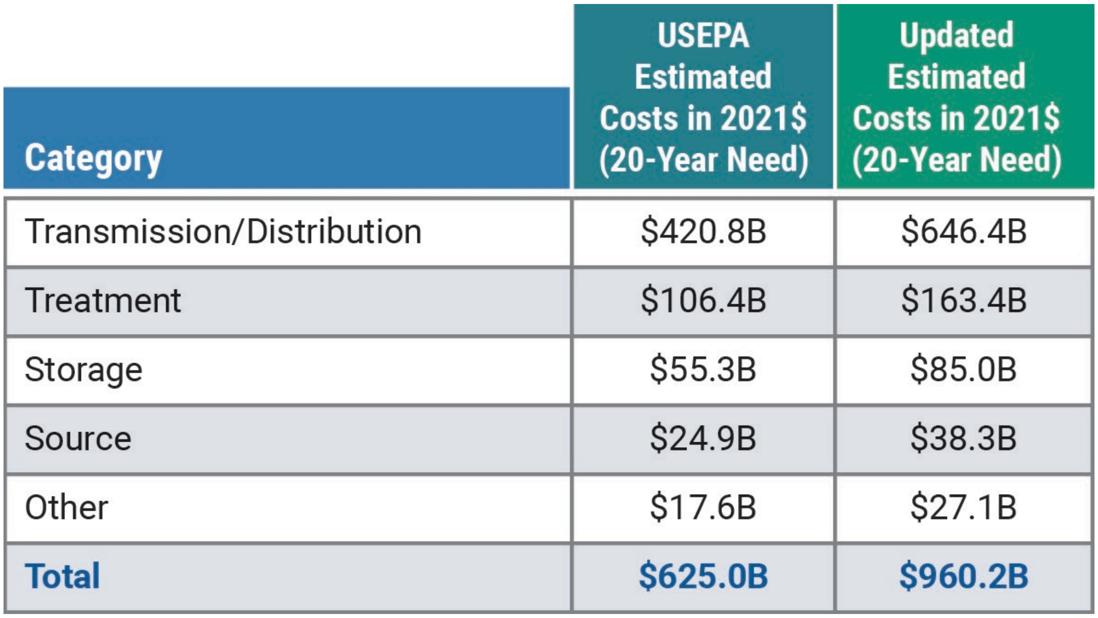
[4] USEPA. *Drinking Water Infrastructure Needs Survey and Assessment: Seventh Report to Congress*. EPA 816-R-23-001, March 2023. 2023. *EPA;* https://www.epa.gov/dwsrf/epas-7th-drinking-water-infrastructure-needs-survey-and-assessment.

We aligned this estimate with the scope of this study, which estimates the need over a 25-year period from 2026 to 2050. We adjusted the DWINSA estimate for inflation[5] and extended the estimate over the 25-year period. This calculation results in an estimated replacement and rehabilitation need of $960.2 billion over the forecast period. The DWINSA estimate, combined with our inflation and temporal adjustment, is summarized in Table 1.

Table 1. Infrastructure Replacement and Rehabilitation Needs – USEPA DWINSA Estimate



Category	USEPA Estimated Costs in 2021$ (20-Year Need)	Updated Estimated Costs in 2021$ (20-Year Need)
Transmission/Distribution	$420.8B	$646.4B
Treatment	$106.4B	$163.4B
Storage	$55.3B	$85.0B
Source	$24.9B	$38.3B
Other	$17.6B	$27.1B
Total	**$625.0B**	**$960.2B**

It is important to note that the DWINSA assessment contains inherent limitations that are likely to result in underestimating the total infrastructure replacement and rehabilitation requirements:

- *Documentation Requirement:* Utilities can only respond with projects that have been documented, have at least begun the planning phase, and have cost estimates. Consequently, if a utility lacks at least a planning phase estimate of project costs, need is not accurately reflected and as such, a significant portion of its actual requirements will remain unquantified and excluded from the survey.
- *Eligibility Constraints:* Only projects eligible for the Drinking Water State Revolving Loan Fund ("DWSRF") can be submitted. While this restriction is useful to the government in determining DWSRF funding allocations to states, it renders many necessary projects ineligible for inclusion in the survey data.
- *Short Planning Horizon:* Utility responses were likely constrained by short-term planning cycles (e.g., five years), significantly distorting the aggregate documented need over a 25-year assessment period. For example, the utility costs for potential future population growth or major regulations are not included in the estimate if utilities have not planned for these costs within their current planning horizon.

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[5] U.S. Bureau of Labor Statistics. (2025). Consumer Price Index for All Urban Consumers (CPI-U). Accessed at: https://www.bls.gov/cpi/data.htm.

Utilizing Water Loss Data to Help Justify Infrastructure Rehabilitation Needs

Physical water losses from water distribution systems, often termed Non-Revenue Water ("NRW"), serve as an ongoing critical indicator of distribution system degradation and help validate the urgent need for comprehensive infrastructure rehabilitation and replacement ("R&R") programs.

Quantification of the Results of Underinvestment

Water loss data support the significant ongoing scope of the water infrastructure rehabilitation challenges across the U.S. National studies cited by the USEPA indicate that, on average, 14% of treated water is lost to leaks within distribution systems. In some areas, reported loss rates can exceed 60%.[6] The American Society of Civil Engineers ("ASCE") reports that across the nation's 2.2 million miles of water pipes, a water main breaks approximately every two minutes.[7] This results in an estimated aggregate loss of 6 billion gallons of treated drinking water daily in the U.S. This volume is sufficient to meet the daily consumption needs of approximately 75 million people.

Financial Consequences

The economic consequences of high NRW rates reinforce the justification for R&R investment. Losses are not uniformly distributed. Bluefield Research reports that five high-density states, California, Texas, Florida, New York, and Illinois, account for over one-third of national losses, collectively losing 2.44 billion gallons daily. In these five states alone, the lost water translates to roughly $6.3 million in uncaptured daily utility revenue.[8]

Continued Need for Reinvestment

The high incidence and volume of water loss from leaky water distribution systems demonstrate that current infrastructure rehabilitation continues to be a significant challenge. Sustained investment in aging water utility infrastructure is not merely a discretionary capital expenditure but a critical requirement for improving the condition of water utility infrastructure, and to help ensure the long-term reliability and economic stability of the nation's water supply systems.

To provide an example of how the DWINSA needs estimate may be conservative, we examined national-level data regarding pipeline inventories, typical pipeline replacement cycles and unit costs, and prepared a bottom-up estimate of the replacement and rehabilitation needs for transmission/distribution pipelines. The *ASCE Report Card for America's Infrastructure (2025)* indicates the nation has about 2.2 million miles of water pipes and a water main break occurs on average every two minutes.[9] A typical replacement rate for water mains is approximately 1% per year (based on a 100-year lifespan), which means that every 100 years, all mains would be replaced.[10] Given the age of the nation's infrastructure, drinking water utilities should be targeting renewing and replacing at least 1% of their distribution/transmission pipelines each year in order to meet that long-term target. Some systems, facing age- and risk-related vulnerabilities, may require even higher annual rates (e.g., 2% or greater) of infrastructure renewal/replacement to achieve long-term stability if they have not kept up with the renewal/replacement needs in the past.[11]

Current planning level cost estimates for drinking water pipeline renewal are based on a cost estimate of $500 - $600 per linear foot (in 2025 dollars). This value is drawn from the literature and our recent project experience.[12] When applying a 1% annual renewal rate to the country's 2.2 million miles of pipeline

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[6] "US water infrastructure: Making funding count," McKinsey & Company, November 24, 2021; https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/us-water-infrastructure-making-funding-count.

[7] American Society of Civil Engineers, 2021 Report Card for America's Infrastructure – Drinking Water; https://2021.infrastructurereportcard.org/cat-item/drinking-water-infrastructure/.

[8] "Water Losses Cost U.S. Utilities US$6.4 Billion Annually." Bluefield Research, April 28, 2025; https://www.bluefieldresearch.com/ns/water-losses-cost-u-s-utilities-us6-4-billion-annually/.

[9] American Society of Civil Engineers, A Comprehensive Assessment of America's Infrastructure, 2025 Report card for America's Infrastructure; https://infrastructurereportcard.org/.

[10] American Water Works Association. *Buried No Longer: Confronting America's Water Infrastructure Challenge*.

[11] American Society of Civil Engineers, *Breaking water mains present US, Canada with $452B problem,* April 22, 2024; https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2024/04/breaking-water-mains-present-us-canada-with-$452b-problem.

[12] "Estimation of Water Pipe Installation Construction Cost," Chee, Lansey, Chee, American Society of Civil Engineers, 2018; https://ascelibrary.org/doi/10.1061/%28ASCE%29PS.1949-1204.0000323.

(equivalent to 22,000 miles per year), the resulting annual need is estimated to cost $58 billion to $70 billion for pipeline renewal/replacement.

Extending this estimate over the 25-year forecast period, and excluding future inflation, the total capital need for distribution and transmission pipelines is projected to range from $1.45 trillion to $1.74 trillion in 2025 dollars, which is approximately 50% to 80% higher than the transmission/distribution estimate included in the DWINSA shown in Table 1. This projected need provides another reference point using recent data of the magnitude of the challenge, demonstrating that the DWINSA estimate is likely conservative. Even the documented DWINSA drinking water infrastructure replacement and rehabilitation need, though estimated at only $960 billion for the 2026 to 2050 period, underscores a financial challenge of staggering proportions for the nation's drinking water utilities.

2.1.2. Infrastructure Service Expansion

The DWINSA estimate explicitly excludes expansion or growth-related capital projects. However, these expenditures represent a major cost driver for many water systems across the U.S that are experiencing population growth. These expenditures must be financed either by new development, by existing rate payers, or both in some combination. Although new expansion often helps fund growth-related infrastructure through system development fees and the addition of revenue from new customers, those contributions are not guaranteed. As a result, existing customers may still be responsible for paying for part or all of the costs associated with these growth-related projects. We estimated the growth-related drinking water distribution/transmission system and treatment capacity costs over the 2026-2050 period using readily available data, as described below.

2.1.2.1. Distribution/Transmission Systems

Expansion-related capital expenditure needs for conveyance infrastructure, pipelines connecting treatment facilities to new service areas and to new customers, were estimated using prior AWWA research. The 2012 *Buried No Longer* report[13] estimated expansion-related distribution and transmission pipeline costs at $802.2 billion over a 40-year period (2011 – 2050). Taking the annual cost need for the 40-year period, adjusting this figure to the current 25-year timeframe (2026-2050), and inflating to 2025 dollars, yields an aggregate cost need for expansion-related water mains of $739.2 billion for the 2026 – 2050 period.

2.1.2.2. Treatment Capacity

A three-part methodology was employed to quantify the cost associated with augmenting treatment capacity for population expansion and to bridge the existing national data gap:

- <u>Projected Population Growth</u>. We based our calculation on the 2023 U.S. Census Bureau projection for national population growth of approximately 22 million people from 2026 to 2050.[14]
- <u>Demand Modeling</u>. We used an average water use of 82 gallons per capita per day ("gpcd"),[15] and applied a peaking factor of 1.6. This figure is drawn partially from the National Research Council[16]

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[13] American Water Works Association. *Buried No Longer: Confronting America's Water Infrastructure Challenge*.

[14] U.S. Census Bureau. National Population Projections: 2017–2060. U.S. Department of Commerce, 2017; https://www.census.gov/data/datasets/2017/demo/popproj/2017-popproj.html.

[15] Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, https://doi.org/10.3133/cir1441.

[16] National Research Council. 2006. *Drinking Water Distribution Systems: Assessing and Reducing Risks*. Washington, DC: The National Academies Press. https://www.nationalacademies.org/projects/WSTB-U-04-06-A.

and from data from our recent rate studies to forecast maximum to average day usage and for long-term capital needs.

- Cost Estimate: We used an industry-based cost range of $10 to $20 per gallon for new treatment capacity. Current drinking water utility planning estimates for drinking water treatment capacity are generally in the range of $10 to $20 per gallon of treatment capacity. This figure is drawn from recent water treatment plant projects, and our recent project experience.[17]

Based on these parameters, the projected cost for growth-related treatment capacity for 2026-2050 ranges from $29.0 billion to $57.7 billion.[18]

2.2. Regulatory Compliance

Costs associated with compliance with existing regulations are in many instances addressed in the existing cost estimates. However, certain regulatory requirements represent critical, non-discretionary cost drivers that are largely excluded from previous infrastructure needs surveys because those surveys pre-date the finalization. Regulations addressing PFAS and lead service line replacement, as described below, fall into this category and therefore are additional costs beyond those captured in prior assessments. These costs must be incurred over compressed compliance timelines, placing immediate pressure on utility finances.

2.2.1. Per- and Polyfluoroalkyl Substances (PFAS) Treatment

The finalization of the USEPA's National Primary Drinking Water Regulation ("NPDWR") for PFAS in 2024 set new, enforceable standards for six types of PFAS to achieve new Maximum Contaminant Levels ("MCLs") in drinking water systems.[19] The NPDWR will, in many cases, require water systems across the country to install advanced treatment to reduce PFAS concentrations to below the new regulatory standards in compliance with the MCLs. Based on a 2023 industry cost model, the annualized costs associated with capital improvements and O&M expenses for PFAS treatment were estimated to be $5.21 billion per year.[20] Approximately 66% of these costs were estimated to be capital costs for new and advanced equipment added to treatment facilities. The remaining 34% of the estimated PFAS treatment costs were for ongoing annual operations costs for materials, maintenance, testing, disposal of removed PFAS, reporting, etc. This estimate was further updated in 2024 to account for the MCLs set by the USEPA in the final NPDWR.[21] Based on the updated 2024 cost model, and adjusting for inflation, the annualized costs associated with capital and O&M expenses for PFAS treatment over the 25-year timeframe (2026-2050) was estimated to be between $59.2 billion and $77.6 billion. This estimate is summarized in Table 2.

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[17] For example, recent water treatment plant expansion projects in Austin, TX, Columbus, OH, and Tampa, FL were estimated to cost $12 per gallon, $17-28 per gallon, and $15 per gallon, respectively. The Austin estimate is from email from Martin Tower, Infrastructure Management Division Manager at Austin Water, City of Austin 2025. The Columbus estimate from: https://cbuswater.com/wp-content/uploads/2024/08/Contractor-Open-House-Update-08022024.pdf. The Tampa estimate is from: https://www.tampabaywater.org/supply/projects/surface-water-plant-expansion/.

[18] Per input from professionals with experience in these states.

[19] USEPA. PFAS National Primary Drinking Water Regulation. Federal Register 89, (April 26, 2024): 2024-07773. https://www.federalregister.gov/documents/2024/04/26/2024-07773/pfas-national-primary-drinking-water-regulation.

[20] WITAF 56 Technical Memorandum, PFAS National Cost Model Report, Prepared by Black & Veatch for AWWA, March 7, 2023; https://awwa.org/wp-content/uploads/AWWA-Comments-on-Proposed-NPDWR-for-PFAS-excl-AppendixE.pdf.

[21] Estimating the National Cost to Remove PFAS from Drinking Water using UCMR 5 Data, Prepared by Black & Veatch and Corona Environmental Consulting for AWWA, July 11, 2024; https://www.awwa.org/wp-content/uploads/Final-Technical-Memorandum-Updating-National-Cost-Estimate-for-PFAS-Standards-using-UCMR-5.pdf.

Table 2. PFAS Treatment Cost Needs

Description	Low-End Estimate (2025$)	High-End Estimate (2025$)
Annual O&M	$0.8B	$1.1B
Total Capital Costs	**$39.2B**	**$50.9B**

The majority of the cost burden to address PFAS is concentrated in near-term capital costs, since the current PFAS MCL compliance deadline is set for April 26, 2029.[22] With this compliance deadline, drinking water utilities are projected to incur substantial capital expenses (estimated at $39.2 billion to $50.9 billion) within the first five years of this report's forecast period. Annual O&M costs are projected to range from $0.8 billion to $1.1 billion. We included the O&M and capital cost estimates for PFAS treatment in our 25-year estimate. In May 2025, Administrator Zeldin publicly announced USEPA's intention to extend the MCL compliance deadline to 2031,[23] but that is not yet effective at the time of this report.

2.2.2. Lead Service Line Replacement

In the wake of the Flint, Michigan water crisis, additional regulations were created that required removal of all lead pipes from drinking water systems by 2037.[24] The Lead and Copper Rule Improvements also require more rigorous testing of drinking water and a lower threshold requiring communities to take action to protect people from lead exposure in water. In addition, the rule requires improvements in communication within communities so that families are better informed about the risk of lead in drinking water, the location of lead pipes, and plans for replacing them. USEPA estimates there are 4.0 million lead service lines ("LSLs") that will require replacement.[25] This estimate is based on the November 2025 LSLs estimate from USEPA.

Cost estimates associated with the replacement of all LSLs vary greatly between sources. One estimate prepared by the USEPA in 2019 estimated the average cost to replace LSLs to be $4,700 per line.[26] In 2022, the AWWA commissioned a report prepared by CDM Smith to refine the estimate of the cost of full LSL replacements in the U.S.[27] The CDM Smith report estimates an average cost of $12,500 (in 2022 dollars) per LSL. This higher estimate is based on costs from four different surveys and used updated actual identification, engineering, replacement, and customer outreach costs from the surveyed utilities.

Using the information contained in the above-referenced reports, we estimated the total cost of LSL replacement by multiplying the estimated average replacement unit cost of $12,500 per line by the number of estimated LSLs (4.0 million). Adjusting for inflation, we calculated a cost of $54.9 billion over the 25-year timeframe (2026-2050). This regulatory-driven cost has a compliance deadline of 2037, meaning these costs will likely be incurred by drinking water utilities over a compressed timeframe of 13 years.

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[22] USEPA. PFAS National Primary Drinking Water Regulation.

[23] *U.S. EPA Announces It Will Keep Maximum Contaminant Levels for PFOA/PFOS*EPA Press Office, May 14, 2025; https://www.epa.gov/newsreleases/epa-announces-it-will-keep-maximum-contaminant-levels-pfoa-pfos.

[24] USEPA. Lead and Copper Rule Improvements; https://www.epa.gov/ground-water-and-drinking-water/lead-and-copper-rule-improvements.

[25] USEPA. 2025 Update to the 7th Drinking Water Infrastructure Needs Survey and Assessment November 2025. https://www.epa.gov/system/files/documents/2025-11/fact-sheet-2025-7th-dwinsa-update.pdf.

[26] USEPA. "National Primary Drinking Water Regulations: Proposed Lead and Copper Rule Revisions." Proposed Rule. Federal Register 84, no. 219 (November 13, 2019): 61684–61774. https://www.federalregister.gov/documents/2019/11/13/2019-22705/national-primary-drinking-water-regulations-proposed-lead-and-copper-rule-revisions.

[27] "*Considerations when Costing Lead Service Line. Identification and Replacement*" prepared by CDM Smith for AWWA, 2022. https://www.awwa.org/wp-content/uploads/CDM-Considerations-when-costing-lead-service-line-ident-replacement.pdf.

2.3. Risk and Resilience

Beyond asset replacement, rehabilitation and regulatory compliance, utilities face increasingly volatile operational cost risks stemming from natural hazards. Drinking water utilities must be prepared for a range of contingencies, and while this is not a new concept, the challenges are evolving. America's Water Infrastructure Act ("AWIA") of 2018 amended SDWA §1433 by mandating a process for evaluating risk and resiliency at community water systems serving over 3,300 people. AWIA required these systems to develop and routinely update robust risk and resilience assessments and emergency response plans.[28] Investment in hardening systems against these risks is essential for maintaining supply security and continuity of service.

Sustaining water service in the face of natural hazards requires preparing for drought, wildfires, extreme precipitation, and shifting weather patterns, necessitating substantial preemptive investment in system hardening and capacity expansion (e.g., source water diversification, advanced treatment for saline or challenging to treat drinking water sources, and physical flood protection). The National Oceanic and Atmospheric Administration ("NOAA") National Centers for Environmental Information ("NCEI") indicated the U.S. sustained 403 weather and climate disasters from 1980–2024 where overall damages/costs reached or exceeded $1 billion (including inflation) for each disaster. The total cost of these 403 events exceeds $2.915 trillion.[29] Increasing weather volatility is creating significant uncertainty that drinking water utilities must account for when planning future projects. These disasters, including drought frequency and intensity as well as severe precipitation events that threaten water supplies, facilities, and water systems nationwide.

Estimates prepared by the National Association of Clean Water Agencies ("NACWA") in 2009 and 2023 quantified the total cost of addressing these natural hazard impacts for drinking water and wastewater utilities.[30,31] The 2023 NACWA estimate separated drinking water costs from wastewater costs and include the capital and O&M costs of interventions taken by drinking water utilities to respond to the impacts of natural hazards, such as reverse osmosis treatment systems, potable reuse systems, and seawater desalination projects. NACWA's estimate included 10% for annual O&M costs. Using the NACWA cost estimates and adjusting the estimates for inflation to reflect 2025 dollars, we estimated the combined capital and O&M expenditures required for climate adaptation and mitigation by drinking water utilities to range from $289.9 billion to $617.2 billion over the 25-year timeframe (2026–2050) in 2025 dollars. This includes implementing technologies such as reverse osmosis and potable reuse systems. The drinking water utility O&M expenses included in the estimate range between $26.3 billion and $56.1 billion and the capital costs included in the estimate range between $263.6 billion and $561.1 billion. We included the drinking water utility O&M and capital cost estimates for natural hazards in our 25-year estimate.

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[28] America's Water Infrastructure Act of 2018. P.L. 115-270. Enacted October 23, 2018. https://www.govinfo.gov/content/pkg/PLAW-115publ270/pdf/PLAW-115publ270.pdf.

[29] National Centers for Environmental Information (NCEI) Billion-Dollar Weather and Climate Disasters December 8, 2025; https://www.ncei.noaa.gov/access/billions/.

[30] National Association of Clean Water Agencies (NACWA). Confronting Climate Change: an Early Analysis of Water and Wastewater Adaptation Costs. Washington, D.C.: NACWA, October 2009. https://www.nacwa.org/docs/default-source/news-publications/White-Papers/2009-10-28ccreport.pdf.

[31] National Association of Clean Water Agencies (NACWA). Resiliency in the Balance: Funding Challenges for Clean Water Utilities in Addressing Climate Adaptation. Washington, D.C.: NACWA, December 2023. https://www.nacwa.org/docs/default-source/resources---public/nacwa-climate-resiliency-report.pdf.

Enhancing Water Supply Resiliency Through Local Resource Development – Metropolitan Water District of Southern California

The Metropolitan Water District of Southern California ("MWD") is the primary water wholesaler serving over 19 million people across 5,200 square miles. MWD's service area encompasses portions of six counties and relies heavily on imported water from two climate-sensitive sources: the Colorado River Aqueduct and the State Water Project (via the California Aqueduct). [32] [33]

Climate and Supply Vulnerability

MWD's long-term water security is severely challenged by climate volatility. The region's imported supply, derived from annual Sierra Nevada snowpack and the highly constrained Colorado River Basin, is increasingly unreliable due to persistent, historically extreme drought conditions. As of late 2025, significant portions of both the Colorado River Basin and California remain in severe or extreme drought, underscoring the long-term impacts on both surface and groundwater reserves.[34] This dependence on climate-vulnerable external sources mandates a strategic shift toward developing stable, local, and drought-proof supplies.

Strategic Solution: Pure Water Southern California (PWSC)

To achieve greater self-sufficiency and supply resiliency, MWD is planning to construct the Pure Water Southern California (PWSC) project in partnership with the Los Angeles County Sanitation Districts (LACSD). PWSC represents a major investment in Indirect Potable Reuse (IPR), decoupling a significant portion of the region's drinking water supply from volatile weather patterns. PWSC could produce up to 150 MGD of purified water using an advanced water treatment process including membranes, reverse osmosis, and ultraviolet light disinfection, to transform recycled water into a safe, high-quality supply. A new 60-mile regional conveyance system will deliver this reliable water source to recharge four critical regional groundwater basins.

Resiliency Benefits

The PWSC project is a component of MWD's climate adaptation strategy. By maximizing the reuse of local resources, it mitigates the risk associated with diminishing imported supplies and fluctuating snowpack, ensuring a supplemental supply for the region's growing population, regardless of external drought conditions.

The project is projected for completion by 2032 and carries an estimated cost of $9 billion, demonstrating the critical strategic importance placed on enhancing regional water security. To date, PWSC has received some federal support, including $125 million from the Bureau of Reclamation and the Department of the Interior.[35]

In addition to providing a new, efficient, and reliable water source, the project is also projected to fuel job creation and the local economy. A 2025 study, conducted by the Los Angeles Economic Development Corporation, found the construction of Pure Water Southern California facilities is expected to generate over $15.1 billion in total economic output and support approximately 75,660 job-years, including 43,700 project-related job-years and another 31,960 job-years across Southern California through indirect and induced effects. The project's total supported labor income in Southern California is estimated to be about $6 billion. Moreover, it will contribute $719.4 million in state and local taxes and $1.4 billion in federal tax revenue.[36]

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[32] Information from the Metropolitan Water District of Southern California website. Accessed at: https://www.mwdh2o.com/how-we-get-our-water/.

[33] Information from the Metropolitan Water District of Southern California website. Accessed at: https://www.mwdh2o.com/our-story/.

[34] CPR News. Colorado's 2025 'Water Year' was abnormally hot and dry. Ishan Thakore, December 1, 2025. https://www.cpr.org/2025/12/01/colorado-2025-water-report-hot-dry/.

[35] Information from the Metropolitan Water District of Southern California website. Accessed at: https://www.mwdh2o.com/building-local-supplies/pure-water-southern-california/.

[36] Institute for Applied Economics. *Metropolitan Water District: Pure Water Southern California, An Updated Economic Impact Study*, Los Angeles County Economic Development Corporation, 2025; https://bda.mwdh2o.com/CEQA%20Record%20of%20Proceeding/D.%20Environmental%20Impact%20Report%20and%20Notices/Draft%20EIR%20Documents%20Cited/13%20-%205.9%20Land%20Use%20and%20Planning/4_LAEDC%20Updated%20Economic%20Impact%20Study_2025.pdf.

2.4. Other Drinking Water Utility Stressors

2.4.1. Hard-to-Treat Water Supplies

Local cost drivers related to drinking water source complexity are increasing due to population strain and diminishing high-quality resources. Communities across the country are currently utilizing water sources that are at or near capacity and many of these communities cannot accommodate the level of growth necessitated by their projected population increases or other drivers of demand, such as data centers. This forces communities to utilize hard-to-treat sources, such as brackish water, reclaimed wastewater, or highly salinized ground or surface water.

Since hard-to-treat water supply costs are highly localized, national aggregate cost estimates have not been compiled. However, there are many published examples of utilities expanding capacity through harder to treat sources, which will likely increase the overall infrastructure costs compared to traditional sources. Recognizing there is no national compilation, examples include:

- ***Source Water Diversification (California):*** Projects using indirect potable reuse and brackish water desalination often carry price tags exceeding $100 million for medium-sized municipalities. For example, the Ventura WaterPure project in California is an indirect potable reuse project that will reduce the discharge into the Santa Clara River Estuary and will eventually provide 4.7 million gallons per day ("MGD") of recycled water, up to 20% of the city's future water supply. It is estimated that the new water purification facility will cost approximately $420 million and improving treatment processes at the existing wastewater treatment plant will cost $254 million, totaling $674 million for one community with a current population of about 110,000.[37] [38]

  Another example is the Antioch Brackish Water Desalination Plant in California (population 117,000). This is a new facility designed to treat brackish surface water from the San Joaquin River, which has experienced rising salinity, and will produce up to 6.0 MGD of potable water. The total projected cost is estimated at approximately $116 million. The plant is intended to supply 30 to 40% of the city's annual drinking water demand, thereby reducing dependence on purchased water and improving resilience to drought and salinity intrusion.[39]

- ***Water Supply Expansion (Florida):*** Some drinking water utilities in Florida are facing water shortage challenges. The shallow surface water and groundwater aquifers currently used for drinking water supplies are increasingly having to be supplemented by other sources. Often, this includes deeper groundwater, which can be more saline and contain contaminants of concern, requiring more advanced (and expensive) treatment technologies. The resulting brine has to be disposed of, often through deep injection. Riviera Beach, with a population of about 40,000, is spending at least $406 million in a Phase 1 treatment facility project to produce 7.5 MGD of additional treated drinking water.[40] Collier County with a population of about 422,000 is spending at least $438 million on a new

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[37] Information from the City of Ventura website. Accessed at: https://www.cityofventura.ca.gov/1650/About-VenturaWaterPure.

[38] "Ventura planned water treatment project now tops $674M." Wes Woods II, VC Star. June 26, 2025; https://www.vcstar.com/story/news/2025/06/26/ventura-planned-water-treatment-project-now-tops-674m/84294261007/.

[39] "California opens $116 million Antioch Brackish Water Desalination Plant." Smart Water Magazine. July 10, 2025; https://smartwatermagazine.com/news/smart-water-magazine/california-opens-116-million-antioch-brackish-water-desalination-plant.

[40] "Riviera Beach launches $400 million water plant." WLRN Public Media, Carolyn DiPaulo, September 9, 2025. https://www.wlrn.org/development/2025-09-09/riviera-beach-launches-400-million-water-plant.

treatment facility to produce 10 MGD of additional treated drinking water and 6 MGD of wastewater reclamation capacity.[41]

- ***Alternative Water Supply Needs (Western Region):*** Utilities dependent on the Colorado River and its tributaries face escalating costs due to drought and water quality degradation. The nearly 25-year drought, coupled with long-term climate variability, has severely compromised the area's water supply reliability. As of November 2025, approximately 57% of the basin remains under severe or extreme drought conditions.[42] Water resource managers face critical uncertainty regarding future yields, as concerns persist that a series of below-average snowpack years followed by dry springs could lead to critically low runoff and record-low reservoir elevations. Major reservoirs across the American West are currently at historically low capacities. Projections indicate that if current trends continue, water levels could eventually dip below the thresholds required for consistent hydropower generation.[43]

  Compounding the issue is the long-term depletion of regional groundwater, which has lost a volume of water comparable to the storage capacity of the nation's largest reservoirs over the last two decades. While the impact is most acute in the Lower Basin, prolonged drought conditions have also become a persistent reality for states across the Pacific Northwest and the Northern Rockies. This instability drives several compounding financial burdens:

    - **Declining water quality**: As the Colorado River's flow decreases, the concentration of dissolved salts and other contaminants increases. This necessitates a shift toward more advanced and costly treatment processes, such as membrane filtration, to maintain potable water standards.
    - **Cost of alternative sources**: Water managers are increasingly forced to explore supplemental sources to offset shrinking surface water supplies. While options like desalination or large-scale recycling offer reliability, they are significantly more energy-intensive and expensive than traditional surface water systems.
    - **Utility Rate Impacts**: The rising costs of advanced treatment and the procurement of new water sources are inevitably passed on to consumers. Municipalities across the region are already implementing or planning significant rate increases to maintain infrastructure and secure future supply.

These specific examples underscore a broader challenge. Regions across the country are facing analogous issues where traditional hydrological assumptions no longer hold, forcing a transition toward more resilient, but more expensive, water management strategies.

The shift toward utilizing increasingly complex and lower quality drinking water sources imposes significant financial burdens on water systems. Although we know that these alternative water supplies are more expensive than more traditional sources, the differences in costs are based on too many localized variables to be able to generalize how much more. These localized expenses are excluded from our aggregate 25-year infrastructure needs estimates because national level data is not yet available. However, hard-to-treat water

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[41] "Collier NE wastewater, water treatment plants proceed", The Naples Press, Aisling Swift, July 4, 2025. https://www.naplespress.com/local-news/collier-ne-wastewater-water-treatment-plants-proceed/article_2862c39c-ba99-5172-a872-a406643979dd.html..

[42] "Rainfall brings #ColoradoRiver drought relief, but concerns for next year's water supply remain," WaterDesk.org, Cassie Sherwood, November 4, 2025; https://coyotegulch.blog/2025/11/06/rainfall-brings-coloradoriver-drought-relief-but-concerns-for-next-years-water-supply-remain.

[43] "Alarming drought outlook threatens the West," Western-Water.com, September 8, 2025; https://www.western-water.com/2025/09/08/alarming-drought-outlook-threatens-the-west.

supplies represent a future financial cost to utilities that will inevitably expand the total national investment requirement.

2.4.2. Emerging Contaminants

Although not able to be quantified, drinking water utilities will likely encounter future expenditures related to future regulation of currently unregulated contaminants and/or other regulatory changes. The ability to identify and reliably quantify many contaminants to very low levels has greatly increased over time. Although it is difficult to predict what contaminants will go through the regulatory process in the future, the contaminant candidate list (CCL) offers clues on what contaminants need additional research and analysis to either rule out as a national concern or further evaluate for potential regulation.[44] The Safe Drinking Water Act establishes a process to nominate contaminants for research and evaluation (the CCL), and when sufficient information about health effects, occurrence, and risk is known, to periodically issue Regulatory Determinations to either proceed with developing a regulation or determine that no national regulation is necessary.[45] For those proceeding to regulation, it takes years to develop a proposal, take comments, develop a final regulation, and then phase in requirements over several additional years. For those found not to warrant a national regulation, non-regulatory health advisories or other guidance may be issued by EPA, which does not directly mandate costs but may still spur action and lead to additional spending. In some cases where a contaminant is mostly found in certain geographic areas, a state-level regulation may also be made by state primacy agencies. Likewise, every six years, the Safe Drinking Water Act requires EPA to evaluate existing regulations for potential improvements, providing another reference point for potential future regulatory activity.[46]

Addressing future contaminants will likely require a combination of advanced treatment technologies, distribution system upgrades, and/or the implementation of operational changes that will impose additional costs on drinking water utilities, but the extent and costs of these potential future regulations cannot be known with sufficient precision to include in this report.

2.4.3. Complex Waste Disposal Requirements

The deployment of advanced treatment technologies to remove contaminants from increasingly complex and lower quality drinking water sources, including brackish water, reclaimed wastewater, or highly salinized ground or surface waters, transfers these contaminants into concentrated residual streams, creating new long-term financial burdens for drinking water utilities. Unlike conventional water treatment residuals, the waste products generated from removing these contaminants are subject to more expensive management and disposal. Costs for disposal can include specialized treatment, transportation, and landfill fees, which vary significantly by location and volume.

Although some complex waste disposal activities may already be captured in infrastructure needs estimate when the need for it is well established, the emerging example of the removal of spent filtration media for PFAS likely is not. The interplay amongst various environmental laws and the status of PFAS compounds within them poses a significant challenge, both in terms of potential liability and in terms of direct costs. How these residuals end up being regulated in the long-term is not clear, but costs could be extensive. As one example, if PFAS-containing water treatment residuals are regulated as hazardous waste under the Resource

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[44] USEPA. Drinking Water Contaminant Candidate List (CCL) and Regulatory Determination; https://www.epa.gov/ccl.

[45] USEPA SDWA Evaluation and Rulemaking Process. https://www.epa.gov/sdwa/sdwa-evaluation-and-rulemaking-process.

[46] USEPA. Six Year Review. https://www.epa.gov/dwsixyearreview.

Conservation and Recovery Act ("RCRA"), they would require disposal in a Subtitle C hazardous waste facility. A recent report calculated a unit cost for disposal at a hazardous waste facility at nearly $2,500 per ton.[47] This report found the cost to be roughly $1,000 per ton more than the nonhazardous alternative and more than $2,400 more per ton for the land application of biosolids or lagoon settling of lime softening sludge. Nationally, this could amount to $3.6 billion annually for PFAS treatment and conventional treatment residuals (e.g., spent GAC, biosolids, coagulant and softening sludge). However, this estimate is not included in the total spending need estimate as very few studies have investigated PFAS in water treatment residuals and their potential to leach, and the ultimate disposal options and requirements over the long-term are not certain.[48]

Beyond PFAS, the expansion of the use of hard-to-treat water supplies for inland communities utilizing brackish water or potable reuse supplies, results in high-salinity brine that must then be managed and disposed. This management often necessitates the construction of zero-liquid discharge ("ZLD") systems that crystalize the brine, which can more than double the capital and operational costs of treatment plants even before the disposal of the crystalized brine.[49]

Given the highly site-specific nature of utility disposal requirements and the lack of standardized national data, these substantial future costs are not currently included in our aggregate 25-year infrastructure needs estimate presented in this report, contributing to the conservativeness of our aggregate estimate.

2.4.4. Cybersecurity

The threat of a cybersecurity incident represents a clear danger not only to drinking water utilities but also to the integrity of national security. Cybersecurity is the top threat facing business and critical infrastructure in the U.S., according to reports and testimony from the Director of National Intelligence, the Federal Bureau of Investigation and the Department of Homeland Security.[50] Since cybersecurity measures are highly localized, national aggregate cost estimates for utilities to implement appropriate and protective cybersecurity measures have not been compiled to-date. A cyber attack could disable water supply and distribution, disrupt billing operations, and more. The potential impact on public health and reputational damage outweighs the cost for implementing basic cybersecurity practices. In response to this risk, Congress enhanced SDWA §1433, as amended by AWIA, to direct drinking water utilities to assess cyber threats and sets an expectation for systems to mitigate risks.[51] While drinking water utilities are working to implement more robust cybersecurity practices in what will likely be continuous iterative process as threats and technology evolve, many have indicated that limitations in technical capacity and resources remain a challenge.[52,53]

Implementing and maintaining adequate cybersecurity measures requires sufficient staffing and resources. . A 2021 Water Sector Coordinating Council survey found that limitation on workforce and technical capacity were challenges in supporting cybersecurity. Nearly half of the utilities surveyed spend less than 2% of their

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[47] "Water Systems Could Face Costly PFAS Waste Rules", Chris Moody and Connor Murray, Journal AWWA, November 2023; https://awwa.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/awwa.2174.

[48] AWWA. Comments submitted by AWWA to EPA. Posted November 10, 2022; https://www.regulations.gov/comment/EPA-HQ-OLEM-2019-0341-0543.

[49] National Alliance for Water Innovation. Technology Roadmap: Municipal Sector., DOE/GO-102021-5565, July 2021. https://docs.nlr.gov/docs/fy21osti/79889.pdf.

[50] American Water Works Association. Cybersecurity & Guidance. https://www.awwa.org/resource/cybersecurity-guidance/.

[51] USEPA. AWIA Section 2013/SDWA Section 1433: Risk and Resilience Assessments and Emergency Response Plans; https://www.epa.gov/waterresilience/awia-section-2013.

[52] AWWA. 2025 State of the Water Industry Report, https://www.awwa.org/state-of-the-water-industry/.

[53] Water ISAC. Cybersecurity: 2021 State of the Sector. Charles Egli, June 17, 2021. https://www.waterisac.org/2021survey.

annual budgets on Information Technology ("IT") and/or Operational Technology ("OT") security.[54] This metric may be misleading, as total spending is not a reliable indicator of improved security or the implementation of baseline cybersecurity controls.IT security focuses on protecting data and digital systems, prioritizing confidentiality, integrity, and availability. OT security protects systems that control physical machinery and equipment processes, prioritizing availability, safety, and operational continuity because disruptions can lead to physical damage or injury.

A key risk with cybersecurity is interruption to continuity of service and the drinking water utilities' responsibility to manage that threat. Water systems are resource stressed for workforce and budget, which includes capacity to support implementation of various cybersecurity controls and transitioning from legacy technology.

A review of data associated with the State & Local Cybersecurity Grant program found the average award to water systems was $150,000. These funds are specifically designated for building cybersecurity resilience and risk mitigation. For illustration purposes, if the $150,000 average award was limited to 10,000 drinking water utilities to address cybersecurity under SDWA § 1433, the investment need would be $1.5 billion. If all 50,000 community water systems were included, the baseline investment need would be $7.5 billion. As these values are based on existing awards and not on total need, they likely represent only a fraction of the total need to address transitions from legacy technology, staffing and implementation of controls to mitigate the dynamic nature of cyber threats. These expenses are not included in the 2026-2050 infrastructure needs estimates because robust national level data are not yet available.

2.5. Infrastructure Needs Summary

Based on the summation of infrastructure replacement, rehabilitation, expansion, regulatory compliance, and risk and resiliency cost drivers, the total infrastructure need from 2026 through 2050 is projected to range between $2.1 trillion and $2.4 trillion (in 2025 dollars), as shown in Table 3. This estimate reflects the baseline requirement to rehabilitate aging transmission and treatment assets, as identified in USEPA's DWINSA, updated with cost escalation and augmented by the substantial costs associated with PFAS treatment, LSL replacement, and measures of natural hazards.

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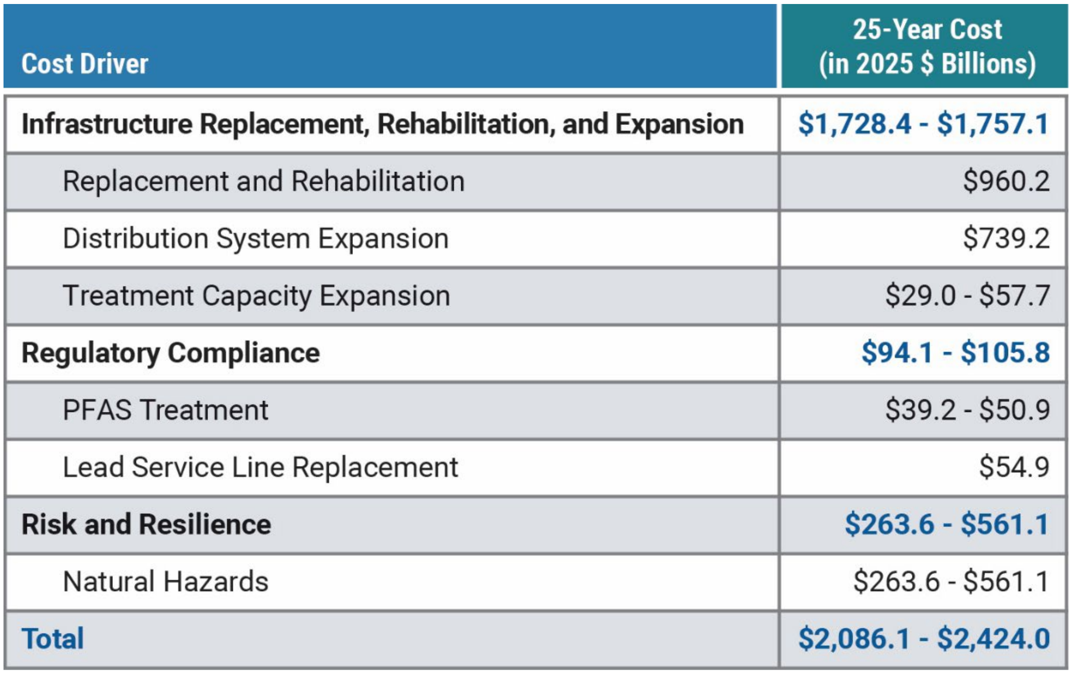
[54] Ibid.

Table 3. Water Utility Capital Infrastructure Needs – 25-Year Costs



Cost Driver	25-Year Cost (in 2025 $ Billions)
Infrastructure Replacement, Rehabilitation, and Expansion	**$1,728.4 - $1,757.1**
Replacement and Rehabilitation	$960.2
Distribution System Expansion	$739.2
Treatment Capacity Expansion	$29.0 - $57.7
Regulatory Compliance	**$94.1 - $105.8**
PFAS Treatment	$39.2 - $50.9
Lead Service Line Replacement	$54.9
Risk and Resilience	**$263.6 - $561.1**
Natural Hazards	$263.6 - $561.1
Total	**$2,086.1 - $2,424.0**

Note that this projection represents a conservative baseline estimate. As detailed in this Section, reliable national-level cost data are not yet available for several emerging cost drivers, specifically addressing cybersecurity, the treatment of hard-to-treat water supplies, the remediation of currently unregulated emerging contaminants, and the complex disposal requirements for treatment residuals. Consequently, costs associated with these specific drivers are excluded from the aggregate national estimate provided herein. The actual national investment requirement will likely exceed our projections as these localized challenges become more widespread and as regulatory frameworks evolve.

3. Funding Availability

3.1. Review of Key Funding Sources

Drinking water utility user fees and rate revenues serve as the primary funding sources to pay for the identified water utility capital and O&M expenses, placing the primary financial obligation on the ratepayer. Consequently, the decision to advance a capital project or program is driven by a balance of technical necessity, competing infrastructure priorities, and the capacity of the customer base to absorb rate increases. Federal programs that help fund or subsidize capital projects can lessen this burden. For drinking water utilities, the primary federal program is the Drinking Water State Revolving Loan Fund ("DWSRF"). Under the DWSRF, the USEPA provides capitalization grants to states, which then administer subsidized loans, some with partial principal forgiveness and most with below market interest rates, to eligible projects.

A variety of other federal programs also provide assistance for water infrastructure projects. For example, in addition to the DWSRF, the USEPA also administers the Water Infrastructure Finance and Innovation Act ("WIFIA"), which assists larger water infrastructure projects that have historically been difficult to fund through DWSRF. The Department of Housing and Urban Development's Community Development Block Grant ("CDBG") program provides funding for economically disadvantaged urban communities, while the Department of Agriculture's Rural Development Water and Environmental Programs ("WEP") serves similar communities in rural areas. Water infrastructure is just one of many project types eligible under CDBG, whereas WEP is limited to water and wastewater infrastructure projects that protect human health. In other words, while many federal programs support water infrastructure projects, eligibility, priorities, and the type of assistance will vary by funding source.[55]

3.2. Trends in Federal/State Spending Data

Funding for drinking water utilities is periodically summarized by the Congressional Budget Office ("CBO").[56] The most recent report, released in February 2025, quantifies state, local and federal spending between 1956 and 2023 utilizing data from the U.S. Census Bureau, State and Local Government Finance Series, and from the Office of Management and Budget.[57] While the CBO reports historical expenditures in 2023 dollars (adjusted herein to 2025 dollars), its dataset aggregates spending related to both drinking water and wastewater utilities. To isolate drinking water infrastructure spending, we applied a 56% allocation factor, based on a U.S. Conference of Mayors publication that reports that 56% of combined water utility expenditures from 1993 to 2020 were for drinking water needs.[58]

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[55] National Association of Clean Water Agencies (NACWA). "Water Infrastructure Funding Parity Report," prepared by Raftelis and Tetra Tech for NACWA, July 21, 2022. https://www.nacwa.org/docs/default-source/resources---public/water-sector-funding-parity-whitepaper-final-(7-21-22).pdf?sfvrsn=63a5c461_2.

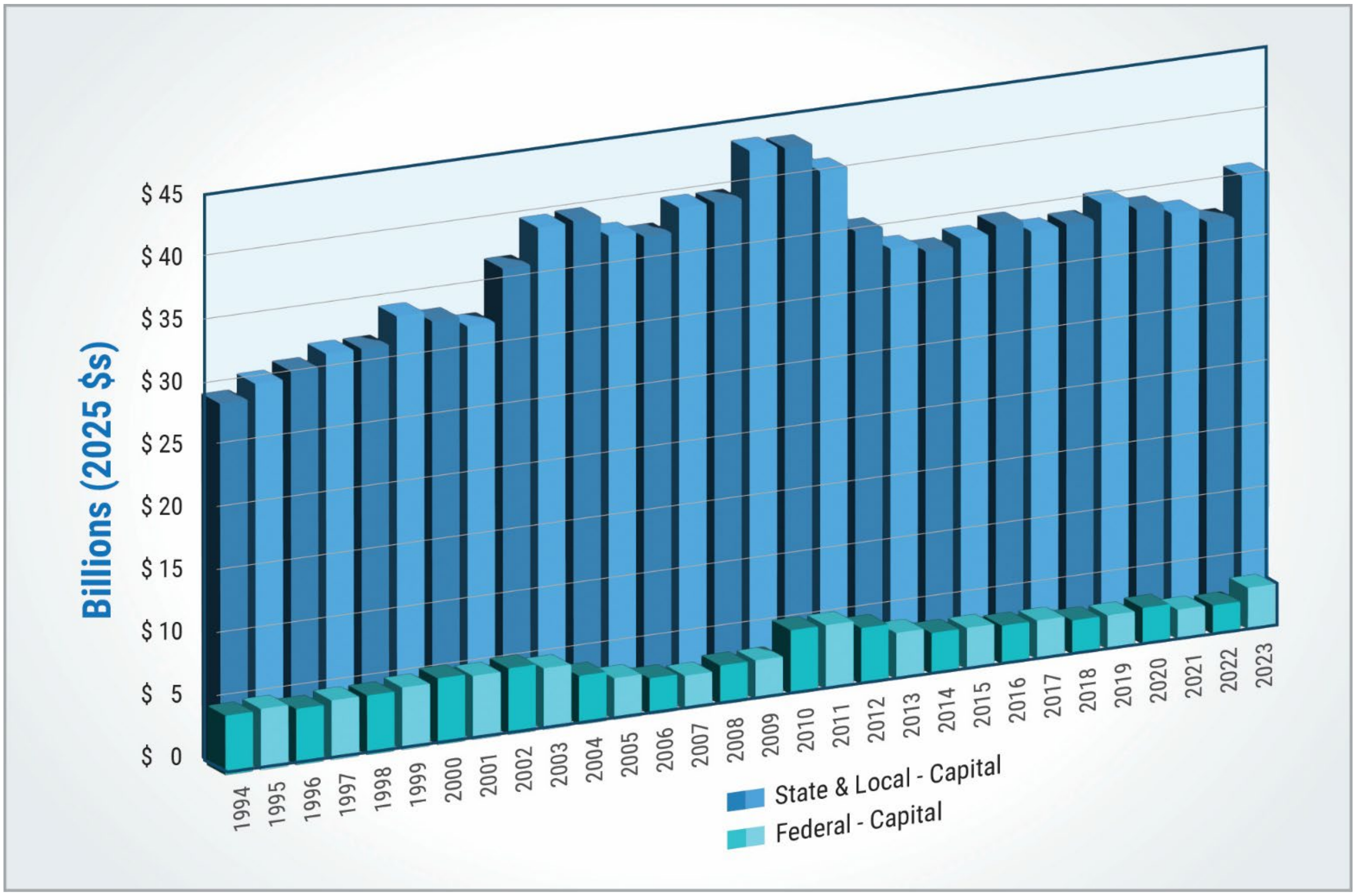
[56] U.S. Congressional Budget Office, "Public Spending on Transportation and Water Infrastructure, 2023", Report 60874, February 2025. https://www.cbo.gov/publication/60874.

[57] Ibid.

[58] U.S. Conference of Mayors Water Council, "$144.6 Billion All-Time High Local Spending on Water and Sewer Utilities in 2020 – CARES Act Fiscal Stimulus Makes an Impact", October 2022. https://www.usmayors.org/2022/12/12/144-6-billion-all-time-high-local-spending-on-water-and-sewer-utilities-in-2020/.

Figure 1 illustrates the estimated capital infrastructure spending for drinking water utilities from 1994 to 2023, distinguishing between federal spending and state and local spending. All past investment figures were converted to 2025 dollars, meaning they were adjusted for inflation to represent the same purchasing power as money spent today. The data shows that throughout this entire timeframe, the vast majority of the capital spending on drinking water utilities was incurred and paid for at the state and local level (84% or more since 1994 and 90% or more since 2014), while the federal contribution to capital infrastructure has remained a minor component of the total investment (16% or less since 1994 and 10% or less since 2014).

Figure 1: Estimated Capital Spending on Drinking Water Utilities by Source



The annual O&M expenses incurred by drinking water utilities (in constant 2025 dollars) was estimated from U.S. Congressional Budget Office estimates of total water sector annual O&M expenses.[59] Similar to above, we applied a 56% allocation factor, to isolate drinking water infrastructure spending, based on a U.S. Conference of Mayors publication that reports that 56% of combined water utility expenditures from 1993 to 2020 were for drinking water needs. The estimate, shown graphically in Figure 2, reveals a distinct trend of steadily increasing O&M costs. Expressing these costs in 2025 dollars allows us to distinguish between price increases caused by normal economic inflation and the specific rising costs of operating water infrastructure. Focusing on the latest 10 years of data (2013 through 2023), capital spending (as shown in Figure 1) was relatively stable, whereas O&M costs grew at an average annual rate of 1.8% after adjusting for inflation, as shown in Figure 2.

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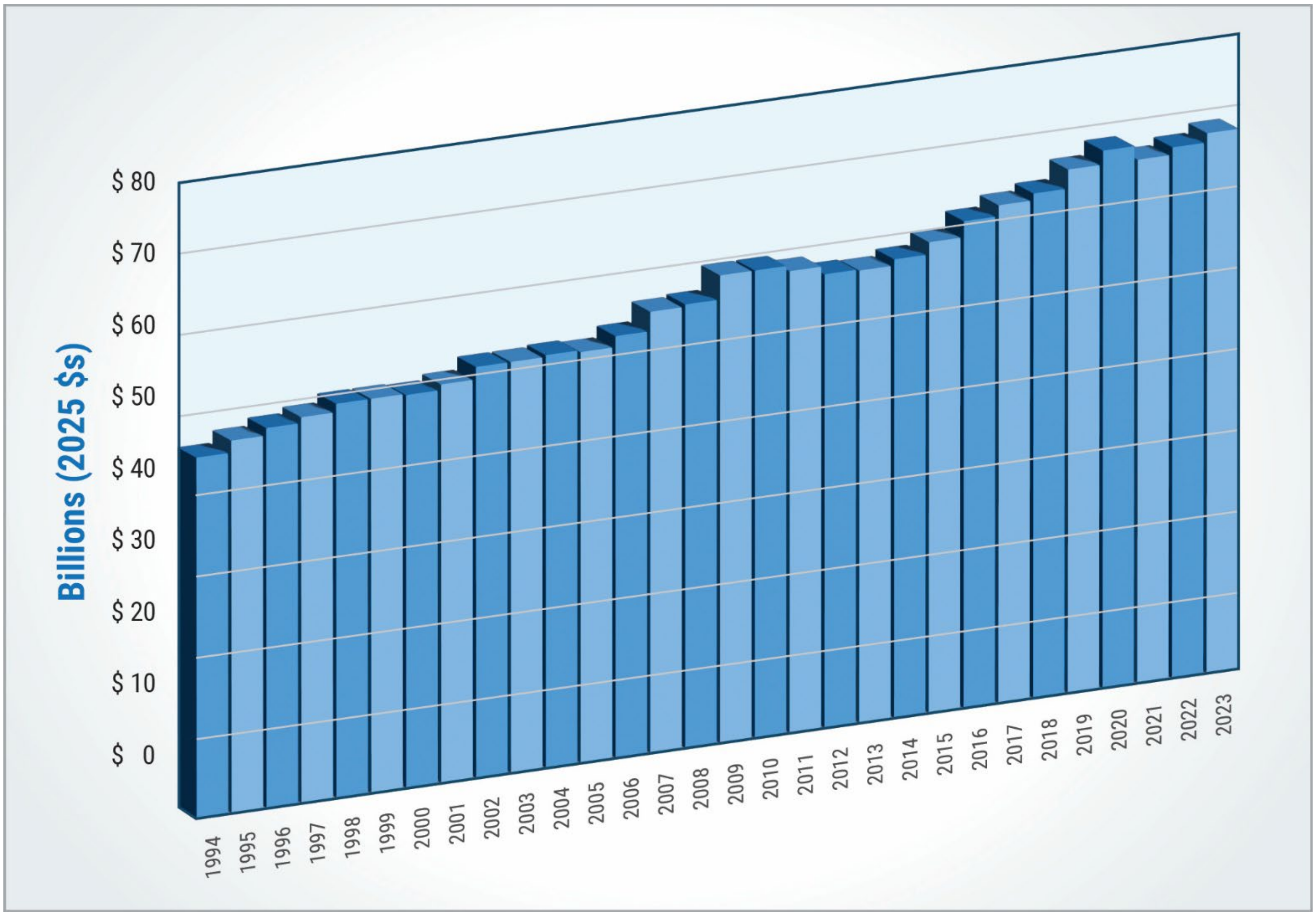
[59] U.S. Congressional Budget Office, "Public Spending on Transportation and Water Infrastructure, 2023", Report 60874, February 2025. https://www.cbo.gov/publication/60874. Spending data in report adjusted from constant 2023 dollars to constant 2025 dollars.

Figure 2: Estimated Aggregate O&M Expenses by Drinking Water Utilities



Drinking water utilities face inflationary pressures related to specific operating expenses, such as power, chemicals, and labor costs. These categories of expenses often rise at rates exceeding the Consumer Price Index (CPI-U) used to adjust the data. While the precise contribution of each factor cannot be isolated within the aggregate national data, the trend indicates that the baseline cost of delivering water service is rising faster than general inflation.

3.3. Infrastructure Investment and Jobs Act

The IIJA, enacted in 2021, included nearly $55 billion for broad water infrastructure for five years. For context, recent annual congressional appropriations to the DWSRF and congressionally directed spending (i.e., earmarks) have averaged approximately $1.1 billion.

The DWSRF program was introduced in 1997 and has become the primary federal funding mechanism directed solely toward drinking water infrastructure. Throughout its nearly 30-year history, the DWSRF program has enjoyed relatively stable funding levels in constant dollar terms.[60] Figure 3 shows the annual funds made available for DWSRF capitalization grants over the life of the program, and with three areas of exception, the available funding has ranged between $1.2 billion - $1.5 billion per year in 2025 dollars. The first exception is the inaugural year in 1997, when nearly $2.4 billion in 2025 dollars was made available. The

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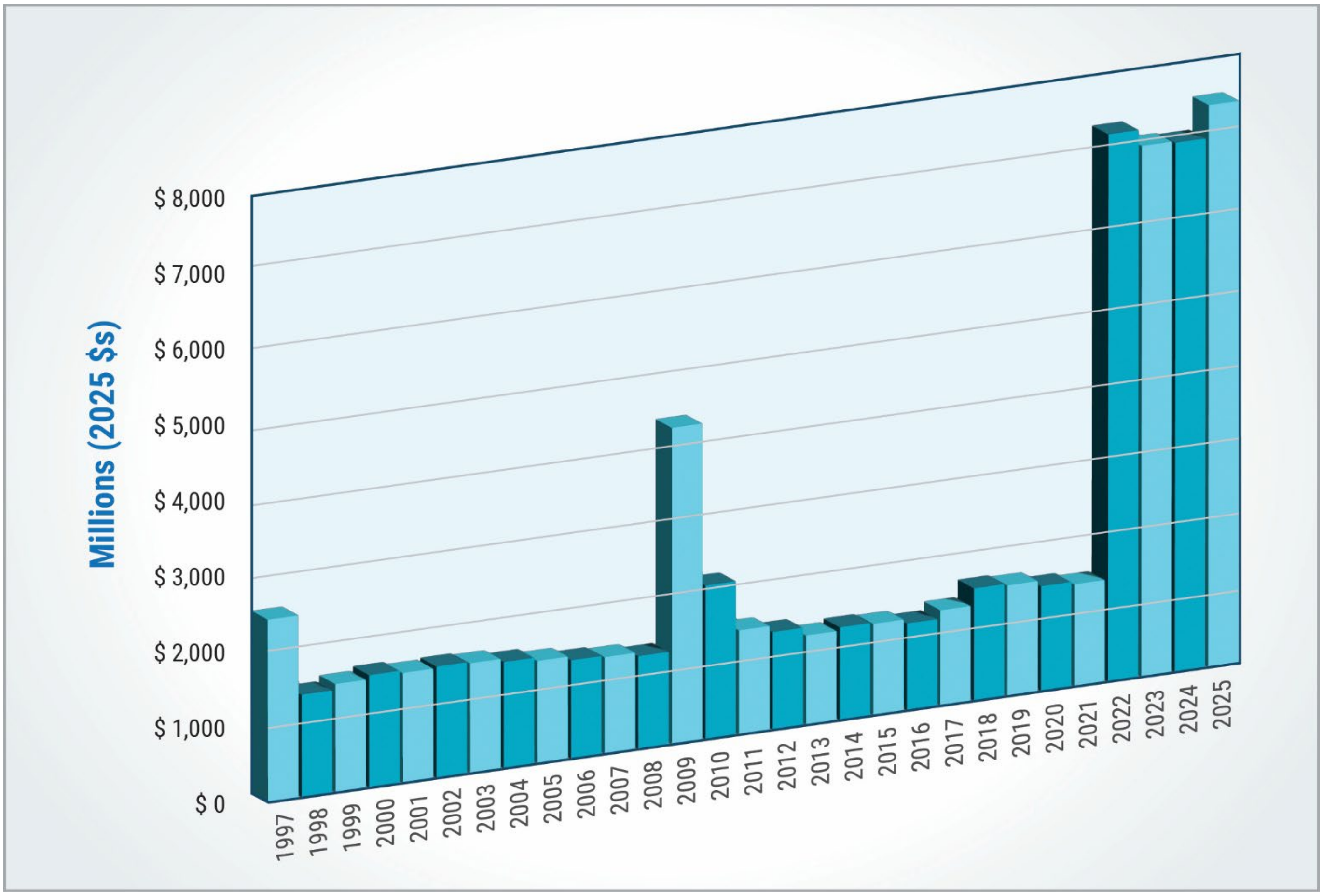
[60] U.S. Congressional Research Service, "The Role of Earmarks in SRF Appropriations in the 118th Congress", Report R48066, 2024. https://www.congress.gov/crs-product/R48066.

second exception is in 2009 and 2010 when approximately $4.1 billion and $2.0 billion in 2025 dollars, respectively, were made available. This surge in funding arose from the American Recovery and Reinvestment Act ("ARRA"),[61] which was passed in response to the Great Recession of the late 2000's. The third exception to the baseline level of funding begins in 2022, with the passage of the IIJA in 2021. The IIJA includes the single largest federal investment in water infrastructure in U.S. history. The bill funded a five year-period (2022 – 2026) for three categories of drinking water infrastructure: $15 billion for LSL replacement, $9 billion to address emerging contaminants (including PFAS), and $11.7 billion for the DWSRF in addition to annual appropriations.

Figure 3: Appropriated Funds for DWSRF Capitalization Grants



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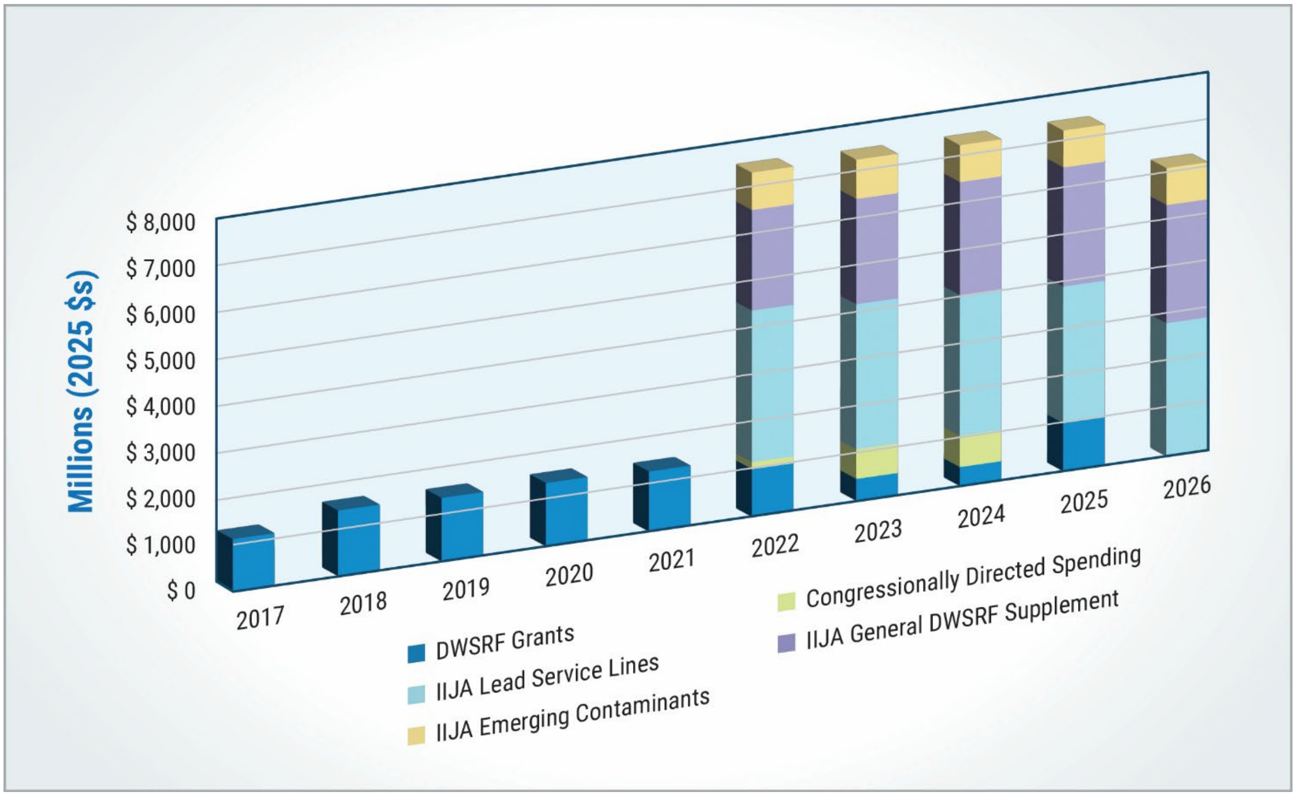
[61] American Recovery and Reinvestment Act of 2009. Pub. L. No. 111-5. https://www.govinfo.gov/content/pkg/PLAW-111publ5/pdf/PLAW-111publ5.pdf.

Despite the enactment of the IIJA in 2021 providing enhanced funding beginning in 2022, the data in Figure 1 reflects only a modest increase in federal capital spending in 2022 and 2023. The dollar amounts in Figure 1 depict federal outlays (actual cash disbursements to states) rather than authorizations, whereas Figure 3 reports authorizations. The administrative process required to obligate and disburse federal funds often spans months or years. Consequently, the full financial impact of the IIJA is expected to appear in spending data over the coming years.

Figure 4 shows the DWSRF and IIJA authorization amounts in 2017 through 2026 in constant 2025 dollars. The spending authorization in 2017-2021 predates the IIJA; the subsequent years show the scale of the increase in funding provided by the IIJA.[62] However, this influx of capital into the water sector is temporary. IIJA funds are scheduled to expire at the end of 2026, and congressional debates regarding potential reductions to core federal water infrastructure programs, such as the DWSRF, have created significant uncertainty about future federal funding levels.[63]

Note that the Congressionally Directed Spending shown in Figure 4 began in 2022, are currently drawn out of the DWSRF capitalization grant appropriations. These amounts are included in Figure 3 above. There is no Congressionally Directed Spending in 2025 due to the use of continuing resolutions to fund federal spending.

Figure 4: DWSRF and IIJA Authorization Amounts



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[62] USEPA. Annual Allotment of Federal Funds to States, Tribes, and Territories; https://www.epa.gov/dwsrf/annual-allotment-federal-funds-states-tribes-and-territories.

[63] At the time the analysis was completed, Congress had not yet authorized DWSRF capitalization grants for 2026 outside of previously authorized IIJA funds.

Ways Federal Support Can Help Address Challenges

The City of Baltimore has leveraged the Water Infrastructure Finance and Innovation Act ("WIFIA") program and State Revolving Loan Fund ("SRF") program several times. One WIFIA loan they received was for $193 million in 2021 to cover water infrastructure rehabilitation, estimated to save $40.4 million to the City and supporting 1,313 jobs.[64] The City also received a WIFIA loan in 2019 for $202 million ($40 million in savings[65]) and another in 2021 for $160.8 million ($51.2 million in savings[66]) to cover their wastewater repair, rehabilitation, and replacement program. In addition, since 2015 the City has received $393.3 million from the SRF as a combination of loans and grants (about $106 million in grants) for their water and wastewater infrastructure.[67]

The Pittsburgh Water and Sewer Authority ("PWSA") received a WIFIA loan in 2023 for $52.5 million to cover their Water Reliability Plan, saving $20 million over other financing and supporting 534 jobs.[68] In addition, PWSA since 2018 has received $795.8 million in Pennsylvania Infrastructure Investment Authority ("PENNVEST") loans and $116 million in PENNVEST grants for water infrastructure rehabilitation, including lead service line replacements.[69] PENNVEST is a financing authority in Pennsylvania that manages the distribution of WIFIA, SRF and other funds to provide low-cost financial assistance to address water, wastewater, stormwater, and non-point source pollution problems that impact public health, safety, the environment, regulatory compliance, and economic development.[70]

The PENNVEST grants and low-cost loans represent significant savings to PWSA in funding their water infrastructure needs and helped to allow lead service line replacements and water main replacement projects to move forward. The benefit of WIFIA to Baltimore and PWSA was the significant flexibility in shaping the debt repayment to match the utility's cash flow needs and to better match the repayment of the debt with the useful lives of the assets that the loans were used to pay for. This helped them smooth out the ratepayer impacts in the near term to help allow the projects to move forward.

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[64] USEPA. 2021. Water Infrastructure Rehabilitation Project. https://www.epa.gov/system/files/documents/2022-01/factsheet-baltimore-water.pdf.

[65] USEPA. 2019. Comprehensive Wastewater Repair, Rehabilitation and Replacement Program. https://www.epa.gov/sites/default/files/2019-02/documents/baltimore_wifiaprojectfactsheet_loanclose.pdf.

[66] USEPA. 2022. Wastewater Infrastructure Rehabilitation. https://www.epa.gov/system/files/documents/2022-01/fact-sheet-baltimore-wastewater.pdf.

[67] Conversation with Garret Halbach, Chief of Budget and Financial Planning, Baltimore DPW, November 17, 2025.

[68] USEPA. 2023. Water Reliability Plan. https://www.epa.gov/system/files/documents/2023-06/Factsheet_Pittsburgh.pdf.

[69] Information obtained in an email from Ed Barca, Director of Finance, PWSA, December 2, 2025.

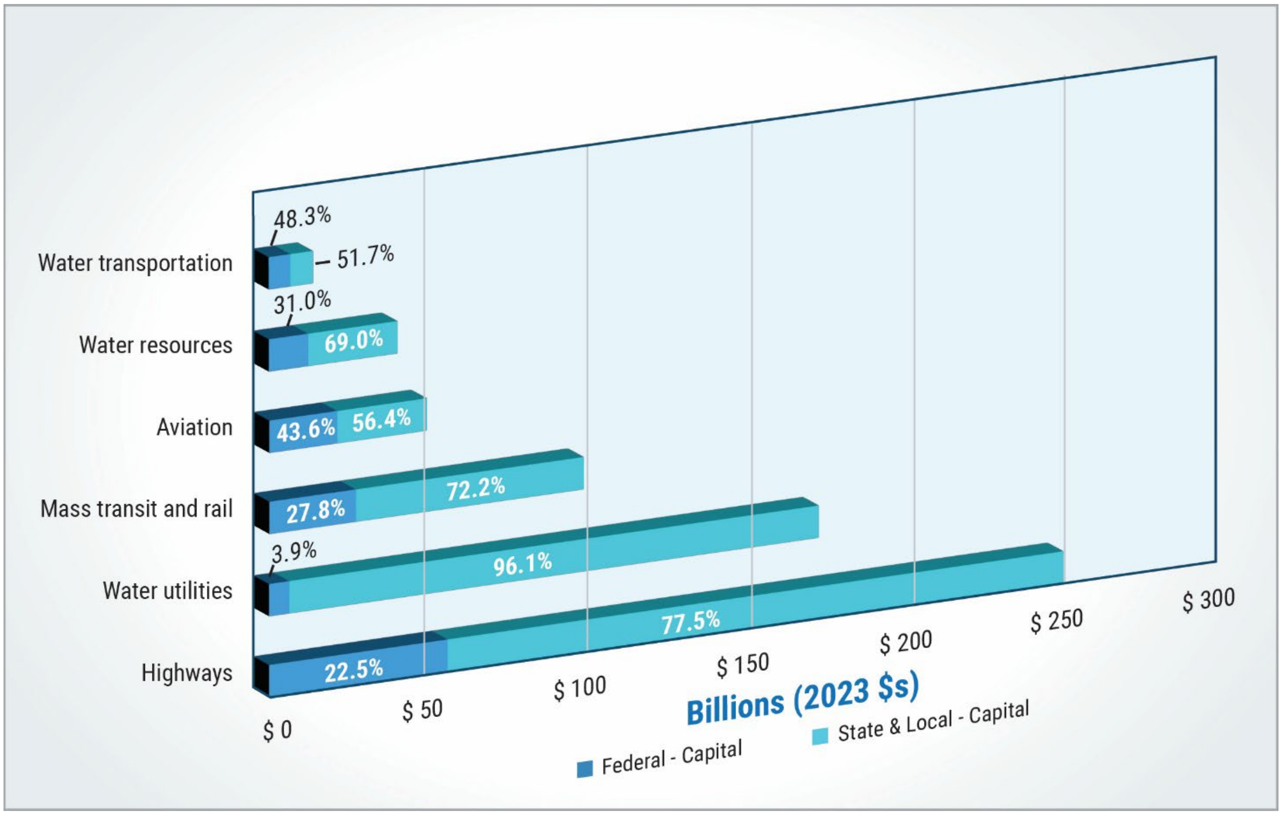
[70] Financial Assistance for Water Quality Improvement Projects in Pennsylvania: Pennsylvania Infrastructure Investment Authority – PENNVEST; https://www.pa.gov/agencies/pennvest.

3.4. Comparison of Federal Funding Support to Other Sectors

Historically, the federal government has provided varying levels of financial support to major infrastructure sectors, including the water sector. However, drinking water utilities have consistently received significantly less federal aid than other major classes of infrastructure. This disparity was comprehensively documented in the 2022 *Water Infrastructure Parity Report*.[71] This report benchmarked federal support for water sector utilities relative to other infrastructure sectors, such as water transportation (i.e., ports), water resources,[72] highways, mass transit and rail, or aviation.

Figure 5 illustrates the total public spending in 2023 across these sectors.[73] In this comparison, "water utilities" aggregates drinking water, wastewater, and storm water utilities. The data reveals a striking imbalance. Despite being the second largest infrastructure sector by total expenditures, water utilities receive the lowest level of federal support, both in absolute dollars and as a percentage of total spending. Specifically, federal sources contribute just 3.9% of total public spending on water sector utilities.[74] In contrast, the next lowest federally subsidized sector (highways), received 22.5% of their funding from the federal government.

Figure 5: 2023 Public Spending on Transportation and Water Infrastructure



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[71] National Association of Clean Water Agencies (NACWA). "Water Infrastructure Funding Parity Report".

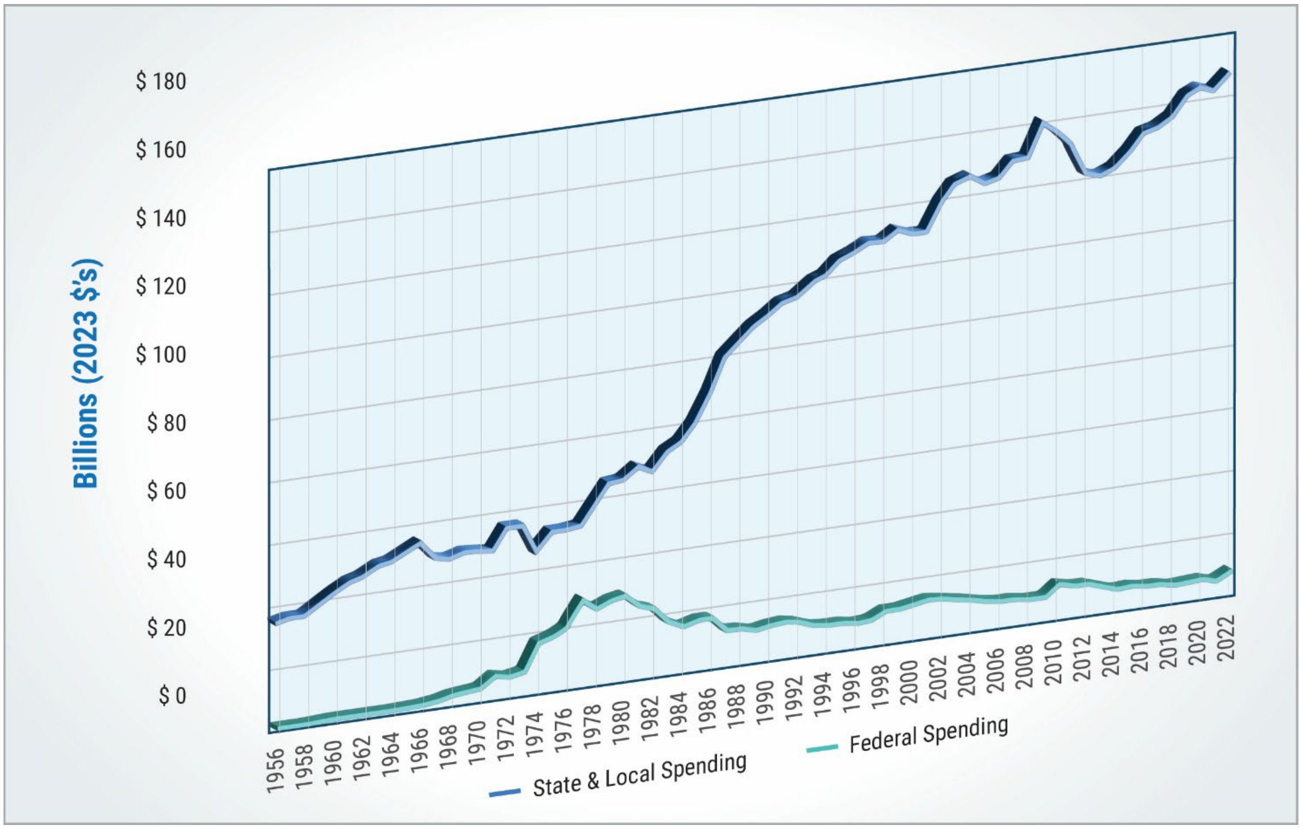
[72] Water resources include water containment facilities (e.g., dams, levees, reservoirs, and watersheds), sources of fresh water (e.g., lakes and rivers), and outlays for navigation by the U.S. Army Corps of Engineers.

[7373] U.S. Congressional Budget Office, "Public Spending on Transportation and Water Infrastructure, 2023", Report 60874, February 2025. https://www.cbo.gov/publication/60874.

[74] Note that this information presented by the CBO compares the total spending on water infrastructure, including O&M and capital spending, and water infrastructure here represents both water and wastewater utility spending. This differs from Figure 1 above that isolates the federal support for drinking water utilities and compares the total federal support to water utility capital spending, which excludes O&M spending.

Figure 6 illustrates the historical divergence in federal funding compared to local spending in the water sector.[75] Over the past 60 years, state and local spending on water sector utilities has roughly quadrupled in real terms (i.e., in addition to increase in spending due to general economic inflation). The data highlights a widening gap where the increasing financial burden of water sector infrastructure has fallen almost exclusively on states and local utilities.

Figure 6: Public Spending on Water Sector Utilities by Source



3.5. Characterization of Investment Gap

The drinking water utility infrastructure gap can be characterized by the difference in current spending levels and the estimated future needed spending levels. As detailed in Table 3, the total capital needs in 2026-2050 were estimated to be between $2,086.1 billion and $2,424.2 billion. To provide a consistent annual benchmark, total capital needs of drinking water utilities were amortized evenly across the 25-year time horizon. Furthermore, since rising operating costs significantly influence household affordability, this analysis also incorporates projected O&M expenses, which continue to outpace general inflation.

Using the midpoint of the projected total capital needs estimate ($2,255.2 billion), we estimate that drinking water utilities in aggregate require an average annual capital investment of roughly $90.2 billion per year through 2050. In comparison, the current baseline for capital spending, calculated as the inflation-adjusted average from 2013 to 2023, is $33.6 billion per year.[76] Comparing the required annual investment ($90.2

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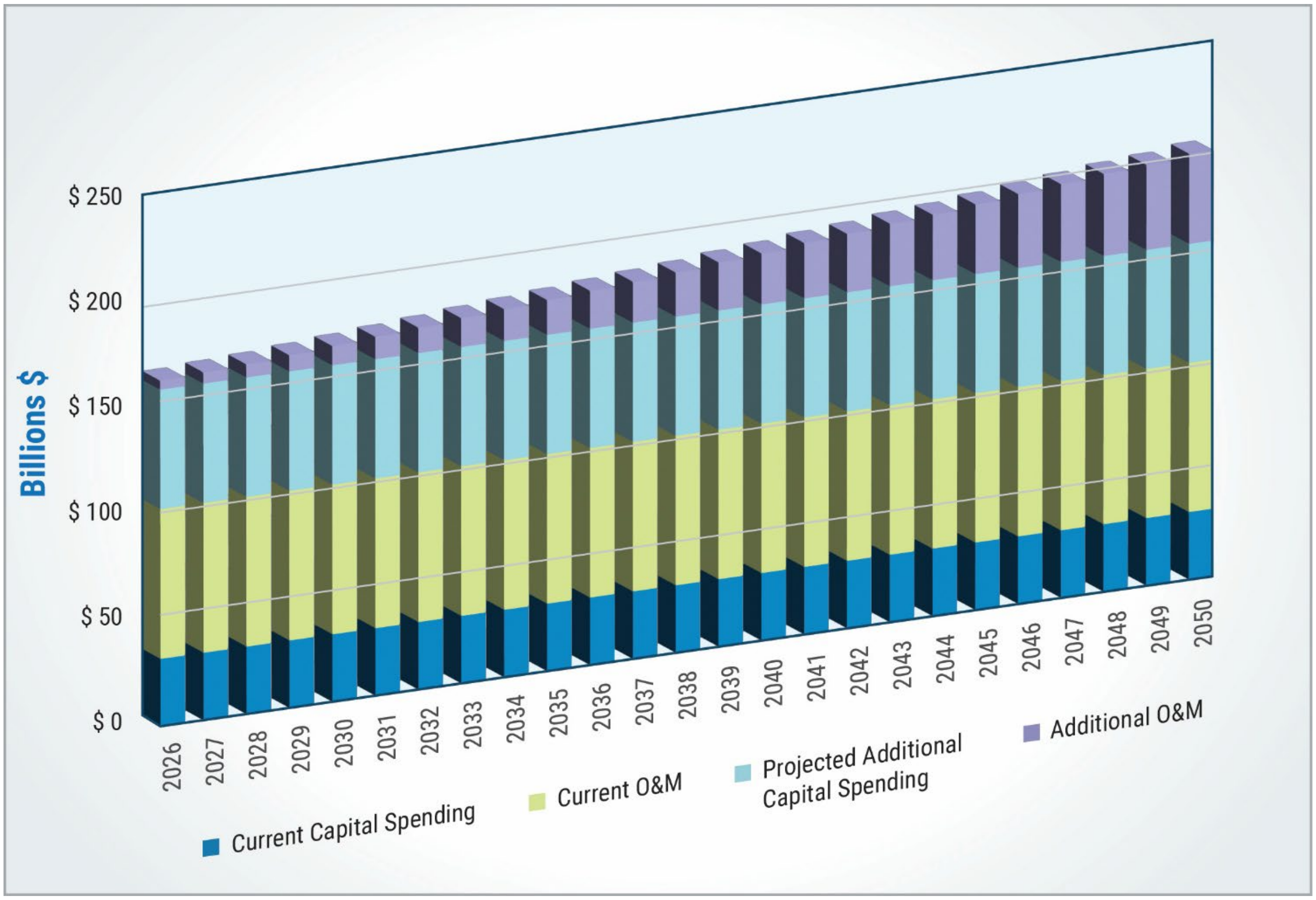
[75] U.S. Congressional Budget Office, "Public Spending on Transportation and Water Infrastructure, 2023", Report 60874, February 2025. https://www.cbo.gov/publication/60874.

[76] The average capital spending over 2013 – 2023 was selected to represent current baseline capital spending for water utilities. Capital spending rates prior to 2013 were elevated, elevated partly due to post-Great Recession stimulus spending and do not reflect the current business environment. Within the period 2013 – 2023, spending rates have little variation, with the low in 2022 at $32.1 billion and the high in 2023 at $35.2 billion.

billion) against the current baseline ($33.6 billion) reveals a substantial annual infrastructure spending gap of approximately $56.6 billion per year.

Regarding operating costs, historical data indicates a consistent growth rate above normal economic inflation of 1.8% per year between 2013 and 2023. Consequently, this analysis projects future O&M requirements in two components: "Current O&M expenses," which were held constant at 2023 levels, and "Additional O&M expenses," which represent the cumulative cost of O&M expenses growing at 1.8% above the normal annual inflation rate. Figure 7 presents the aggregate of these projections to illustrate the total spending requirement over the 25-year period (2026 – 2050), categorized by current capital spending, additional needed capital spending (i.e., the capital funding gap), current O&M spending, and additional O&M spending.

Figure 7: Projected Water Utility Spending



Our analysis estimates that the current spending by drinking water utilities, including annual capital and O&M spending of approximately $101.6 billion in 2025 dollars, is insufficient to meet future needs. Closing the funding gap requires adding $56.6 billion in capital investment each year, while rising operational costs are projected to add an additional $42.1 billion in annual need by 2050 in 2025 dollars. This brings the total annual need to $200.3 billion by 2050 in 2025 dollars. The projected total represents a doubling of the necessary financial resources and purchasing power, rather than simply a higher price tag caused by general economic inflation. This additional $98.7 billion of annual capital and O&M spending by 2050 will be a burden borne by ratepayers if additional support from federal or state sources are not realized. Between 2012 and 2021 the annual capitalization grants to the DWSRF program averaged just $1.3 billion in 2025 dollars, representing just 1.4% of capital spending needs. In other words, the projected additional drinking water utility spending by 2050 will be 76 times the recent baseline DWSRF funding levels.

4. Affordability Impacts of Needed Investments

The widening disparity between water utility infrastructure investment needs and available federal funding creates an inevitable pressure on local water rates. As utilities move to address the projected 25-year needs, the financial burden will increasingly fall upon ratepayers. To understand the magnitude of the future drinking water utility customer financial burden, the following analysis quantifies the current baseline of water affordability in the U.S. and projects how the burden on low-income households will intensify if local ratepayers are forced to fully finance the nation's infrastructure needs without increased federal support.

4.1. Introduction to Water Affordability

4.1.1. Water Affordability Background and Context

Water affordability is a pressing issue in many communities across the U.S. The USEPA recently estimated that between 12.1 and 19.2 million households nationwide (approximately 9% to 15% of all households) meet thresholds that indicate they may struggle to afford basic water services.[77] For some, water affordability is a chronic issue; others have unexpected crises that affect their ability to pay. Low-income households who do pay their water bill are often forced to make trade-offs that affect their health and well-being.[78]

At the same time, as described throughout this report, the cost of providing clean, safe, and reliable water services is growing. Cities, towns, and utilities nationwide will continue to require higher levels of investment to address aging infrastructure, regulatory requirements, climate change impacts, emerging contaminants, lead service line replacements, and other issues. With limited external funding, water and sewer utility rates will necessarily increase, exacerbating affordability challenges for low-income households.

Drinking water utilities have historically examined affordability within the context of nationally mandated regulatory requirements and utility financial capability to deliver water services in full compliance with applicable laws and regulations. Traditional affordability metrics, such as USEPA's Residential Indicator ("RI"), were initially developed with this lens. Over the past decade, practitioners have developed more robust approaches and methods for better examining affordability at the household level. This report applies these approaches, and examines additional metrics and data, to quantify the scale and depth of affordability challenges for households within the U.S., both now and into the future, as funding needs continue to grow. Specifically, the following sections examine affordability challenges as follows:

- Characterizing current affordability challenges for U.S. households, with a focus on low-income households and their ability to meet basic needs.
- Applying established water affordability metrics to quantify the burden of water service costs and estimate the number of households facing affordability challenges.

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[77] USEPA. 2024. *Water Affordability Needs Assessment: Report to Congress.* EPA 830-R-24-015. Accessed on September 2, 2025: https://www.epa.gov/system/files/documents/2024-12/water-affordability-needs-assessment.pdf.

[78] Environmental Financial Advisory Board. 2025. *Advancing Water Affordability Nationwide: A Framework for Action.* USEPA. Accessed on November 11, 2025: https://www.epa.gov/system/files/documents/2025-07/efab-fact-sheet.pdf.

- Examining the impact of future water bill increases on low-income households to understand how rising water bills may exacerbate affordability risks.

4.1.2. Defining Drinking Water Affordability

While there is no universally accepted definition of household water affordability, it is commonly described as the ability of households to pay for water services without experiencing undue economic hardship.[79] Such hardship occurs when financially constrained households must sacrifice other essential goods and services to cover their water bills. Examples include forgoing medical care or prescriptions, skipping nutritious meals, or struggling to pay for childcare, transportation, or home energy services. Households facing water shutoffs also experience economic hardship, as the loss of water service can render a home uninhabitable.

These concepts are reflected in the definition of household affordability developed by a panel convened by the AWWA in 2021 to explore alternative approaches for evaluating affordability as part of rulemaking under the SDWA.[80] For the purposes of this report, we adopt the panel's definition of affordability as:

> *". . . . the ability of a customer to pay the water bill in full and on time without jeopardizing their ability to pay for other essential expenses."*

While this definition is conceptually sound, affordability remains a subjective and context-dependent issue. How much is "too much" for a low-income household to pay? In most cases, it is not the water bill alone that pushes households into financial distress, it is the cumulative burden of meeting basic needs.

4.1.3. Origins of the 2.5% Threshold

A commonly cited benchmark for drinking water affordability is 2.5% of median household income ("MHI"). This figure stems from historical USEPA policy, which the agency developed to assess the national-level affordability of regulatory options for small communities. Specifically, in the past, USEPA stated that it would consider a NPDWR to be unaffordable for small systems (serving populations under 10,000) if compliance would result in a household water bill exceeding 2.5% of the MHI for those communities.

Importantly, this threshold was intended for application to small systems in aggregate, not to individual utilities or households. Despite its narrow regulatory origin, the 2.5% threshold has taken on outsized influence in broader affordability discussions. It is often inferred that a combined annual water and wastewater bill of less than 4.5% of community MHI is affordable, allocating 2.5% for drinking water and 2% for wastewater and combined sewer overflow controls.[81] This inference, while widespread, lacks a formal basis and does not necessarily reflect the lived realities of low-income households facing layered cost burdens.

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[79] Raucher, R., J. Clements, E. Rothstein, J. Mastracchio, and Z. Green. 2019*. Developing a New Framework for Household Affordability and Financial Capability Assessment in the Water Sector*. Prepared for AWWA, NACWA, and WEF. Accessed November 25, 2025: https://www.awwa.org/wp-content/uploads/Developing-New-Framework-For-Affordability.pdf.

[80] American Water Works Association (AWWA). 2021. *Improving the Evaluation of Household-Level Affordability in SDWA Rulemaking: New Approaches*. Accessed November 25, 2025: https://www.awwa.org/wp-content/uploads/Improving-Evaluation-Household-Level-Affordability-SDW-Rulemaking.pdf.

[81] See USEPA (2024), *Water Affordability Needs Assessment: Report to Congress.* EPA 830-R-24-015, for additional background on affordability thresholds for water, wastewater, and stormwater costs.

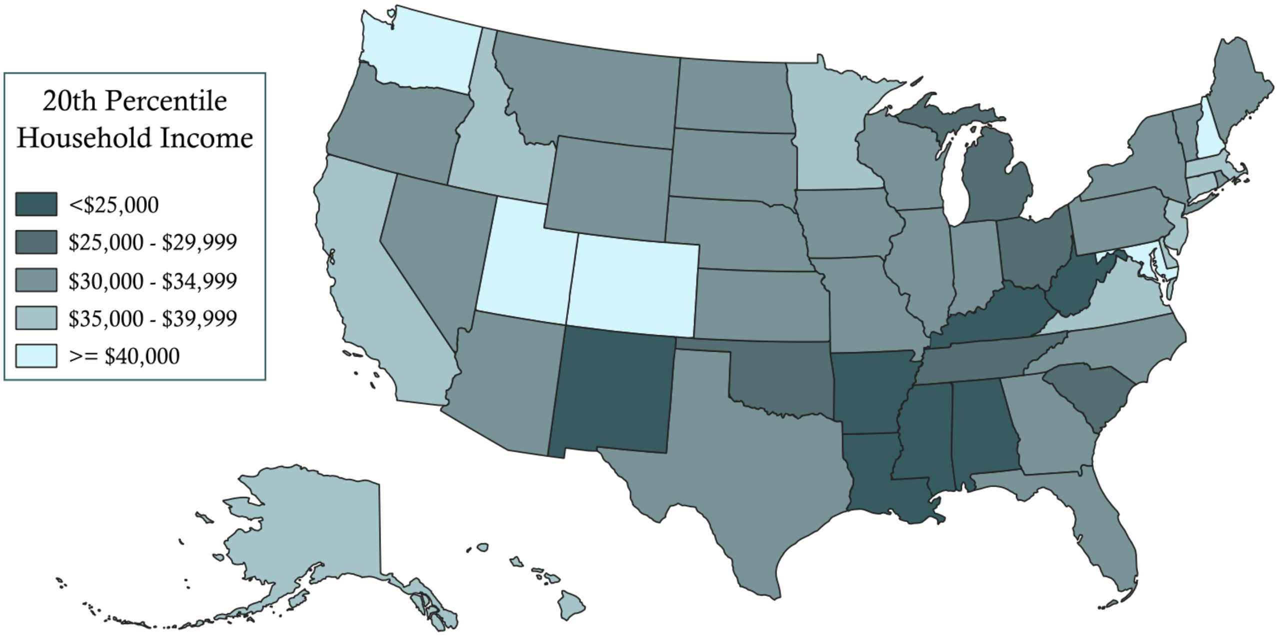
4.2. Household Affordability Challenges: A National Overview

Quantifying the scope of financial hardship requires a robust analysis of the economic realities currently facing households across the U.S. To conduct this analysis, we relied primarily on federally available data sources, including the 2023 U.S. Census American Community Survey ("ACS") and Public Use Microdata Sample ("PUMS") one-year datasets, Bureau of Labor Statistics ("BLS") Consumer Expenditure Survey ("CEX"), and Federal Reserve Economic Data ("FRED"), unless otherwise noted.

4.2.1. Income Levels and Non-Discretionary Spending

The MHI in the U.S. is currently $81,600; this varies significantly at the state level – ranging from $56,800 in Mississippi to $106,100 in Massachusetts. Based on data from the ACS, 20% of U.S. households earn less than $31,800 per year. Like MHI, the 20th percentile income (also referred to as the upper limit of the lowest quintile income, "LQI") also varies by state - from $22,100 in Mississippi to $46,100 in Utah. As shown in Figure 8, the 20th percentile income is generally lower in the Southeastern U.S. and some more central eastern states and is higher in the west. The 20th percentile income is often used to represent low-income populations because it captures a broader segment of economic vulnerability than traditional poverty measures, as is explained in more detail below.

Figure 8: Upper Limit of Lowest Quintile Income by State

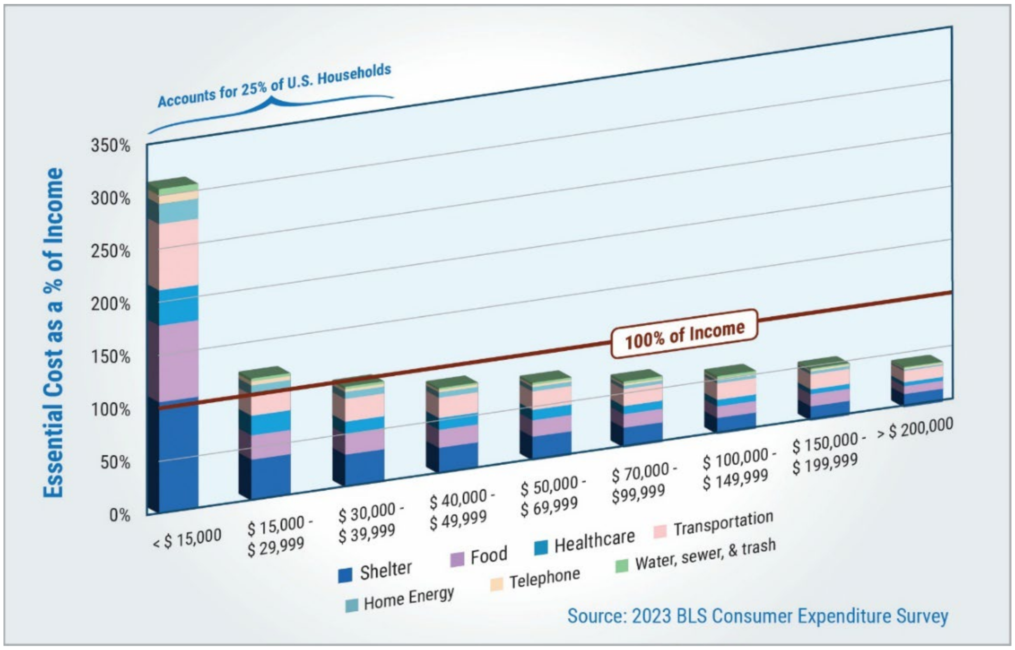


Source: ACS PUMS 2023 single-year estimates

It is not sufficient to examine income alone to fully understand household affordability challenges at the national scale; we must also consider the extent to which income levels enable households to meet their basic needs. This depends not only on earnings, but on the cost of essential goods and services, such as housing, medical care, food, and all forms of utilities. Essential goods and services are those that are required for a household to meet their most basic needs and maintain health, hygiene, and employment.

Figure 9 and Table 4 present data from the BLS CEX, showing the amount that households spend on select essential items, including shelter, food, healthcare, transportation, home energy, phones, and water, sewer, and trash collection services, as a percentage of their after-tax income, by income category. These data indicate that for up to one quarter of U.S. households, these expenditures account for 95% or more of their income. Even households earning between $50,000 and $70,000 per year spend an average of 74% of their income on these non-discretionary items. This leaves little room for other important needs, such as childcare, clothing, and household emergencies. Notably, across all income categories, water, sewer, and trash services (combined) make up a small portion of household costs; however, the CEX data indicate that households in lower income categories do not have capacity to absorb even a small increase in their expenses.

Figure 9: Essential Household Expenditures as a Percentage of Household After-Tax Income, by Income Category



Source: 2023 BLS Consumer Expenditure Survey

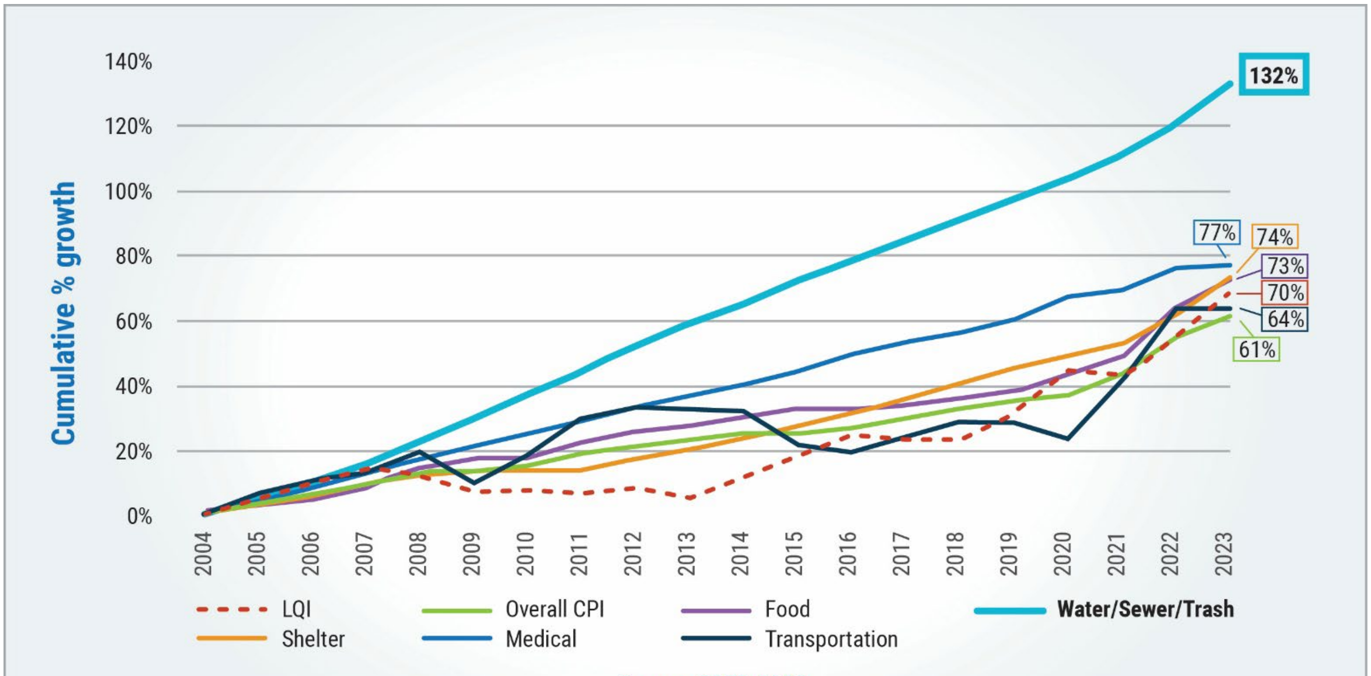
Table 4: Select Household Essential Expenditures as a Percentage of Household Income, by Income Category

Household Income Category (before tax)	Average Annual Income (after tax)	Cost of essential expenses as % of household income	% of U.S. households (Cumulative %)
< $15,000	$7,880	308%	9% (9%)
$15,000 - $29,999	$23,211	115%	10% (18%)
$30,000 - $39,999	$35,538	95%	7% (25%)
$40,000 - $49,999	$44,292	81%	7% (32%)
$50,000 - $69,999	$56,491	74%	13% (45%)
$70,000 - $99,999	$77,472	61%	16% (61%)
$100,000 - $149,999	$108,701	53%	17% (78%)
$150,000 - $199,999	$147,286	48%	9% (87%)
> $200,000	$259,392	37%	13% (100%)

Source: 2023 BLS Consumer Expenditure Survey, U.S. Census 2023 PUMS single year estimates

At the same time, the costs for essential goods and services are rising, and in some cases, outpacing growth in incomes for the lowest income earners. Figure 10 presents the nominal increase in the CPI for the four largest household cost categories reported above (shelter, food, healthcare, and transportation), as well as for water, sewer, and trash costs (combined), compared to growth in the upper limit of the LQI over the last 20 years (2004 – 2023). As shown, the upper limit of the LQI increased by 70% over this period, while costs for shelter, healthcare, and food grew by 74%, 77%, and 73%, respectively. Overall, transportation has experienced a lower increase, although this has varied considerably over time. The CPI for water, sewer, and trash experienced a significantly greater increase than other categories – growing 132% in nominal terms.

Figure 10: Increase in LQI and CPI for shelter, medical, transportation, and food cost categories



Source: FRED 2025

4.2.2. Federal Poverty Level

Approximately 10.6% of the U.S. population is living in poverty (2024 estimate), down from 14.7% in 2015.[82] Historically, U.S. poverty thresholds have been used as a benchmark for identifying households struggling to meet basic needs and determining eligibility for certain public assistance programs. However, this metric has significant limitations, as it is based on outdated assumptions about household spending and consumption patterns and does not account for regional differences in cost of living.[83]

Many households earning well above the federal poverty level ("FPL") have trouble paying for basic expenses.[84] Federal, state, and local governments frequently set eligibility for social assistance programs at 150% or even 200% of the FPL. The 200% FPL threshold has been used as a general rule of thumb for

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[82] Shrider, E, and C. Bijou. 2025 September 9. Poverty in the United States: 2024. U.S. Census Bureau. https://www.census.gov/library/publications/2025/demo/p60-287.html.

[83] Stratus Consulting. 2013. Affordability Assessment Tool for Federal Water Mandates. Prepared for U.S. Conference of Mayors, AWWA, and Water Environment Federation. Available: https://www.awwa.org/wp-content/uploads/affordability-assessment-tool-for-federal-water-mandates.pdf.

[84] The United Way. 2025. The State of Alice in the United States. Available: https://www.unitedforalice.org/national-overview#4.5/36.316/-95.842.

defining economically vulnerable populations.[85] Currently, approximately 28% of the U.S. population live in households earning less than 200% of the FPL (2024).

Established measures of income adequacy indicate that the scope of affordability challenges is much greater than indicated by poverty thresholds, including even 200% of the FPL. For example, United Way's Asset Limited, Income Constrained, and Employed ("ALICE") Project continues to provide critical insights into the scale of financial hardship across the U.S. ALICE refers to households who have incomes above the FPL but who still struggle to afford basic necessities.[86] A cornerstone of the project is the Household Survival Budget, which estimates the minimum cost of five essentials (housing, childcare, food, transportation, and health care) tailored to household type and county-level costs. According to the 2025 national report, 42% of U.S. households fall below the ALICE threshold: 13% in poverty and an additional 29% classified as above the ALICE threshold. This means over 55 million households are unable to meet basic needs, despite many having steady employment. This is in line with the BLS CEX data presented above.

4.2.3. Geographic Variations in the Cost of Living

The cost of living varies widely across the U.S. An income that affords a comfortable lifestyle in the Southeast may fall short of covering basic expenses in major West Coast cities. To examine these geographic differences, this analysis uses Regional Price Parities ("RPPs")—a metric published by the Bureau of Economic Analysis (BEA) that measures state-level price differences relative to the national average. RPPs express cost-of-living variations as percentage deviations from national price levels. By adjusting household incomes using RPPs, we can better compare incomes and household water burdens across states.

Figure 11 illustrates the 20th percentile income by state, both unadjusted (published data that does not account for cost-of living differences) and adjusted (standardized according to the RPPs). Adjusted incomes are benchmarked to the national average, providing a proxy for buying power among low-income households. As shown, several Southern states—such as New Mexico, Arkansas, Alabama, Tennessee, and South Carolina—shift into higher income categories when adjusted for cost of living (as indicated by lighter shading). This reflects the fact that while incomes are lower, so are local prices. Conversely, states like New York, California, and Washington shift downward, revealing that relatively high incomes are offset by elevated living costs, meaning households in these states have less purchasing power to meet basic needs.

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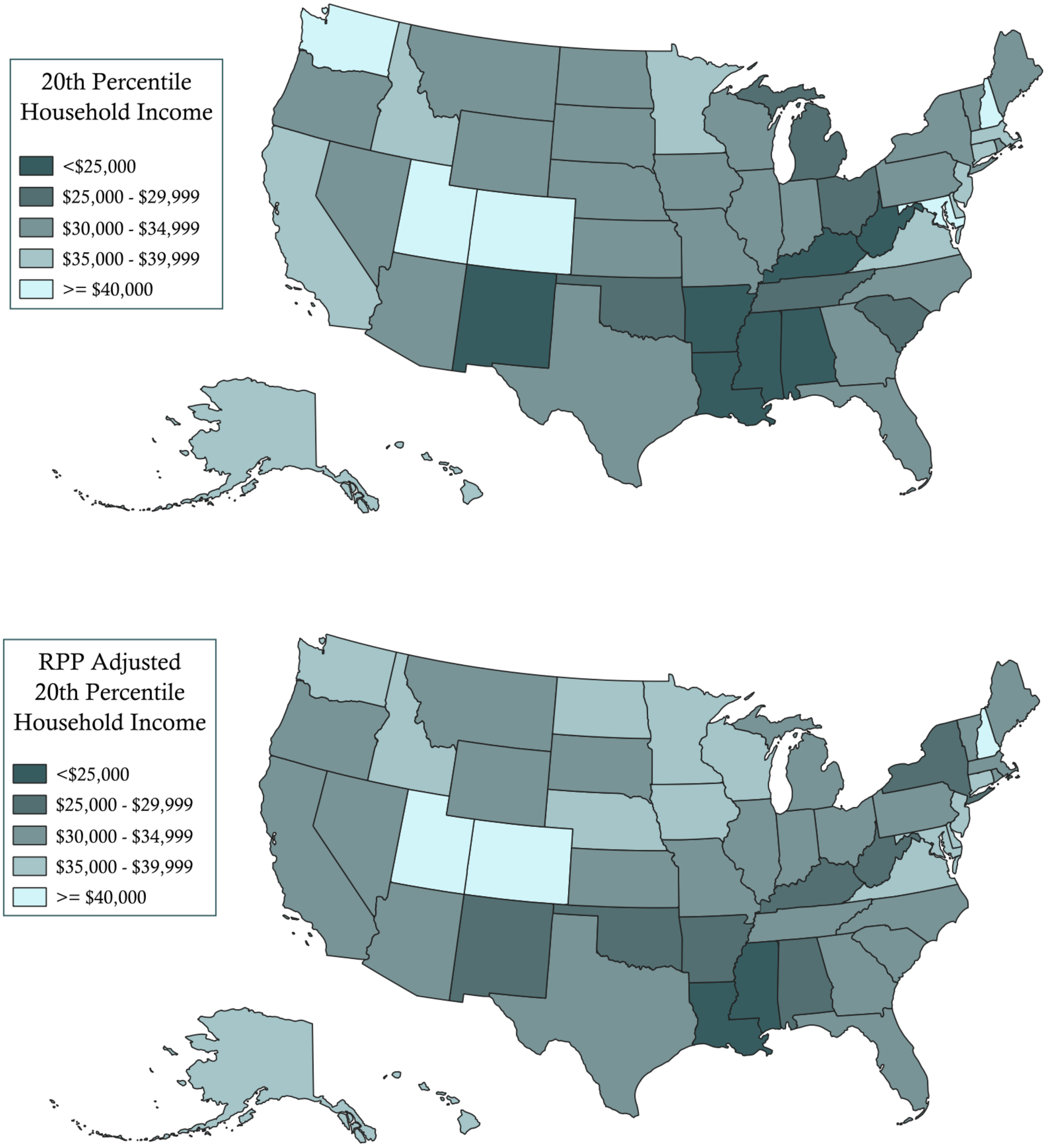
[85] Glicksman, A. and L. Ring. 2021. Defining Poverty as an Eligibility Requirement for Supportive Services. Innov Aging. Dec 17;5(Suppl 1):426–7. https://doi.org/10.1093/geroni/igab046.1656. PMCID: PMC8969935.

[86] As of 2023, the ALICE Project has expanded its reach to cover all 50 states, Washington D.C., and Puerto Rico, offering a standardized methodology to assess local cost-of-living pressures.

Figure 11: Upper Limit of the Lowest Quintile Income by State (above) and RPP adjusted Upper Limit of Lowest Quintile Income by State (below)



4.3. Current Water Affordability Challenges

Moving from broad economic indicators to sector-specific impacts, the following analysis examines the cost of water services for low-income households. By applying established affordability thresholds, we identify how water bills interact with other essential expenses to create cumulative affordability challenges for vulnerable populations.

Water Supply Issues Drive Funding Gap for Old Bridge Municipal Utilities Authority

The experience of the Old Bridge Municipal Utilities Authority ("OBMUA") in New Jersey illustrates the compounding financial gap created when utilities face significant infrastructure needs that are not supported by existing utility rates. Following New Jersey Department of Environmental Protection ("NJDEP") mandates in the 1980s to combat seawater intrusion, OBMUA was compelled to reduce local groundwater withdrawals from 8 MGD to 4 MGD.[87] While the original regulatory framework anticipated a 25-year aquifer recovery period, the coastal well rights have not been restored, rendering a permanent loss of low-cost local supply.

Financial Impacts of Water Supply Issues

To bridge the supply deficit, OBMUA entered into a purchase agreement with a private investor-owned utility ("IOU") for up to 9 MGD of source water. This shift in water supply has exposed the Authority to escalating operational costs that consistently outpace inflation. The shift to purchased water has resulted in source water cost premiums of over 30% compared to continuing to use local groundwater sources. Wholesale rates from the supplier increased by an average of 8% annually through 2017.[88] This trend has continued since then, with the OBMUA 2025 Budget Workshop citing a 6.3% year-over-year increase in purchased water expenses.[89]

With the supplier filing a new two-year rate case with the New Jersey Board of Public Utilities (NJBPU) in 2025 and seawater intrusion projected to worsen, OBMUA faces a widening divergence between its revenue requirements and the escalating cost of bulk water imports, placing additional pressure on water rates and customer bills. This case underscores the long-term economic vulnerability introduced when environmental factors strand local infrastructure assets and render local water supplies unusable.

4.3.1. Household Water and Sewer Costs

There is no comprehensive national database that reports drinking water service costs or utility-specific water rates for residential customers. Several sources do report average household costs or costs associated with a specific level of use, although some of these sources combine drinking water costs with the costs of other utilities. For example, the 2023 BLS CEX survey estimates the average annual household cost of water, sewer, and trash services to be approximately $850 nationally (when adjusted to 2025 dollars). The CEX reports differences across income categories, with bills ranging from an average of $434 (5.1% of income) for households earning less than $15,000 to $1,347 (0.5% of income) for households earning greater than $200,000. The U.S. Census PUMS also reports data from households on the cost of water service; however, it is not clear whether (or how many) households may be including sewer and/or stormwater services in their responses.

A 2024 survey administered by the U.S. Department of Health and Human Services to examine the effectiveness of the temporary Low-Income Household Water Assistance Program ("LIHWAP") asked utilities to report water and sewer bills for residential customers using 5,000 gallons per month.[90] For a 2.5-person household, this amounts to approximately 65 gallons per person per day, with bills amounting to $1,258 per year. Finally, for a study commissioned by AWWA and several other water industry organizations

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[87] Information from Old Bridge Municipal Utilities Authority website, accessed at: https://obmua.com/about-us/.

[88] "OBMUA groundwater cutbacks mandated by the NJDEP" presentation accessed at: https://www.facebook.com/OldBridgeMUA/videos/395055017589932/.

[89] Middlesex Water Files for Rate Request, Middlesex Water, June 30, 2025; https://investors.middlesexwater.com/news-releases/news-release-details/middlesex-water-files-rate-request.

[90] U.S. Department of Health and Human Services, Office of Community Services. 2024. *LIHWAP Water Utility Affordability Survey Report: Understanding Water Affordability Across Contexts*. Accessed on November 25, 2025: https://acf.gov/sites/default/files/documents/ocs/lihwap-survey-report-03-14-24.pdf.

to examine the potential for a Federal Low-Income Water Customer Assistance Program Assessment (“LIWCAP”), researchers estimated average household water and sewer costs (separately) by state based on multiple drinking water utility surveys and available utility data.[91] This report assumed a use of 50 gallons per person per day for the average household size of 2.5 people, approximately 3,750 gallons per month with a resulting average annual household cost of $954. Table 5 compares water and sewer cost estimates across these various sources.

Table 5: Comparison of Water and Wastewater Costs by Source (2025 USD)

Source	Average Annual Household Cost for Water and Sewer Services	Key Assumptions
BLS CEX	$850	Reports survey responses of urban consumers for water, sewer and trash services; average respondent household size is 2.5 people.
ACS PUMS	$766	Reports weighted household survey responses from Census; applies to households who pay for water directly; asks households to report household water costs. Likely that some/many household water costs also include sewer services.
LIWHAP survey	$1,258	Survey of utilities by Department of Health and Human Services; based on use of 5,000 gal/month.
LIWCAP report	$954	Estimates based on multiple drinking water utility surveys and utility-specific data; reflects basic use of 50 gpcd for the average U.S. household size (2.5 people), equal to 3,750 gal/month. Broken out by water and sewer costs (costs for water alone average $429 per year nationally).

*Estimates updated using CPI for water, sewer, and trash from dollar year in which they were reported.

Each data source described above offers distinct strengths and limitations. The BLS and ACS datasets are consistently collected and updated, making them valuable for tracking changes in household costs over time. The ACS PUMS data enables deeper analysis of water bills by household characteristics such as size, income, and age. However, neither BLS nor ACS data isolate drinking water costs from sewer and/or trash collection costs.

Estimates from the LIHWAP survey reflect water consumption levels that exceed those typically used in affordability analyses, potentially overstating household costs for many low-income households. In contrast, the LIWCAP report provides disaggregated estimates for water and wastewater charges, by state, calibrated to reflect a level of use of 50 gpcd for the average household size. For the remainder of this analysis, we therefore rely on the estimates from the LIWCAP report—both state-level and national—as the baseline for household water costs.

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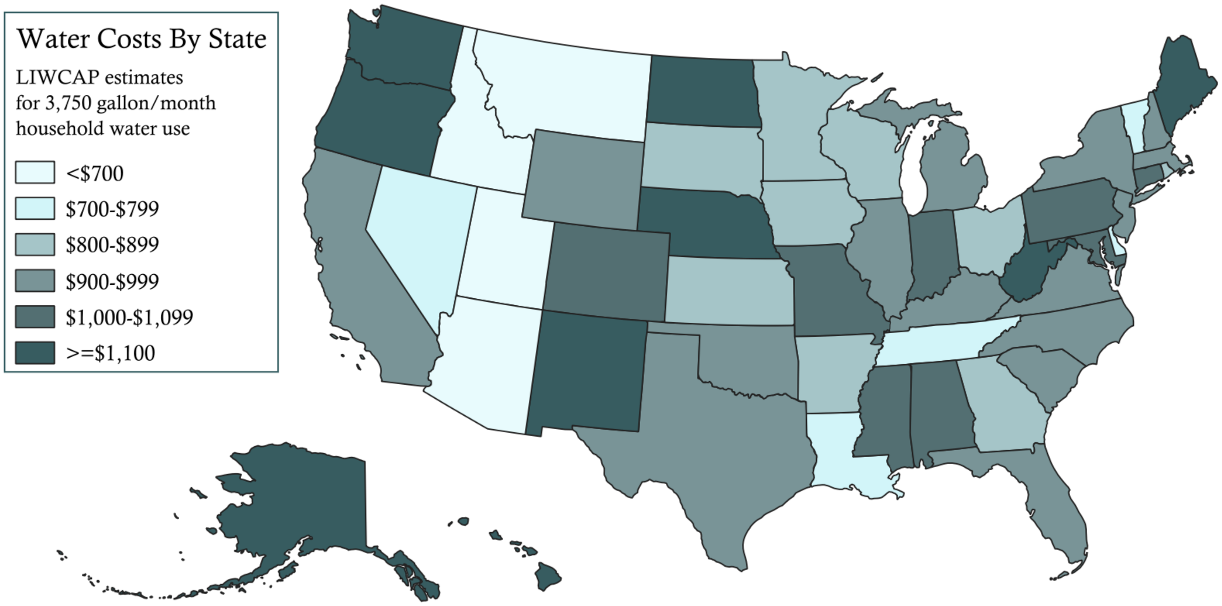
[91] Berahzer, S. I., J. Clements, Z. Green, J. Mastracchio, R. Raucher, E. Rothstein, and M. Teodoro. 2023. *Low-Income Customer Assistance Program Assessment*. Prepared for American Water Works Association, Association of Metropolitan Water Agencies, National Association of Clean Water Agencies, National Association of Water Companies, and the Water Environment Federation. Accessed on November 25, 2025: https://www.awwa.org/wp-content/uploads/low-income-water-customer-assistance-program-assessment-report.pdf.

Figure 12 shows household drinking water and sewer costs based on the estimates from the LIWCAP report, again, assuming an average household use of 3,750 gallons per month. Costs vary significantly by state, with several states in the Rocky Mountain region showing costs of less than $700 per year. The lowest bill is in Arizona, where the annual cost amounts to $607 for the average household size. A handful of states (e.g., Alaska, Hawaii, Oregon) have costs estimated to be more than twice that amount.

Figure 12: Estimated Annual Household Drinking Water Costs by State, Assuming 50 gpcd for Average Household Size

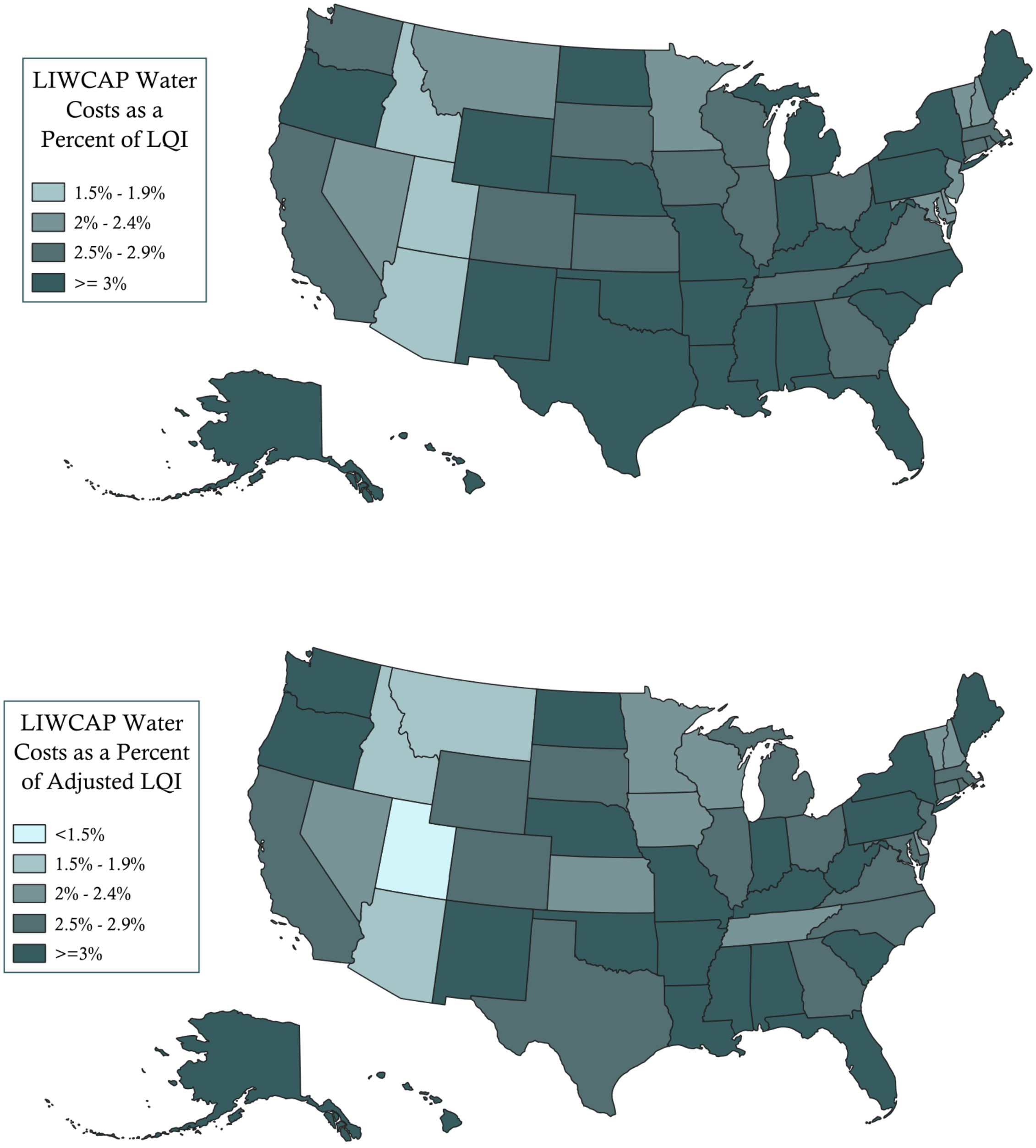


Source: LIWCAP Assessment, 2025 dollars

Note: Water and sewer costs reflect water use of 3,750 gallons per month, 50 gpcd for a 2.5-person household

Figure 13 shows how estimated household water and sewer costs compare to the upper limit of the LQI, both unadjusted (a) and adjusted (b) with regional price parities, in each state. As shown, water and sewer costs currently exceed 3% of the 20th percentile income in many states, although fewer states exceed this threshold when incomes are adjusted to reflect differences in the cost of living.

Figure 13: LIWCAP Water and Sewer Costs as a Percent of Lowest Quintile Income by State (above) and as a Percent of Lowest Quintile Income adjusted with RPPs (below)



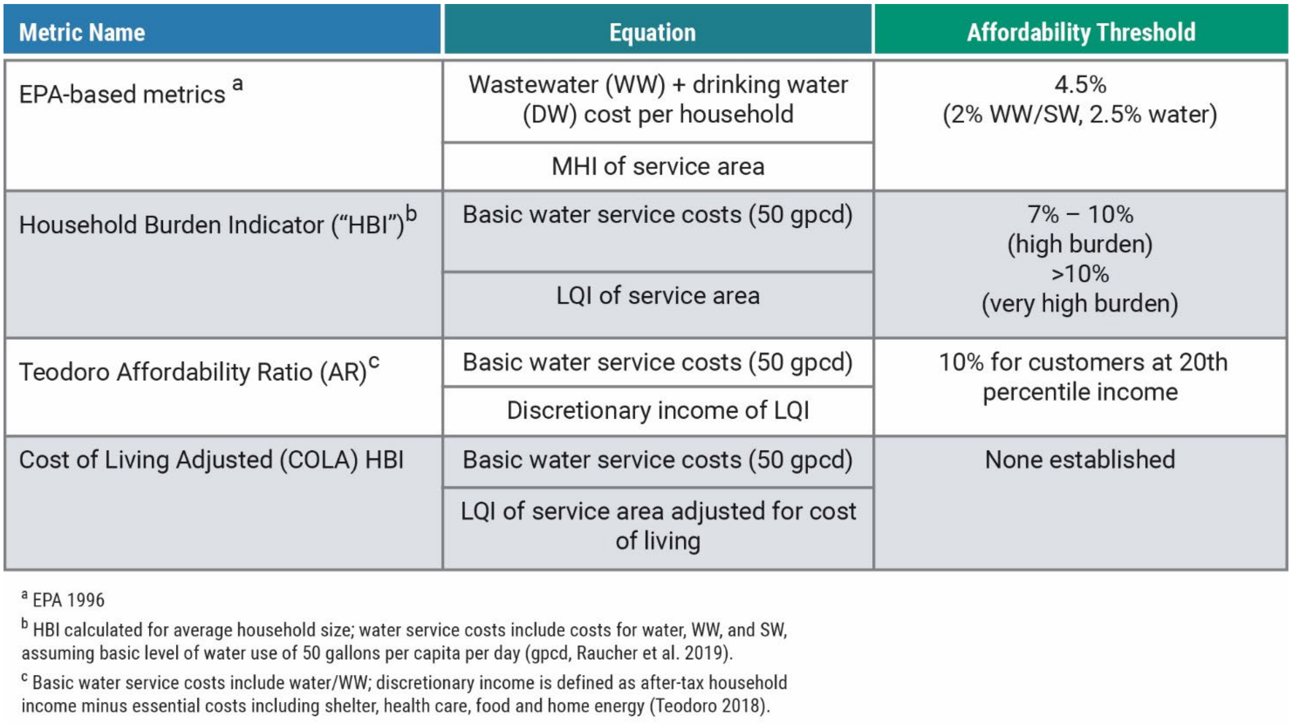
Note: Water and sewer costs reflect water use of 3,750 gallons per month, 50 gpcd for a 2.5-person household

4.3.2. Overview of Common Water Affordability Metrics

Historically, USEPA evaluated affordability within a regulatory context by comparing household water and sewer costs to a community's MHI. Although not originally intended to assess household-level affordability, this approach gave rise to widely cited affordability benchmarks: 2.5% of income for water and 2.0% for wastewater have long been considered as thresholds for community level affordability. Despite longstanding critiques, particularly around its limitations for assessing affordability among low-income households and/or in economically diverse communities, these thresholds have persisted and continue to influence sector discourse and policy framing.

Over the past decade, practitioners have developed alternative metrics and approaches intended to better capture the burden of household water costs on low-income households. These include household-level burden indicators that account for regional cost-of-living differences and focus explicitly on income-constrained households. Table 6 summarizes the most used household burden metrics in current practice.

Table 6: Summary of Household Burden Affordability Metrics



Metric Name	Equation	Affordability Threshold
EPA-based metrics [a]	Wastewater (WW) + drinking water (DW) cost per household MHI of service area	4.5% (2% WW/SW, 2.5% water)
Household Burden Indicator ("HBI")[b]	Basic water service costs (50 gpcd) LQI of service area	7% – 10% (high burden) >10% (very high burden)
Teodoro Affordability Ratio (AR)[c]	Basic water service costs (50 gpcd) Discretionary income of LQI	10% for customers at 20th percentile income
Cost of Living Adjusted (COLA) HBI	Basic water service costs (50 gpcd) LQI of service area adjusted for cost of living	None established

[a] EPA 1996

[b] HBI calculated for average household size; water service costs include costs for water, WW, and SW, assuming basic level of water use of 50 gallons per capita per day (gpcd, Raucher et al. 2019).

[c] Basic water service costs include water/WW; discretionary income is defined as after-tax household income minus essential costs including shelter, health care, food and home energy (Teodoro 2018).

Other metrics are designed to capture the prevalence of affordability challenges within a community through socioeconomic data. For example, the team of researchers who developed the HBI proposed that it be applied along with the Poverty Prevalence Indicator ("PPI"), which reflects the percentage of households within a community earning less than 200% of the FPL. Together, the HBI and PPI are designed to assess both the depth and breadth of affordability challenges within a community.

Likewise, the USEPA introduced the Lowest Quintile Poverty Indicator ("LQPI") as part of its updated Financial Capability Assessment Guidance[92]. The LQPI is intended to help assess the financial burden of Clean Water Act requirements based on six community socioeconomic indicators and how they compare to national averages or established values. The first indicator compares the upper limit of the LQI in a

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[92] U.S. EPA. 2024. *Water Affordability Needs Assessment: Report to Congress*. EPA 830-R-24-015.

community to the national upper limit of the LQI, while others benchmark the percentage of the population living below 200% FPL, percentage of households receiving SNAP benefits, percentage housing units that are vacant, unemployment levels, and trends in household growth. These indicators reflect the prevalence of affordability challenges, as well as a community's ability to pay for infrastructure improvements necessary to meet regulatory requirements.

4.3.3. Households Facing Water Affordability Challenges

This report focuses on quantifying the number of households likely facing affordability challenges. Specifically, we use data from the U.S. Census PUMS to compare water costs (i.e., state level estimates from the LIWCAP report) to individual household incomes. PUMS provides anonymized, household-level data drawn from the ACS, allowing researchers to analyse income, housing costs, and demographic characteristics with greater flexibility than pre-tabulated Census products. Using PUMS data allows us to estimate the number of households, by state, for which water and sewer costs exceed specific income thresholds.

In a 2024 assessment, the USEPA considered two affordability threshold values, 3% and 4.5% of household income spent on drinking water and wastewater bills combined.[93] Applying these same benchmarks, we estimate the following:[94]

- 13.1 million households (10.0% of total households) pay more than 4.5% of their income for water and sewer services.
- 21.5 million households (16.4% of total households) pay more than 3.0% of their income for water and sewer services.
- It would cost $5.42 to $8.96 billion in 2025 to make water services affordable to these households, e.g., by providing a subsidy or reducing costs to ensure that all households paid less than 4.5% and 3.0% of their income, respectively, for basic water and sewer services.

Examining drinking water costs alone, and applying the EPA-based 2.5% threshold, we estimate that approximately 10.2 million households (7.8% of total households) are water burdened (i.e., they pay more than 2.5% of their income for water). It would cost $1.94 billion in 2025 to make drinking water affordable for these households. This cost is expected to grow over time as household water costs continue to outpace inflation.

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[93] Ibid.

[94] To be consistent with the way the U.S. Census calculates housing burden and related metrics, our estimate of the number of households facing affordability challenges excludes households reporting zero or negative incomes.

Small Systems Affordability Challenges

There are nearly 40,000 small community water systems in the U.S. that serve 3,300 or fewer people (EPA SDWIS 2025). Many of these systems face urgent investment needs to maintain and modernize their drinking water infrastructure. With costs recovered from a limited number of households and businesses, many of these small systems - and the communities they serve - are at heightened risk of affordability challenges.

The Drinking Water Infrastructure Needs Assessment Survey (DWINSA, EPA 2023) reports infrastructure needs by system size. We paired this information with data from EPA's Safe Drinking Water Information System (SDWIS) to examine how costs are distributed across affected populations (see table below). This analysis indicates that small systems will need to shoulder a significant burden to maintain access to clean and reliable drinking water. As shown in the table below, while small water systems in the U.S. serve 7% of the population, they account for 16% of the annual $38.4 billion investment need derived from the DWINSA (See Section 2.1).

Drinking Water Infrastructure Need by System Size and Population Served

System size category	% of population served[a]	% of need
Small (<=3,300)	7%	16%
Medium (3,301 – 100,000)	45%	45%
Large (>100,000)	48%	39%

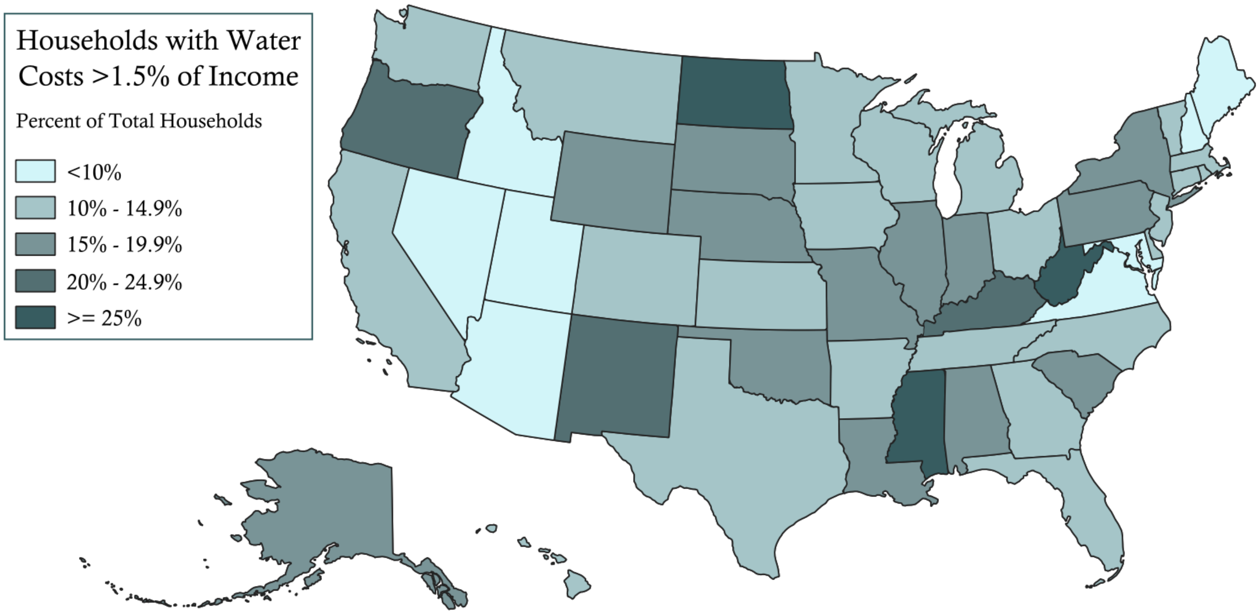
a. Excludes households not served by a community water system.

Based on the DWINSA-related costs alone, we estimate that the annual per capita need for large systems is approximately $96 ($240 per year for an average household), while for medium systems, per capita needs amount to $117 per year ($234 for an average household). Small systems face the largest challenge, with annual per capita needs of $267 ($534 per household). This is 180% higher than the estimated per capita needs for large systems. Again, these estimates represent only those needs reported in the DWINSA; they do not include the additional important investment needs discussed in this report, such as related to those related to PFAS, lead service line replacement, and natural hazards.

The 2.5% cost as a percentage of income threshold for drinking water is greater than the 2.0% threshold typically applied to wastewater; however, average household sewer costs exceed those for drinking water in most states (all but nine based on the LIWCAP report data). Thus, examining drinking water costs in isolation while relying on the traditional 2.5% threshold underestimates the number of households struggling to pay for overall water service. An alternative approach is to examine water and sewer costs using proportional thresholds. For example, nationwide, drinking water costs account for 45% of the total estimated water and sewer bill (drinking water accounts for $429 while sewer costs amount to $525). If we assume the traditional 2.0% threshold for wastewater, a proportional threshold for drinking water would be close to 1.5%. We estimate that currently, 19.0 million households (14.5% of all households) pay more than 1.5% of their income for drinking water. It would cost $3.65 billion to ensure water affordability for these households.

Figure 14 shows the percentage of households in each state that currently pay more than 1.5% of their income for basic drinking water services.

Figure 14. Percentage of Households Paying More than 1.5% of their Income for Basic Drinking Water Services



Source: LIWCAP Assessment, 2025 dollars

Note: Water and sewer costs reflect water use of 3,750 gallons per month, 50 gpcd for a 2.5-person household

Finally, as noted throughout this report, affordability challenges rarely stem from a single household bill. Instead, they emerge cumulatively, reflecting the combined cost pressures faced by low-income households across essential needs. In this context, examining total housing costs provides critical insight into broader affordability risks. Researchers have established thresholds to assess housing cost burden. A severe housing burden typically refers to households spending more than 50% of their income on housing, leaving limited resources for necessities such as food, healthcare, and transportation. A moderate housing burden applies to households spending between 30% and 50% of their income on housing.

Based on ACS 2023 single year data, approximately 15% and 16% of all U.S. households currently have a severe (> 50%) and moderate (between 30% and 50%) housing burden, respectively. Housing costs are defined as gross rent for renters and selected monthly owner costs for homeowners. Gross rent includes contract rent plus the estimated monthly cost of utilities and fuels, if paid separately by the renter. Selected monthly owner costs include mortgage payments (if applicable), property taxes, insurance, utilities (electricity, gas, water, sewer, and other fuels), and any homeowners association or condominium fees.

4.4. Affordability Assessment: Impacts of Closing the Funding Gap

Limited federal funding for drinking water utilities means that a significant portion of increased investments in drinking water infrastructure and rising O&M costs will likely be borne by residential water utility customers. This section estimates changes in household water costs through 2050 under two spending scenarios:

1. Continued baseline levels of capital spending per household (no real increases) with a small real increase in O&M spending, consistent with spending patterns over the past 20 years.
2. Capital spending per household increases consistent with the identified funding need in order to close the funding gap identified in this report without federal support.

For both scenarios, we consider relevant affordability metrics and estimate the number of households that will likely face affordability challenges. This analysis compares the years 2026 to 2050, in alignment with the preceding sections of this report.

4.4.1. Key Assumptions and Methods

As described previously, this analysis relies on average household water and sewer costs by state, calibrated to reflect a basic level of water use—defined as 50 gpcd for a 2.5-person household. We updated these costs from 2019 to 2025 dollars using the CPI for water, sewer, and trash, as published by BLS.

- Under the 2050 baseline spending scenario, we assumed that household water costs would continue to grow following historical trends. Specifically, we applied the BLS-reported average annual real increase in the cost of water, sewer, and trash services over the last 20 years (1.89% increase above inflation).
- For the second scenario, under which ratepayers bear the costs of meeting the funding gap, we assumed household bills would increase from the baseline scenario based on the projected percentage increase in spending on capital and O&M, including historical increased O&M spending per household.

We applied a real annual growth rate of 0.20% to project incomes beyond 2023, which reflects the real increase in incomes for households in the lowest income quintile from 2006 through 2023 based on data from the Federal Reserve.[95] We also assumed that income distribution will remain the same through 2050 and that the number of households will grow by 0.27% per year, again based on historical trends.[96] To estimate future housing burden, we incorporated historical changes in housing costs from the ACS.

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[95] Federal Reserve Economic Data. 2024. Income Before Taxes: Income Before Taxes by Quintiles of Income Before Taxes: Lowest 20 Percent (1st to 20th Percentile), U.S. Dollars, Annual, Not Seasonally Adjusted. Available: https://fred.stlouisfed.org/.

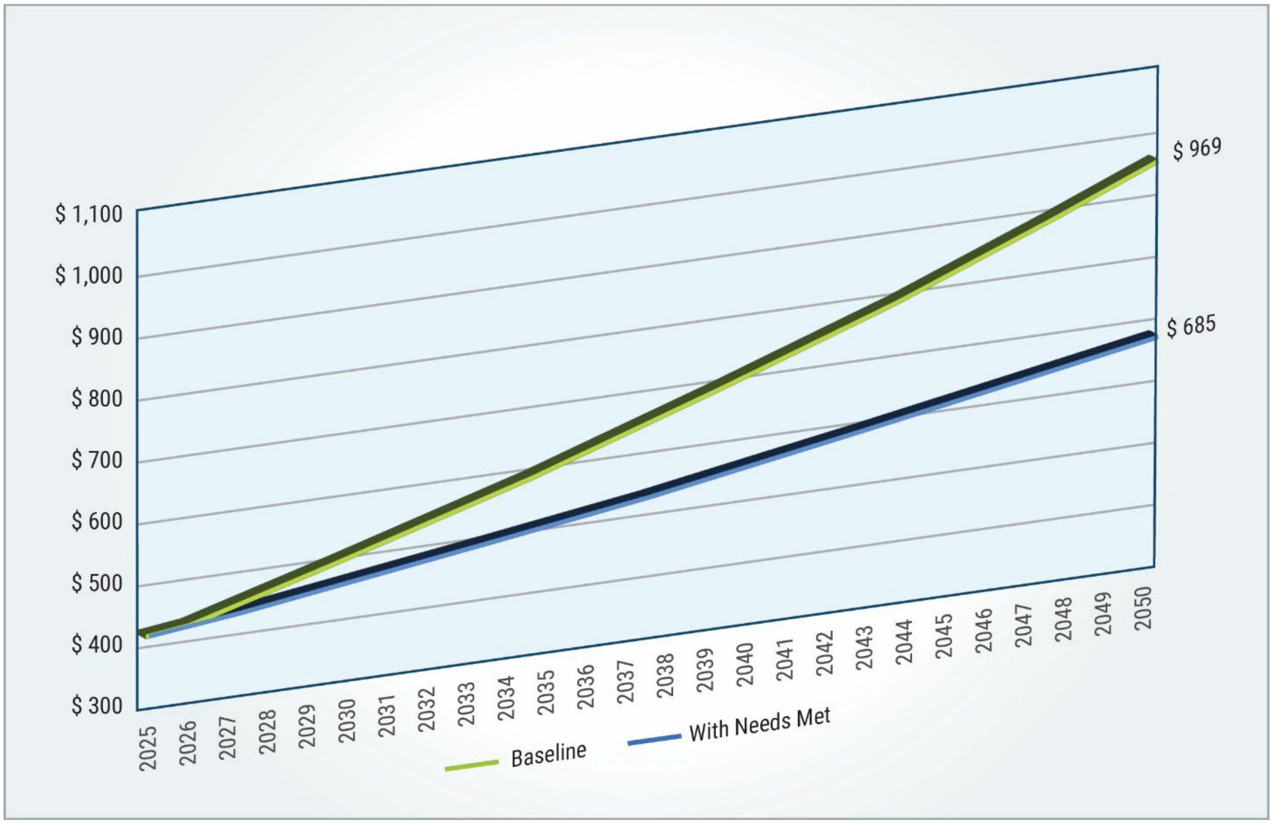
[96] Statista. 2025. Number of households in the U.S. from 1960 to 2025. https://www.statista.com/statistics/183635/number-of-households-in-the-us/?srsltid=AfmBOorT7CXcd5nwFW1gave2T6eYUtqPtWQnmw6NxsGjseAv-4wCQ4bR.

We assumed 50% of future investments are financed and 50% are cash-funded (referred to as PAYGO) to reflect the reality that for most drinking water utilities, a portion of capital infrastructure projects are debt financed. O&M costs for PFAS are phased in over time to reflect full implementation by 2029, per the final rule. This affordability analysis relies on the same assumptions put forth in the funding gap analysis with regards to projected capital and O&M needs. However, the affordability analysis assumes that growth will pay for itself, so costs for growth/expansion are assumed not to impact household bills. Finally, because future investment/spending needs are not allocated across states, we assume the same percentage increase in household bills for all U.S. households.

4.4.2. Growing Water Affordability Challenges

Under the baseline spending scenario, the average household drinking water bill would increase from $429 in 2025 (in 2025 dollars) to approximately $685 (in 2025 dollars) in 2050, representing a 60% real increase. If the gap in infrastructure funding is entirely borne by ratepayers, household drinking water bills could rise to $969 in 2050 (in 2025 dollars), a 41% increase over the 2050 baseline spending scenario and a 126% increase over 2025 baseline levels (Figure 15). This is reflective of the average increase for all households; it will vary based on several factors, including household water use, system size, and utility needs, among others.

Figure 15 Projected Real Increase in Annual Household Water Bills (2025$) under Baseline and Increased Spending to Meet Need



Based on the estimated increase in household water bills and income growth, we determined the number of households who would likely face drinking water affordability challenges under both 2050 scenarios, applying the 1.5% and 2.5% thresholds. We also estimated the costs (in the applicable year) associated with making drinking water affordable for the fiscally challenged households. Sewer costs (and associated thresholds) are not included in this analysis because we did not project the full funding need for the wastewater sector.

As summarized in Table 7, the projected increase in water service costs significantly expands the segment of the population facing water affordability challenges. If the identified funding cap is closed by increases in utility rates, the analysis indicates the following impacts:

- Approximately 30.4 million households (21.5% of the U.S. total) would spend more than 2.5% of their income on drinking water services.
- Approximately 53.5 million households (37.8% of the U.S. total) would spend more than 1.5% of their income on drinking water services.

An estimated $13.6 billion in annual federal assistance would be required by 2050 to subsidize these households to the point where their water bills remain below the 2.5% affordability threshold. Furthermore, we estimate that 19.0 million households (14.5% of all households) currently pay more than 1.5% of their income for drinking water. We estimate that it would cost $3.65 billion to ensure water affordability for these households.

Table 7: Drinking Water Affordability 2025, 2050 Scenarios

Source	2025 Current Baseline	2050 Baseline	2050 Full Burden
Average annual drinking water bill (50 gpcd for 2.5-person household, 2025 $s)	$429	$685	$969
Average annual drinking water bill (as a percentage of LQI)	1.24%	1.89%	2.67%
Number (and %) of households paying more for water than specified income threshold			
2.5% of income threshold	10.2 M (7.8%)	20.2 M (14.3%)	30.4 M (21.5%)
1.5% of income threshold	19.0 M (14.5%)	36.9 M (26.1%)	53.5 (37.8%)
Annual cost to make bills affordable in 2050 (i.e., less than specified threshold, 2025 $s)			
2.5% threshold	$1.94 B	$6.31 B	$13.6 B
1.5% threshold	$3.65 B	$11.6 B	$24.5 B

[1] The 2050 Baseline Scenario assumes current levels of capital spending per household would continue (no real increases) with a small real increase in O&M spending, consistent with spending patterns over the past 20 years.

[2] The 2050 Full Burden Scenario assumes capital spending per household increases consistent with the identified funding need in order to close the funding gap identified in this report without federal support. It also includes a small real increase in O&M spending, consistent with spending patterns over the past 20 years.

4.5. The Importance of Federal Funding Support

The analysis presented in this section demonstrates that the convergence of aging infrastructure replacement, strict regulatory compliance for contaminants, such as PFAS and LSL replacement, and necessary resilience upgrades has created a financial requirement that far exceeds the capacity of the traditional rate-based funding model. With total annual spending needs projected to reach $200.3 billion by 2050, relying exclusively on local rate increases to close the annual infrastructure gap would place an unsustainable burden on ratepayers, potentially resulting in 53.5 million households paying more than 1.5% of their household income for drinking water, and 30.4 million of those households paying more than 2.5%. Recognizing the conservative assumptions of this analysis and additional cost drivers that could not be nationally quantified, the costs and thus the affordability impacts are likely to be even greater.

Currently, the federal share of public spending on water sector utilities sits at approximately 3.9%, an amount disproportionately low compared to other critical infrastructure sectors. If this trend continues, states and communities will continue to stretch limited budgets while trying to maintain adequate levels of service and balance affordability challenges. Necessary investments may be deferred, likely resulting in more costly fixes over the long term and potentially public health challenges.

To ensure that safe, reliable drinking water remains accessible without driving millions of households into economic hardship, it is imperative that federal investment in the water sector evolves into a more significant, sustained long-term commitment that supports the sector’s growing financial reality.

5. Summary of Findings and Conclusions

By analyzing existing data sources and recent regulatory impact analyses and comparing these against the current drinking water utility funding levels and household income trends, several key findings emerged regarding the drinking water utility funding gap and resulting affordability implications:

5.1. Report Findings

Infrastructure Needs Cost Projections. The total cost to address drinking water infrastructure needs over the next 25 years (2026–2050) is estimated to fall between $2.1 trillion and $2.4 trillion (in 2025 dollars). While the replacement and rehabilitation of existing assets accounts for a significant portion of this total, new cost drivers, specifically regulatory compliance for PFAS and LSL replacement, as well as hardening systems against natural hazards, add hundreds of billions of dollars to the national tab.

Infrastructure Funding Gap. Current capital spending by drinking water utilities averages approximately $33.6 billion annually. Capital investment would need to increase by approximately 168% to an average of $90.2 billion per year to address the need, resulting in an annual infrastructure funding gap of $56.6 billion. Under current funding models, the federal government only provides approximately 3.9% of total public spending on water sector utilities, significantly lower than the federal contribution to other infrastructure sectors such as highways (22.5%). Furthermore, while the IIJA provided a temporary influx of capital, these funds are scheduled to expire after FY2026, while O&M costs continue to rise at a rate exceeding inflation.

Projected Impact on Household Costs. If the identified funding gap is closed entirely through increases in local utility rates, the financial burden on households will increase substantially. Under a "Baseline" scenario, comprised of continued historical spending trends, the average annual household drinking water bill is projected to rise from $429 in 2025 to $685 by 2050 (in 2025 dollars). However, if drinking water utility spending increases to fully address the funding gap, and the spending is paid for through increases in local utility rates, the average annual water utility bill is projected to reach $969 by 2050 (in 2025 dollars). This represents an increase of roughly 126% over current levels before factoring in cost inflation.

Affordability Analysis. The projected increase in water service costs significantly expands the segment of the population facing water affordability challenges. If the identified funding gap is closed by increases in utility rates, the analysis indicates the following impacts:

- Approximately 30.4 million households (21.5% of the U.S. total) would spend more than 2.5% of their income on drinking water services.
- Approximately 53.5 million households (37.8% of the U.S. total) would spend more than 1.5% of their income on drinking water services.

An estimated $13.6 billion in annual assistance would be required by 2050 to subsidize these households to the point where their water bills remain below the 2.5% affordability threshold. Furthermore, we estimate that currently, 19.0 million households (14.5% of all households) pay more than 1.5% of their income for drinking water. It would cost an estimated $3.65 billion to ensure water affordability for these households today.

5.2. Conclusion

The analysis demonstrates that the cost to maintain regulatory compliance, ensure system resilience, and support population growth exceeds the current financial capacity of drinking water utilities' traditional rate-based funding model alone. With total annual spending needs (capital plus O&M) projected to reach $200.3 billion by 2050, relying solely on local rate increases will place a measurable portion of the U.S. population into a status of water unaffordability. Water utilities will need access to a suite of tools in order to meet the challenges presented by aging infrastructure, new regulations, hazards, and ensuring affordable rates. Closing the infrastructure gap will likely require a combination of rate adjustments, customer assistance programs, and significant federal investment to soften affordability impacts on communities.

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A Better World
Through Better Water

Engineering
Eric Lindman, Public Works Director

DATE: April 8, 2026
TO: Wausau Water Works Commission
SUBJECT: Report for the Corrosion Control Treatment Optimization Study submitted to the WDNR.

PURPOSE

Provide information and copy of the report submitted to the WDNR for their review and concurrence.

BACKGROUND

The USEPA determined the new water treatment facility provides a new water source (change in treatment strategy) which needs to be evaluated for corrosion control treatment (CCT). This study began in 2022 with harvesting lead service lines from the distribution system and setting them up in pipe loops to determine if Wausau's current CCT can/should be optimized. The CCT currently in use is the introduction of sodium silicate to the finished drinking water to prevent the leaching of lead and copper from pipes into the drinking water. The CCT study was established to determine if sodium silicate was the best way to manage CCT or if other additives may perform better relating to CCT. The attached report are the findings and recommendations of the CCT study. The report has been reviewed by staff and has now been submitted to the WDNR for their review and concurrence/approval. The report recommends Wausau continue using Sodium Silicate and, in addition, add Orthophosphate as a corrosion inhibitor.

It is a long report with lots of data, but I would focus on the following sections to understand the findings and recommendations:
Section 2 to understand what we were studying and how we conducted the study, Section 4.7 for a summary of the pipe loop results leading to recommendations and Section 5 for the recommendations based on the results. This is a first look at our CCT study with the recommendations. We plan to bring in CDM Smith later this year once the WDNR has approved the study to go over the results in detail.

One of the key take aways from this report is that our current CCT is performing adequately and there are no concerns.

RECOMMENDATION

Discussion only. This recommendation, if approved by the WDNR will require Wausau Water Works to install an Orthophosphate feed system. This will be required to be operational within 2-years of the WDNR final approval of the CCT Report.

FINAL REPORT

MARCH 27, 2026

Wausau Water Works Corrosion Control Treatment Study

Prepared for:

Wausau Water Works

CDM Smith

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Acronyms and Abbreviations

<	Less than
%	Percent
°C	Degrees Celsius
°F	Degrees Fahrenheit
µg/L	Micrograms per liter
µS/cm	Microsiemens per centimeter
AWWA	American Water Works Association
Ca	Calcium
$CaCO_3$	Calcium carbonate
Cl	Chloride
Cl_2	Chlorine
Cu	Copper
CCT	Corrosion control treatment
CSMR	Chloride-to-sulfate mass ratio
EPA	Environmental Protection Agency
ft	Feet
GAC	Granular Activated Carbon
gpm	Gallons per minute
hr	Hour
ICP-AES	Inductively coupled plasma atomic emission spectrometry
ICP-MS	Inductively coupled plasma mass spectrometry
L	Liter
LCR	Lead and Copper Rule
LCRI	Lead and Copper Rule Improvements
LOESS	Locally estimated scatterplot smoothing
LSL	Lead service line
LSLR	Lead service line replacement
Mg	Magnesium

mg/L	Milligrams per liter
MGD	Million gallons per day
mL	Milliliters
Mn	Manganese
n.d.	Non-detect
NH_3-N	Ammonia-nitrogen
NOM	Natural organic matter
NTU	Nephelometric Turbidity Units
P	Phosphorus
Pb	Lead
PFAS	Per- and Polyfluoroalkyl substances
PO_4	Orthophosphate
POU	Point-of-use
SEM-EDS	Energy-dispersive X-ray spectroscopy
Si	Silicon
SiO_2	Silicate
SO_4	Sulfate
S.U.	Standard units
VOC	Volatile Organic Carbon
WDNR	Wisconsin Department of Natural Resources
WTP	Water Treatment Plant
WWW	Wausau Water Works
XRD	X-ray diffraction

1.0 Introduction

1.1 Background

Wausau Water Works (WWW) supplies approximately 4.2 million gallons per day (MGD) of drinking water to approximately 16,000 customers. WWW transitioned to a new water treatment plant (WTP) on December 20th, 2022 (**Figure 1-1**). The new WTP receives ground water from six wells and treats it with conventional treatment processes, including rapid mix, coagulation, flocculation, settling, filtration, and disinfection. Additional treatment processes include aeration and air stripping, anion exchange, corrosion control through pH adjustment and sodium silicate addition, and fluoridation. Granular activated carbon (GAC) contactors were added in November 2024 for the removal of per- and polyfluoroalkyl substances (PFAS).

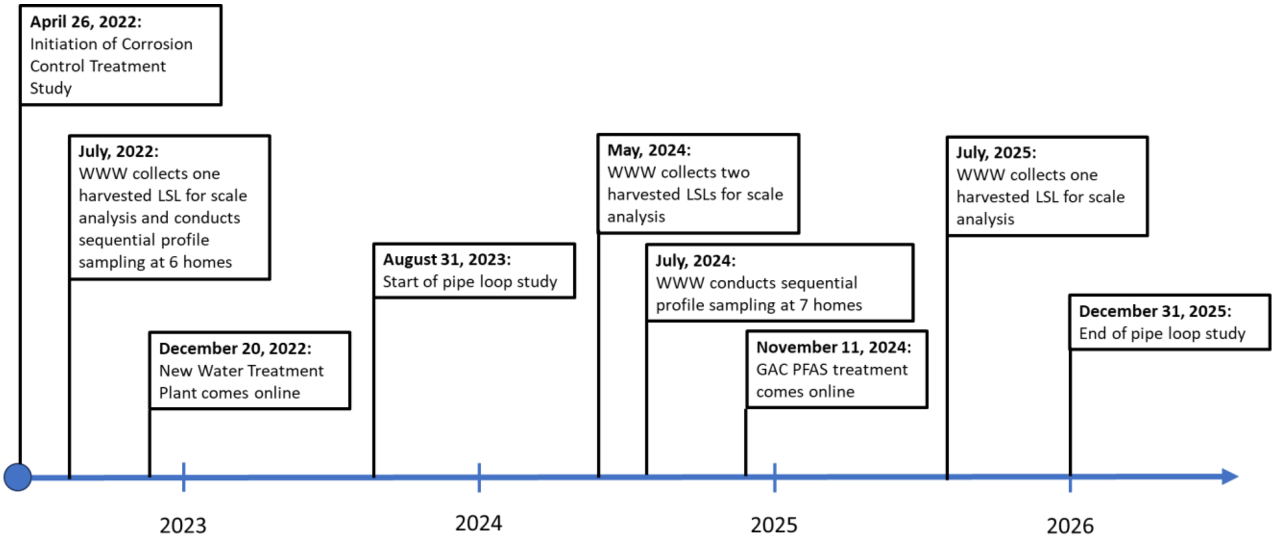


Figure 1-1 Timeline of Corrosion Control Study Activities and Key Water Treatment Changes

The anion exchange process at the new WTP is used for natural organic matter (NOM) removal. This process raised concerns about a potential increase in the water's chloride-to-sulfate mass ratio (CSMR), as anion exchange can increase chloride concentrations while reducing those of sulfate. Elevated CSMR is generally associated with increased galvanic corrosion between dissimilar metals in service lines and premise plumbing (e.g., copper pipes with lead solder). In response to these concerns, the Wisconsin Department of Natural Resources (WDNR) required WWW to conduct a demonstrative corrosion control treatment (CCT) study using finished water from the New WTP and submit a report identifying the optimal corrosion control strategy. The overarching goals were to determine how changes in water quality from the new treatment process could impact WWW's corrosion control program and to identify an effective approach for corrosion control. To meet this goal, the program was divided into five key deliverables:

- **TM-1 Data Collection Memorandum** (Oct 22, 2022) - This technical memorandum (TM) presents a summary of key historical water quality and chemical dosing parameters requested and received from WWW. This data was used to develop the Desktop Modeling Analysis report.
- **TM-2 Desktop Modeling Analysis** (Aug 21, 2023) – This TM summarized historical water quality data, geochemical and water quality modeling analysis, and pipe scale analysis to assess corrosion potential within a distribution system.
- **TM-3 Pipe Loop Testing Plan and Lead Service Line Harvesting Protocol** (July 26, 2023) – This TM presented a testing and sampling plan for the flow-through pipe loop study. In addition, a lead service line (LSL) harvesting protocol was provided.
- **TM-4 Summary of Wausau Harvested Lead Service Line Scale Analysis 2022, 2024 and 2025** (Oct 9, 2025) – This TM summarized pipe scale analysis for harvested LSLs collected in 2022, 2024 and 2025 to evaluate how water quality changes from the new WTP impacted lead scale.
- **Corrosion Control Treatment Study Report (This report)** – The final report presents the results of the pipe loop study and focuses on long-term corrosion control under the new water quality rather than on transitional effects. Specifically, it provides an evaluation of the impacts of adding orthophosphate as a corrosion inhibitor in a pipe loop system with WWW's finished water on lead corrosion control and on general water quality in the distribution system. This report also incorporates key findings from all the TMs. Recommended short-term and long-term corrosion control strategies are included.

1.2 Objectives

This final report presents a summary of key findings and recommendations from the TMs, with the detailed analyses provided in **Appendix A** and **Appendix B**. This study aimed to evaluate existing corrosion control performance, characterize water quality factors influencing corrosion, identify potential impacts from the treatment change, and evaluate corrosion control treatment optimization strategies. Specifically, the study focuses on activities that were to:

- Review historical water quality from the Old and New WTP and use water quality modeling to predict corrosion characteristics of finished water from each WTP.
- Review historical Lead and Copper Rule (LCR) sampling results. Although not included in the original study plan, WWW conducted sequential profile sampling in 2022 and 2024 to evaluate potential impacts of the treatment change on lead and copper release. These results are evaluated in the context of the upcoming Lead and Copper Rule Improvements (LCRI).
- Conduct pipe scale analysis of harvested lead service lines from the distribution system to evaluate impacts of the treatment change on lead scale morphology and chemical composition.
- Conduct a pipe loop study to evaluate long-term corrosion control treatment strategies using finished water from the New WTP. The pipe loop study evaluated the impacts of adding orthophosphate (1.0 or 3.0 milligrams per liter [mg/L] as orthophosphate [PO_4]) as a corrosion inhibitor in a pipe loop system with WWW's finished water on lead corrosion control and on general water quality in the distribution system. The study specifically evaluates the impacts on lead and copper corrosion, mineral formation, and overall water quality.

- Provide short-term and long-term recommendations to optimize corrosion control and maintain compliance with lead and copper regulations.

2.0 Methodology

2.1 Historical Water Quality and Compliance Review

A review of WWW's historical finished water quality and compliance data was conducted to assess long-term trends, treatment performance, and regulatory compliance. The review focused on evaluating key water quality parameters relevant to corrosion control, aesthetic water quality, and regulatory compliance.

Historical data were obtained from WWW's routine compliance monitoring records, monthly operators records, and state reporting systems (i.e. Drinking Water Watch). Available data typically included pH, alkalinity, hardness, temperature, disinfectant residuals, and LCR sampling data. Sampling frequency varied by parameter and regulatory requirement. The dataset representing finished water quality measurements collected at the point of entry (POE) encompassed all available records from 2020 to 2025. LCR sample data covered the period of 2002 to 2020.

Results of the historical review were used to evaluate characteristics of finished water quality at both the Old and New WTP, effectiveness of CCT, and consistency with regulatory goals. Observed trends were also compared with water quality changes to support development of future treatment recommendations.

2.2 Sequential Profile Sampling

WWW conducted sequential profile sampling in homes with LSLs in 2022 and 2024. Samples collected in 2022 represent water quality from the Old WTP, while samples collected in 2024 represent water quality from the New WTP. Initially, six sites were sampled in 2022; three of those sites were later removed due to lead service line replacements (LSLRs), and four additional sites were added in 2024. Sequential sampling was conducted using a first-draw sample followed by fourteen 1-liter samples collected sequentially to characterize lead and copper concentrations throughout the premise plumbing and service line.

2.3 Pipe Loop Study

This section summarizes the methodology used for the pipe loop study conducted to evaluate the impact of orthophosphate dosing on water quality and lead and copper corrosion. For the purposes of this study, a pipe skid refers to the complete experimental assembly used to simulate lead service line and premises plumbing conditions. Each pipe skid is comprised of multiple pipe loops, which operate in parallel under controlled hydraulic and water quality conditions. The pipe loops contain both permanent and temporary pipe test sections. Permanent test sections remain in place for the duration of the study and are used to evaluate long-term water quality and corrosion performance, while temporary test sections are removed at specific times during the study and analyzed to support detailed pipe scale characterization.

The study consisted of operating three parallel pipe skids under controlled conditions to simulate representative lead service line and premises plumbing materials and hydraulics. Water quality was monitored under a control condition reflecting the current system water quality, as well as under treatment conditions with orthophosphate applied at target concentrations of 1.0 and 3.0 mg/L as PO_4. Routine sampling and monitoring were performed to assess changes in key water quality parameters and corrosion-related indicators, allowing for direct comparison of control and orthophosphate-treated conditions.

2.3.1 Pipe Loop Construction and Siting

Three pipe skids were constructed. Each pipe skid had three replicate harvested lead pipe loops and three replicate copper with lead solder pipe loops (**Figure 2-1**). Each pipe loop skid consisted of the following test pipe materials:

- Three harvested LSL pipe loops each comprised of two permanent test sections of ¾-inch (inner diameter) harvested lead service lines, 7-feet (ft) long. Nine 6-inch temporary test sections, three sections in each pipe loop, taken from the same pipes as the permanent lead test sections. The LSLs were harvested from thirteen homes serviced by WWW, and the recovered pipe segments were distributed among the pipe loops to achieve an approximately even distribution based on historical water use.
- Three new copper pipes with lead solder each comprised of ¾-inch, type K copper pipe with 50/50 lead-tin solder, 7-ft long. 4-ft. 10-in strips of lead solder was inserted into the center of each copper pipe section, and the pipe was then uniformly heated for 5-minutes using heating tape to melt the solder and bond it to the interior copper pipe surface. This process produced a consistent contact area of lead solder across the pipe loops.

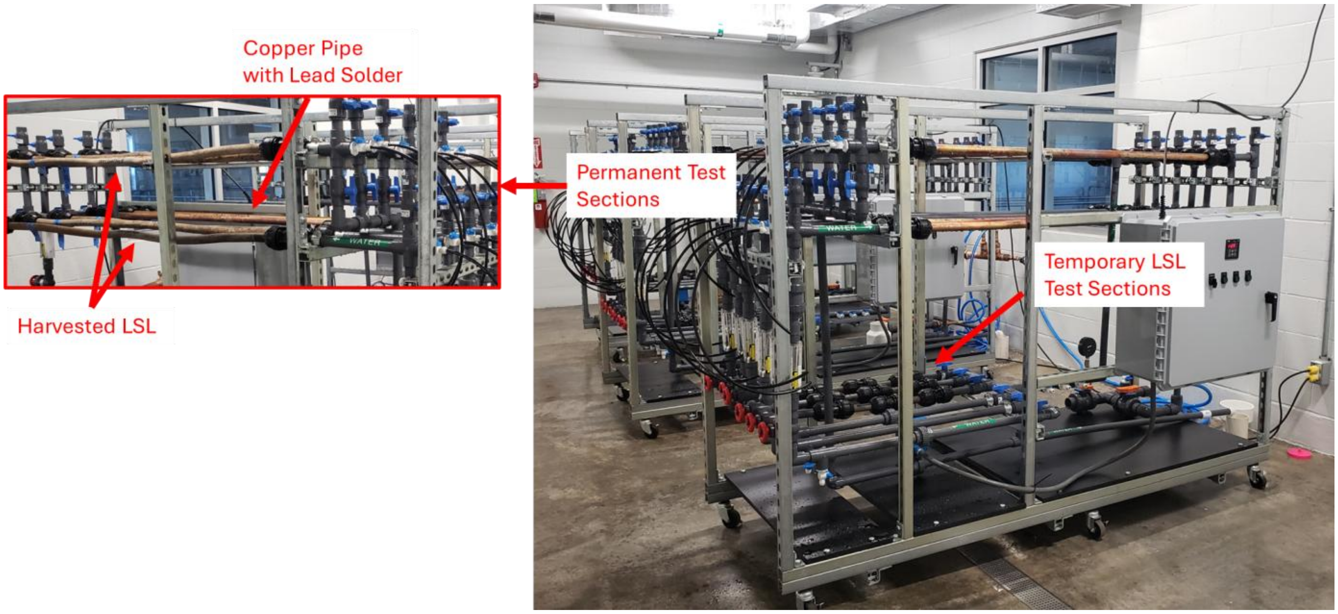


Figure 2-1 Example of Pipe Loop Skid

The pipe skids also consisted of flow control and chemical metering systems. The pipe skids were installed in an enclosed room adjacent to the WWW WTP laboratory. The room was equipped with adequate water supply, drainage, and electrical service to support operation of the three pipe loops. The pipe loops were operated at ambient indoor temperature and were not exposed to external environmental conditions.

2.3.2 Summary of Test Conditions and Study Phases

Table 2-1 presents a summary of the study's test conditions. Each test condition had three replicate pipe loops. The control pipe loops (Skid C) were maintained as a reference condition and were continuously supplied with finished water from the treatment plant throughout the study. The test pipe loops (Skid A and Skid B) were also supplied with finished water, with orthophosphate added via chemical metering pumps installed on each skid to achieve the target treatment conditions. Skid B was operated with orthophosphate dosed at a target concentration of 1.0 mg/L as PO_4, while Skid A was operated with orthophosphate dosed at a target concentration of 3.0 mg/L as PO_4. Initially, orthophosphate was added in the form of phosphoric acid (Carus 4105, pH < 1.0). However, this resulted in a 0.6-unit drop in pH at the 3.0 mg/L PO_4 dose. While the WTP could adjust pH at full scale if phosphoric acid were used, there was no practical means to adjust pH in the pipe loops. Consequently, a buffered orthophosphate (Carus 4500, pH ~ 5.1-6.1) was substituted on October 17, 2025 to mitigate the pH drop in the pipe loops.

Table 2-1 Summary of Test Conditions

Pipe Skid	Pipe Loop	Test Material	Replicate	Test Condition
C	1-3	Harvested lead service lines	3	**Control** – Receives finished water with current dose of Sodium Silicate at 35 mg/L as SiO_2. This is finished water leaving the plant.
	4-6	Copper pipe with lead-containing solder	3	
B	1-3	Harvested lead service lines	3	**1.0 mg/L PO_4 and 35 mg/L as SiO_2 Sodium Silicate** – Receives finished water with 1.0 mg/L as PO_4 of orthophosphate added.
	4-6	Copper pipe with lead-containing solder	3	
A	1-3	Harvested lead service lines	3	**3.0 mg/L PO_4 and 35 mg/L as SiO_2 Sodium Silicate** – Receives finished water with 3.0 mg/L as PO_4 of orthophosphate added.
	4-6	Copper pipe with lead-containing solder	3	

Key: SiO_2 – silicate

The study phases were comprised of an acclimation period with three conditioning phases and the testing phase (**Figure 2-2**). Under the conditioning phases, all pipe loops were conditioned using finished water supplied by the WWW, which included sodium silicate added at 35 mg/L as SiO_2 and adjusted with caustic soda to a pH of 8.5. Water was pumped through each of the pipe loops at a flow rate of 2.5 gallons per minute (gpm).

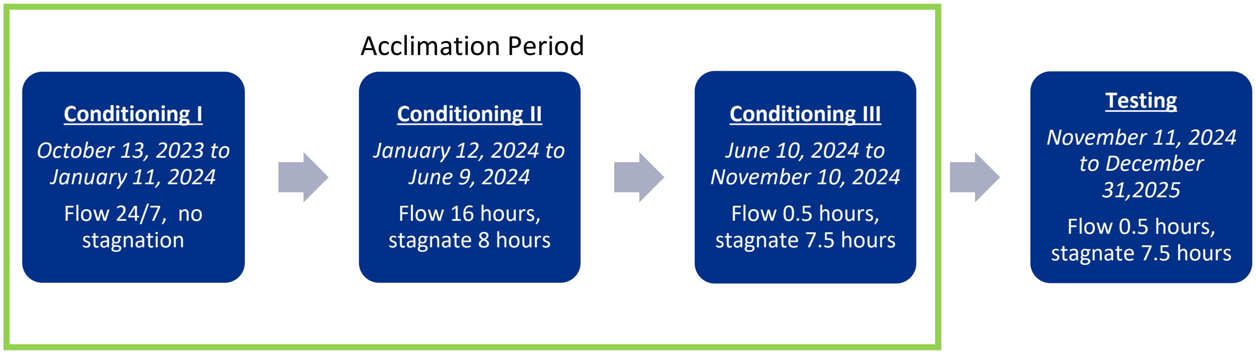


Figure 2-2 Duration and Flow Pattern of Experimental Phases

The first conditioning phase was operated under continuous flushing to rapidly condition pipe scale within the test sections. The second conditioning phase introduced an 8-hour period of stagnation. Samples were collected following the stagnation period to track the progression of conditioning. Stable lead release in this study was defined as having less than 25 percent (%) relative standard deviation across the last seven consecutive measurements for each permanent test section. Once lead release stabilized under these conditions, the study advanced to the third conditioning phase.

During the third conditioning phase, each of the pipe loops were set to flow at 2.5 gpm for 30 minutes, followed by 7 hours and 30 minutes of stagnation. This cycle was repeated three times per day, resulting in approximately 225 gallons of water passing through each pipe loop daily. This volume was based on an estimated average household water use of 225 gallons per day, calculated by dividing the average daily water production (4.2 million gallons per day, as provided by WWW) by the number of households reported in the 2021 census (18,740 households). Once lead measurements stabilized under these operating conditions, the testing phase was initiated. The testing phase followed the same flow and stagnation pattern as the third conditioning phase. Water entering each loop represented the test water quality conditions of the study (**Table 2-1**).

2.3.3 Sample Collection and Analysis during Testing

See **Appendix C** for the detailed sampling plan. Samples were collected monthly for Conditioning Phases 1 and 2. During the Conditioning 3 Phase and testing phase, weekly samples were collected by WWW operators from the pipe loops at the end of one of the 7.5-hour stagnation periods. After the samples were collected, the 30-minute flow period would start. The sampling volume required from each pipe loop was 1.5 liters, and these were collected at a flow rate of approximately 2.5 gpm.

Immediately after collection, samples were analyzed in-house by WWW for pH, temperature, turbidity, orthophosphate, and free and total chlorine. Samples were also sent to Northern Lake Service Inc. for additional laboratory analyses (e.g., metals, water quality).

2.3.4 Data Analysis

To determine when testing could advance to the next phase, lead and copper release stability was evaluated by confirming that each permanent test section exhibited a relative standard deviation of less than 25 percent across the final seven consecutive weekly measurements.

To compare experimental conditions, the percent reduction in median concentrations of the final seven consecutive weekly measurements in Conditioning Phase 3 relative to the testing phase was used as the primary comparison metric. This same approach was also applied to the control experiments, allowing comparison of trends between the test loops and the control loops. Including the control helps account for potential seasonal effects or continued pipe conditioning that may influence metal release during the testing period. This approach accounts for differences in baseline pipe behavior and was applied to lead release from harvested lead pipes and to copper release from copper pipes with lead solder.

Since the copper pipes with lead solder were newly fabricated for this study, they were expected to begin as comparable replicates with similar initial conditions. However, directly comparing lead concentrations between the acclimation and testing phases for each pipe would not clearly separate treatment effects from continued passivation of the solder surface over time. Therefore, for lead release from copper pipes with lead solder, an alternative comparison approach was used. Median lead concentrations at the end of the testing phase under each phosphate treatment condition were compared directly to those observed under the control condition.

Statistical significance was evaluated using the Wilcoxon signed-rank test with a significance level (α) of 0.05. Ninety-five percent confidence intervals for median values were estimated using a non-parametric bootstrap resampling approach with 1,000 iterations. Bootstrapping is well suited for small datasets because it does not rely on distributional assumptions and uses repeated resampling of the observed data to more robustly characterize uncertainty when sample sizes are limited.

A LOESS (Locally Estimated Scatterplot Smoothing) model was used to estimate trends in water quality and metals release data by fitting localized regressions to subsets of the dataset and generating a smooth curve that represents the overall trend. This approach is beneficial because it can capture nonlinear patterns and short-term variability without assuming a specific functional relationship. It is mainly used to describe patterns in the observed data.

2.4 Pipe Scale Analysis

To evaluate the impacts of the treatment change on lead scale in the distribution system, four LSLs were harvested and sent to to Washington University in St. Louis for pipe scale analysis; one in 2022 representing finished water from the Old WTP, two in 2024 and one in 2025 representing water quality from the New WTP. In addition, pipe scale analysis was also performed at the end of the pipe loop study on four lead pipe coupons, two from each skid receiving orthophosphate, to evaluate the impact of orthophosphate addition on lead mineralogy. Detailed discussion of the results of the harvested LSL and pipe loop scale analysis is presented in **Appendix B** and **Appendix F**, respectively.

Pipe scale analysis included visual inspection, cross-sectional imaging, elemental mapping using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), crystalline phase identification with X-ray diffraction (XRD), and quantitative elemental composition using inductively coupled plasma mass spectrometry (ICP-MS).

For visual inspection, each pipe was cut open, the top layer of scale was photographed, removed and collected, and then the bottom layer was also photographic, removed, and collected. A cross section was prepared by filling one end with an epoxy-hardener mixture, then curing, cutting, and polishing the section. Five areas were analyzed using a Thermo Fisher Quattro S E-SEM with EDS to determine elemental composition.

For XRD analysis, the scraped top and bottom layers were visually distinguished by color and analyzed using a Bruker D8 Advance X-ray diffractometer with copper (Cu) Kα radiation, with samples mounted on MTI 1-inch low-background silicon (Si) holders to identify crystalline mineral phases.

Other portions of the scraped-off scale were weighed and digested in a 3:1 (by volume) mixture of concentrated hydrochloric and nitric acids at 100 degrees Celsius (°C) for two hours to dissolve the solids. The dissolved samples were then analyzed using a PerkinElmer NexION 2000 ICP-MS to determine the quantitative elemental composition.

3.0 Facilities Description and Water Quality Review

3.1 Overview

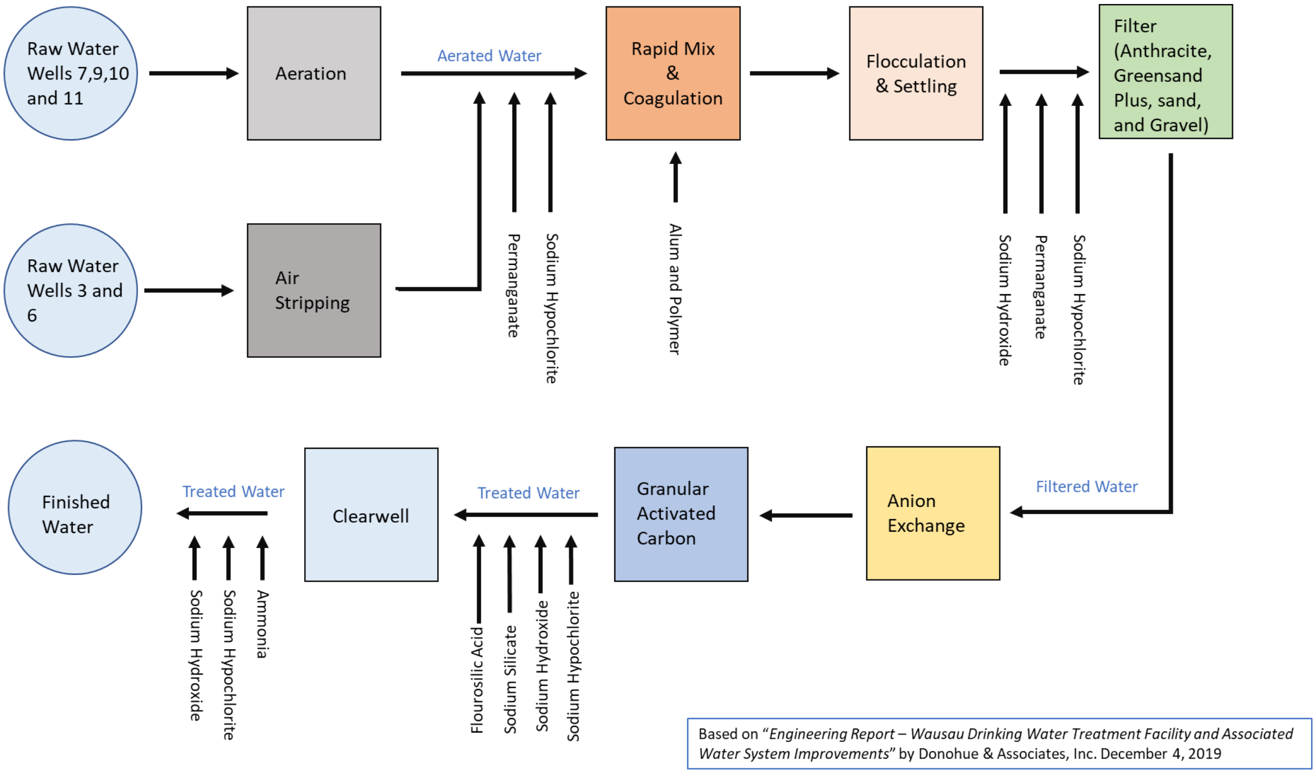
This section provides an overview of WWW's previous and existing treatment facilities, service line inventory, and historical compliance with the LCR (2002 to 2020). It also summarizes finished water quality and presents the results of the harvested lead service line analysis.

3.2 Previous Water Treatment Process

The Old WTP consisted of conventional filtration with lime softening, including gravity aeration, chemical mixing, flocculation, solids separation, recarbonation, and rapid gravity filtration. Sodium hypochlorite was added for disinfection, hydrated lime was added to raise the water pH, aluminum sulfate (alum) was used for coagulation in solids contact clarifiers, carbon dioxide was used to lower the water pH, and fluoride was added for consumer dental health. Air stripping towers were added in 1985 to remove volatile organic compounds (VOCs) from the well water. In 1999, the old WTP was expanded with a similar process excluding recarbonation and filtration processes (Donohue & Associates, Inc. 2019).

3.3 Existing Water Treatment Process

WWW transitioned to its new WTP at the end of December 2023. The New WTP uses aeration for four wells and air stripping for two of the wells to remove VOCs (**Figure 3-1**). Aerated water is then treated with permanganate for iron and manganese oxidation, and sodium hypochlorite for disinfection. Alum and polymer are added in rapid mix for coagulation, followed by flocculation and settling. Sodium hydroxide is added to increase the water pH. After settling, the water is filtered through mixed-media filters. Filtered water passes through an anion exchange process then GAC media. Hydrofluorosilicic Acid is added for fluoridation, and sodium silicate and caustic soda are added for corrosion control. The water then goes through a clearwell and is treated with ammonia (for chloramine disinfection), sodium hypochlorite, and sodium hydroxide before being sent to the distribution system.



Based on "*Engineering Report – Wausau Drinking Water Treatment Facility and Associated Water System Improvements*" by Donohue & Associates, Inc. December 4, 2019

Figure 3-1 Process Flow Diagram for New WTP

3.4 Service Line Inventory

As of March 12, 2026, about 22% of utility-owned service lines are lead. The majority of remaining service lines (67%) are copper installed after the lead ban, with an additional 1.5% identified as copper with an unknown installation date. Approximately 3% of service line materials are unknown, while the remainder are plastic or iron (**Figure 3-2**). One utility-owned service line is galvanized iron. Approximately 43% of the customer-owned service lines have unknown materials. About 5% of the customer-owned service lines are confirmed lead service lines and 42% are copper with unknown installation dates (**Figure 3-2**). The remaining lines are iron or plastic.

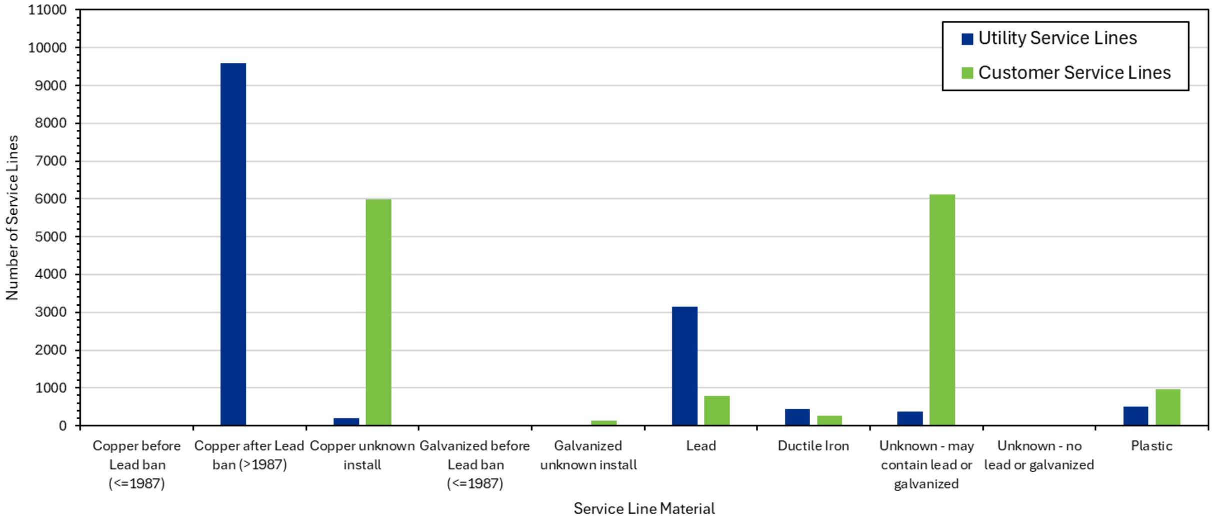


Figure 3-2 Service Line Inventory as of March 12, 2026

3.5 Comparison of Old WTP and New WTP Finished Water Quality

After the switch to the New WTP, WWW noted more consistent water quality in the distribution system, disinfectant residuals were better maintained without additional effort, and there were fewer customer complaints of discolored water. Key water quality parameters, including alkalinity and hardness, remained similar between the old and new WTPs (**Table 3-1**). Chloride concentrations at the Old WTP ranged from 20–27 mg/L between April and September 2022 but increased to approximately 50–60 mg/L from September to December 2022 (**Figure 3-3**). Samples collected from the New WTP between April and May 2023 showed chloride concentrations of 60–70 mg/L. However, samples collected in 2024 showed substantially lower chloride levels, with a median concentration of 31 mg/L. Sulfate concentrations at the Old WTP were relatively consistent, with a 10th–90th percentile range of 7.0–14 mg/L. Under the New WTP, sulfate concentrations were lower, ranging from 1.0–5.1 mg/L. These changes resulted in an increase in CSMR under the New WTP, ranging from 5.8 to 29 compared to 1.6 to 7.5 at the Old WTP.

Table 3-1 Comparison of Finished Water from the Old and New WTP

Parameter	Old WTP	New WTP
Alkalinity (mg/L as $CaCO_3$)	84 (70-100)	86 (10-100)
Hardness (mg/L as $CaCO_3$)	88 (78-102)	82 (64-99)
Calcium (mg/L as Ca)	24 (21-26)	15 (14-21)
Magnesium (mg/L as Mg)	4.8 (4.5-5.1)	5.3 (5.2-7.1)
Chloride (mg/L as Cl)	50 (23-60)	31 (26-60)[1]
Sulfate (mg/L as SO_4)	8.0 (7.0-14)	3.4 (1.0-5.1)[1]
Chloride-to-Sulfate Mass Ratio	6.3 (1.6-7.5)	8.8 (5.8-29)
Silicate (mg/L as SiO_2)	35 (32-38)	35 (33-37)
Turbidity (NTU)	No information	0.12 (0.11-0.14)
Total Dissolved Solids (mg/L)	130 (121-139)	115 (100-160)
Iron (mg/L as Fe)	0.02 (n.d.-0.05)	0.02 (n.d-0.04)
Manganese (mg/L as Mn)	0.10 (n.d.-0.20)	0.009 (n.d.-0.020)
pH (S.U.)	8.7 (8.5-8.9)	8.5 (8.0-8.8)
Temperature (°F)	No information	52 (51-53)
Total Chlorine (mg/L as Cl_2)	2.8 (2.3-3.2)	2.1 (1.9-2.3)
Free Ammonia (mg/L as NH_3-N)	No information	0.07 (0.01-0.13)
Total Ammonia (mg/L as NH_3-N)	No information	0.50(0.43-0.56)

Note: 1 – Chloride and sulfate data were collected from the pipe loop influent receiving WTP finished water.

Median pH observed during this study at the New WTP is lower (8.5) compared to the historical data from the Old WTP (8.7) (**Figure 3-3**). Following startup of the PFAS treatment system on October 11, 2024, pH began to decrease and became highly variable through May 2025 due to issues with caustic soda dosing. Once this issue was addressed, the median pH increased back to 8.7 (8.5-9.0).

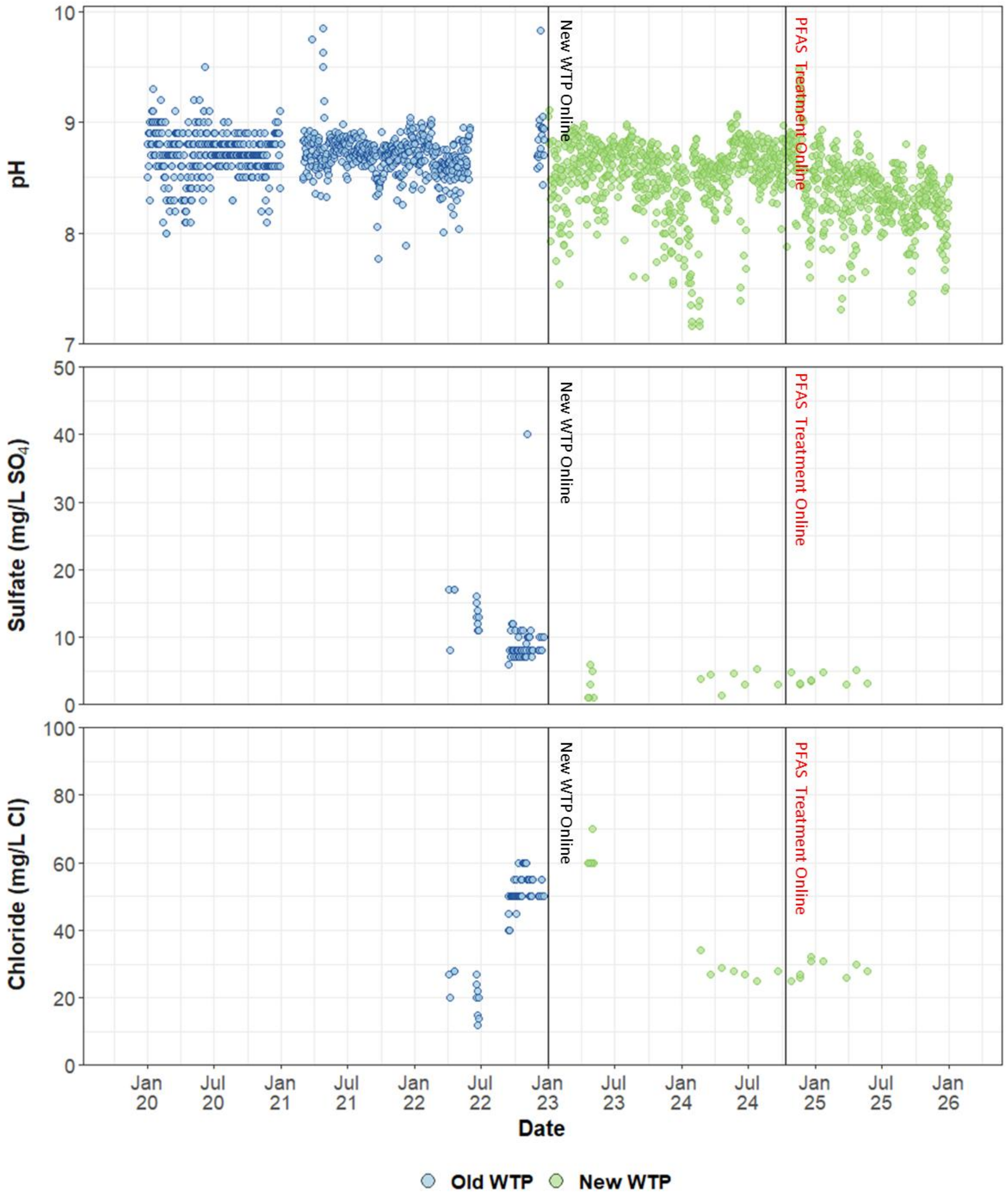


Figure 3-3 Comparison of pH, Sulfate and Chlorides from the Old and New WTP

3.6 Lead and Copper Sampling Results

3.6.1 Historical Lead and Copper Compliance Sampling

Between 2002 to 2020, the 90th percentile lead and copper concentrations were typically below the respective LCR action levels of 15 micrograms per liter (µg/L) for lead and 1,300 µg/L for copper (**Figure 3-4**) in the first liter samples. However, the 90th percentile lead concentrations exceeded the lead action level in two sampling rounds; 90th percentile lead concentrations in 2005 and 2014 were 15.3 and 16 µg/L, respectively. The 90th percentile lead concentrations have not exceeded the LCR action level since then and are typically below 10 µg/L. The WDNR has not required WWW to conduct LCR compliance sampling since 2020.

Wisconsin is following the LCR but will soon be subject to more stringent regulations informed by the U.S. Environmental Protection Agency (EPA). In October 2024, the EPA promulgated an updated rule, the Lead and Copper Rule Improvements (LCRI), which strengthens the LCR by including provisions to improve public health, such as prioritizing monitoring homes with lead service lines, requiring first and fifth liter sampling, and lowering the lead action level to 10 µg/L. For sampling, the higher lead concentration between the first liter and the fifth liter must be reported for calculating the 90th percentile. In homes with LSLs, the fifth liter is expected to present higher lead concentrations than the first liter. Compliance with the LCRI was originally scheduled for November 2027; however, implementation has been paused due to a legal challenge filed by the American Water Works Association (AWWA). The challenge primarily relates to concerns over implementation timelines and feasibility rather than the underlying technical basis of the rule. As a result, any changes to the LCRI as a result of that challenge are not anticipated to materially affect lead and copper sampling requirements.

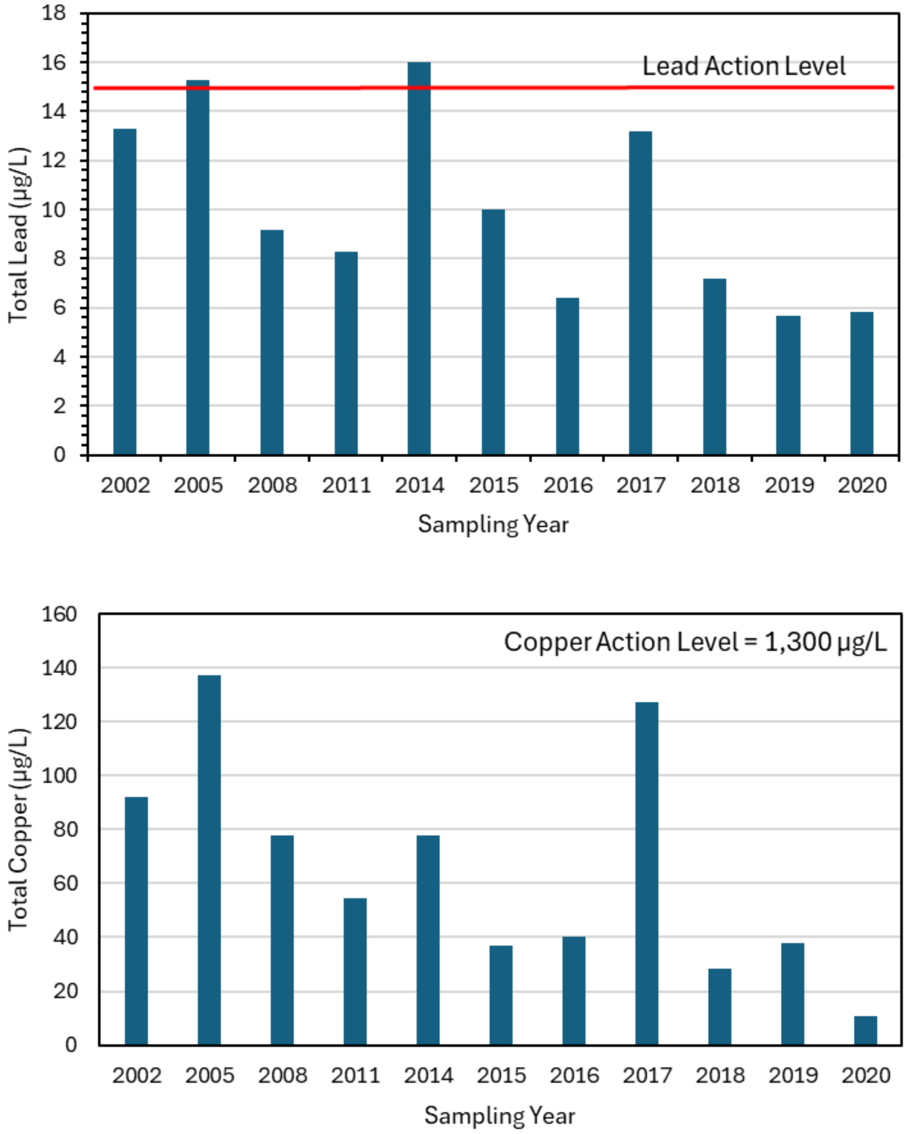


Figure 3-4 Historical 90th Percentile Lead and Copper Concentrations in the First Liter (2002-2020)

3.6.2 Potential Impacts of New Water Quality and Regulations on Lead and Copper Compliance Sampling

To evaluate the impact of water quality changes and potential implications of upcoming lead and copper regulations, WWW conducted sequential sampling at ten sites. Samples collected in 2022 represent water quality from the Old WTP, while samples collected in 2024 represent water quality from the New WTP.

Copper in the first liter samples, typically representing water in the premises plumbing, were compared. A similar trend was observed for copper, with 90th percentile concentrations lower in 2024 than in 2022 (90^{th} percentile: 8.4 µg/L vs. 21 µg/L in 2022). In 2022, copper concentrations ranged from 2.0 to 41 µg/L, whereas in 2024 they ranged from 0.74 to 9.4 µg/L (**Figure 3-5**).

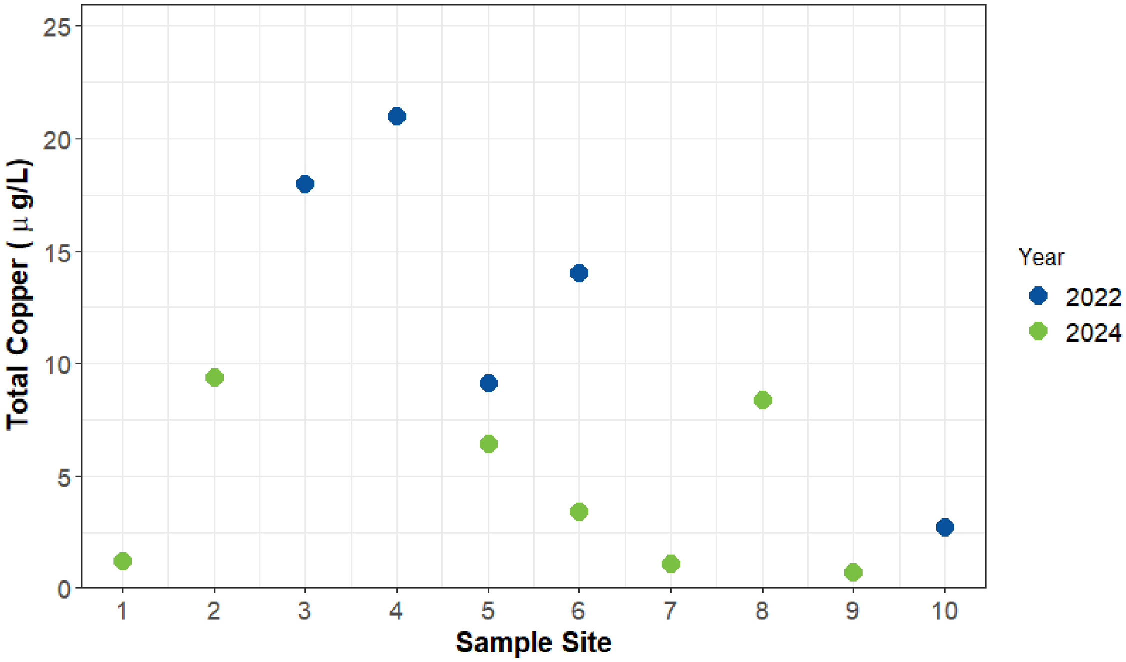


Figure 3-5 Comparison of Copper Concentrations from 1st Liter Tap Samples Collected in 2022 and 2024 from Homes with Lead Service Lines

Note: The data shown is for first liter samples from six samples collected in 2022 and seven samples collected in 2024.

Fifth liter lead concentrations from the sequential sampling were used to evaluate the impact of water quality changes since the fifth-liter is typically considered to capture water in the lead service line. In 2022, lead concentrations ranged from 0.50 to 75 µg/L, whereas in 2024 concentrations ranged from below detection to 21 µg/L (**Figure 3-6**). These results suggest that the new WTP did not negatively impact lead and copper corrosion in the distribution system.

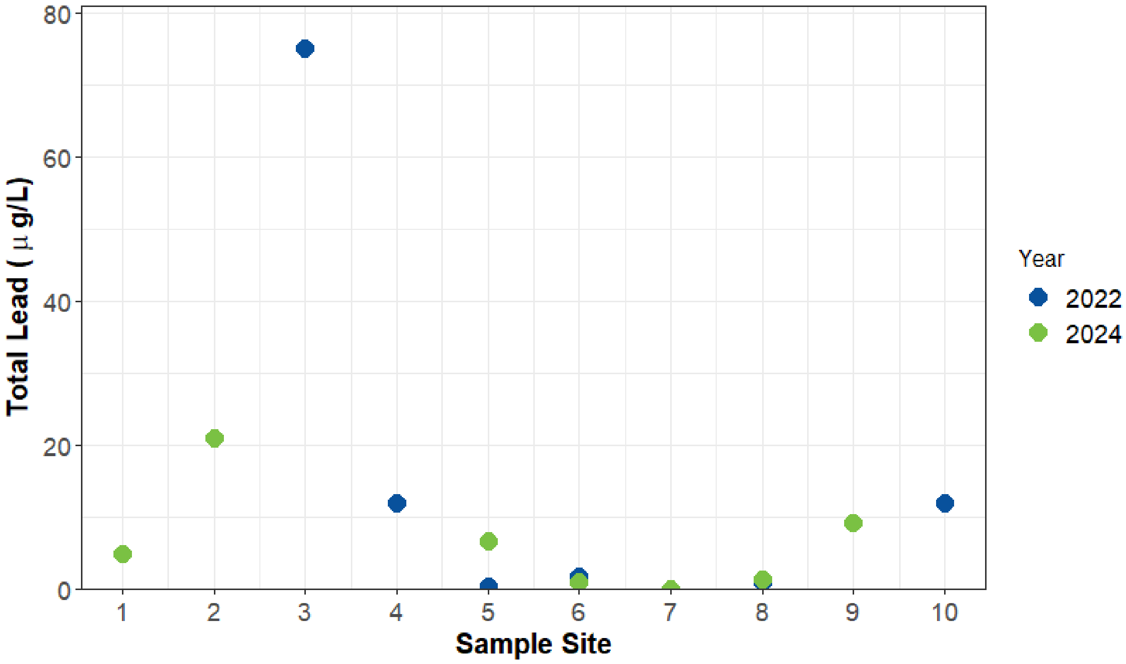


Figure 3-6 Comparison of Lead Concentrations from 5th Liter Tap Samples Collected in 2022 and 2024 from Homes with Lead Service Lines

Note: The data shown is for fifth liter samples from six samples collected in 2022 and seven samples collected in 2024.

The more stringent sampling requirements under the LCRI may result in higher lead levels when the 5th liter sample is used for compliance at sites with lead service lines. Sequential sampling results indicate that, under current water quality conditions, WWW may have the potential to exceed the upcoming LCRI lead action level of 10 µg/L. Across the 10 sampling sites, the highest lead concentrations were observed in the fifth-liter samples, with concentrations reaching up to 75 µg/L (**Figure 3-7**). In addition, 5th liter concentrations were 4.2 times greater than the 1st liter concentrations on average, with a 90th percentile concentration of 19.2 µg/L.

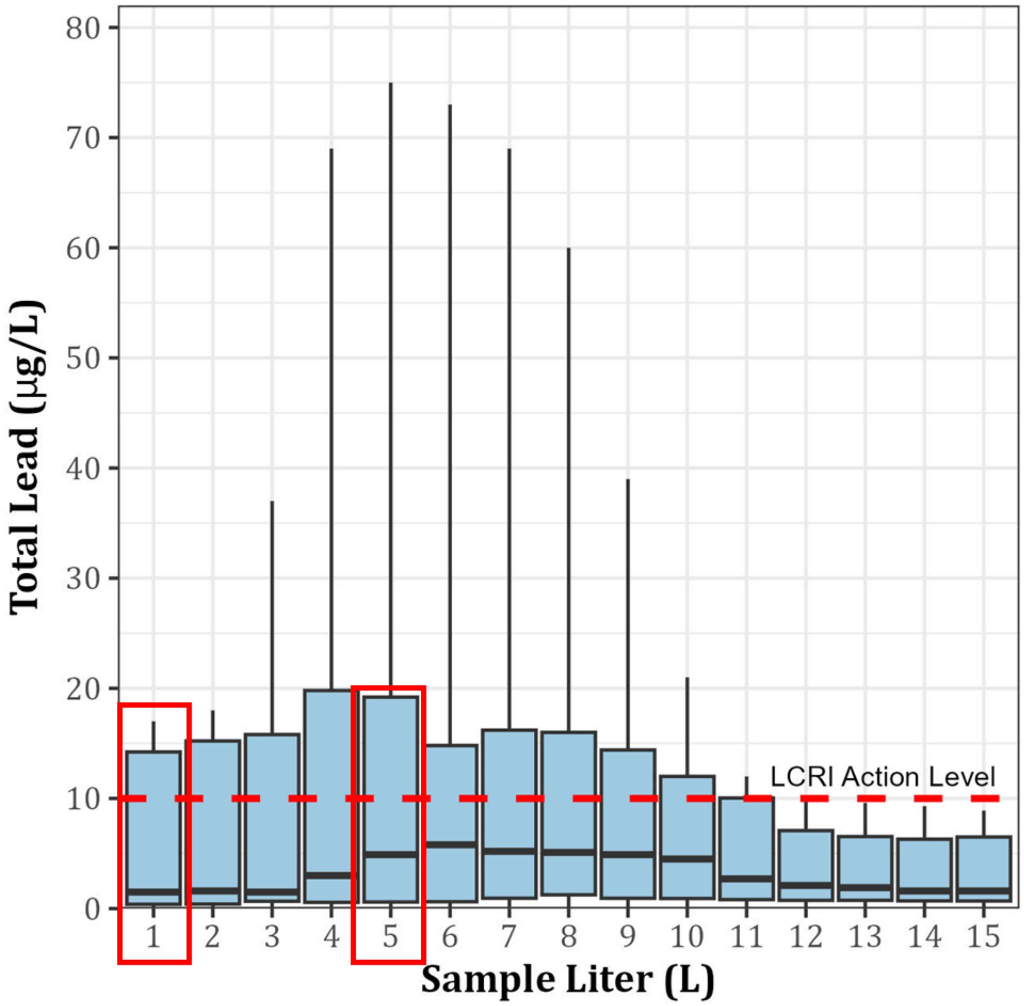


Figure 3-7 Lead Concentrations from Sequential Sampling (2022 and 2024)
Note: The black horizontal bar represents the median lead concentration. The lower and upper bounds of the box represent the 10th and 90th percentiles, respectively. The vertical bars represent minimum and maximum lead concentrations.

3.7 Harvested Lead Service Line Scale Analysis

Four pipes were harvested from WWW's system for scale analysis—one in July 2022 (1221 S. 4th Ave), two in May 2024 (1316 N 2nd Street and 3025 N 12th Street – Pipe 1316 and Pipe 3025, respectively), and one in July 2025 (105 E Oak Street – Pipe 105)—and sent to the Chemical and Environmental Analysis Facility at Washington University in St. Louis.

Pipe scale composition varied among the segments analyzed, reflecting differences in location and water chemistry rather than treatment impacts (**Table 3-2**). In addition to the crystalline phases that were identified and that are discussed below, the scale layers also contained abundant amorphous materials. The pipe from 2022, Pipe 1221, had scale layers that contained cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$). Cerussite was more abundant in the bottom layer, while litharge (PbO) was only found in a small amount in the bottom layer. The two 2024 pipe segments, Pipe 1316 and Pipe 3025, were broadly similar, with lead as the dominant element and cerussite present in the bottom layers of both pipes . Pipe 3025 also contained abundant hydrocerussite, while Pipe 1316 showed elevated manganese, including ramsdellite in the top layer. Differences in texture and color were observed, with Pipe 3025 exhibiting a fluffy top layer.

Pipe 105, harvested in 2025, showed a distinct mineralogical profile, with lower abundances of cerussite and hydrocerussite and a greater presence of calcite and magnetite, consistent with a high-hardness groundwater system and local distribution conditions. Overall, the observed differences are attributed to spatial variability within the distribution system rather than anion exchange and GAC treatment. While pipe scale mineralogy does not indicate significant changes following implementation of PFAS treatment, lead and copper tap monitoring data collected from homes in WWW's service area after PFAS treatment was implemented are not available to evaluate potential impacts on metals release.

Amorphous layers were present on the pipes, with each pipe having a different mix of elements present. Aluminum was consistently observed on the scale of all the pipes analyzed, indicating it is a common component of the pipe deposits. In addition, some pipes also contained detectable amounts of silicon, manganese, zinc, phosphorus, and calcium. The presence of these additional metals and minerals may reflect contributions from treatment chemicals (i.e., silicate, aluminum coagulant) or from source water (e.g., phosphorus, manganese, and calcium).

Table 3-2 Summary of Scale Analysis of Harvested Pipe from the Distribution System

Pipe Segment	Visual Characteristics	Dominant Crystalline Minerals	Other Minerals Present	Dominant Elements in Top Layer	Dominant Elements in Bottom Layer	Other Elements Present
Pipe 1221 (2022)	Top layer – brown, rough Bottom layer – white, compact	Cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$)	None identified	Aluminum (28.1 milligrams per gram (mg/g)) Iron (44.7 mg/g) Calcium (49.5 mg/g) Lead (288.1 mg/g)	Lead (692.3 mg/g)	Aluminum and calcium
Pipe 1316 (2024)	Top layer - dark black Bottom layer - brown	Cerussite ($PbCO_3$)	Ramsdellite (MnO_2)	Manganese (234.8 ± 18.1 mg/g) Lead (106.5 ± 8.2 mg/g)	Lead (347.2 ± 26.8 mg/g) Manganese (125.6 ± 9.7 mg/g)	Aluminum, phosphorus, silicon, and zinc

Pipe Segment	Visual Characteristics	Dominant Crystalline Minerals	Other Minerals Present	Dominant Elements in Top Layer	Dominant Elements in Bottom Layer	Other Elements Present
Pipe 3025 (2024)	Top layer - fluffy brown Bottom layer - yellowish	Cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$)	Phosphohedyphane-like solid ($Ca_8Pb_2(PO_4)_6(OH_2)$)	Lead (213.9 ± 16.5 mg/g)	Lead (538.7 ± 41.6 mg/g) Copper (133.2 ± 10.3 mg/g) Zinc (86.9 ± 6.7 mg/g)	Aluminum, manganese, phosphorus, silicon, and zinc
Pipe 105 (2025)	Top layer - fluffy and light brown Bottom Layer - dark brown	Calcite ($CaCO_3$)	Cerussite ($PbCO_3$), hydrocerussite ($Pb_3(CO_3)_2(OH)_2$), and magnetite (Fe_3O_4)	Lead (416.7 ± 32.2 mg/g) Calcium (225.5 ± 17.4 mg/g) Iron (120 ± 9.3 mg/g) Manganese (100.7 ± 7.8 mg/g)	Lead (485.4 ± 37.5 mg/g) Iron (120 ± 9.3) Manganese (79.7 ± 6.1)	Aluminum, silicon, and zinc

3.8 Section Summary

Most water quality parameters remained similar after the switch to the new WTP. However, chloride (51 to 21 mg/L) and sulfate (8 to 3.4 mg/L) decreased. pH temporarily decreased following the addition of PFAS treatment due to a caustic soda pump issue but rebounded to a median of 8.7 after the issue was resolved.

Prior to the pH control issue after PFAS treatment was added, the New WTP water quality did not appear to increase lead or copper concentrations in samples. However, sequential sampling results indicate that fifth-liter lead concentrations were, on average, approximately 4.2 times higher than first-liter concentrations. The 90th percentile fifth-liter concentration across the 10 sites sampled in 2022 and 2024 was 19.2 µg/L. Under current water quality conditions, these results suggest that WWW has the potential to exceed the upcoming LCRI lead action level of 10 µg/L. This analysis is limited by the small number of samples but is useful for identifying potential impacts.

LSL scale mineralogy was generally similar under water quality from the Old and New WTPs, with the lead carbonate minerals cerussite and hydrocerussite as the dominant minerals. Pipe 105 also exhibited calcite in the top layer, indicating that calcium carbonate precipitation is occurring in some areas of the distribution system. Elemental composition of the top scale layers was dominated by calcium, iron, and manganese, with lesser amounts of aluminum, phosphorus, silicon, and zinc.

4.0 Pipe Loop Study Results

4.1 Overview

CDM Smith conducted a desktop modeling analysis of WWW's historical water quality data and recommended that WWW consider evaluating orthophosphate addition as a corrosion control strategy (TM-2 – Desktop Modeling Analysis, CDM Smith, August 21, 2023). Finished water alkalinity and hardness were comparable between the old and new WTPs. However, the estimated CSMR increased substantially, from a ratio of approximately 6.3 to 40.

Based on these findings, a pipe loop study was recommended to evaluate lead and copper corrosion with orthophosphate doses at 1.0 and 3.0 mg/L asPO_4 using the Newt WTP finished water. The potential discontinuation of silicate addition was discussed as a test condition; however, it was determined that the initial phase of the pipe loop study should focus on evaluating varying orthophosphate doses without introducing additional treatment changes. Removing silicates from the treatment can be evaluated in the future.

This section summarizes the results of the pipe loop study, with a focus on water quality conditions, pipe scale characteristics, and lead and copper release observed across the tested materials and treatment conditions. Results are presented for harvested lead pipes, and new copper pipes with lead solder to evaluate the effects of orthophosphate treatment on metal release and scaling.

Water quality parameters relevant to corrosion control and metal solubility are first summarized to provide context for the observed release trends. Lead release results from harvested lead pipes are evaluated, with particular attention to differences in lead release behavior between the baseline (Conditioning Phase 3) and testing phases. Scale analyses conducted on orthophosphate-treated lead pipe sections are then discussed to characterize the composition and stability of the corrosion scales formed under orthophosphate treatment.

For copper release from copper pipes with lead solder, a similar analytical approach was applied by comparing steady-state copper release under baseline and testing conditions. Lead release from copper pipes with lead solder in the control skid decreased during the testing phase, suggesting that additional time was required for a passivating scale to fully develop. As a result, lead release was evaluated by comparing concentrations observed under each phosphate treatment condition against the control condition rather than against baseline values.

Prior to evaluating treatment impacts, all pipe sections underwent an acclimation period to allow corrosion scales to stabilize. Lead and copper release stability was assessed by confirming that each permanent test section had total lead concentrations that exhibited a relative standard deviation of less than 25 percent across the final seven consecutive measurements of Conditioning Phase 3. Detailed results from the acclimation phase are provided in **Appendix D**.

4.2 Water Quality

4.2.1 Total Alkalinity, Total Hardness, and Silicate

Alkalinity, hardness, and silicate were monitored monthly throughout the study. The acclimation period covered Conditioning Phases 1, 2 and 3 from November 13, 2023 to November 10, 2024. During this time, influent water quality parameters were generally stable across the three skids, with alkalinity ranging from 61 to 74 mg/L as calcium carbonate ($CaCO_3$), hardness from 60 to 68 mg/L as $CaCO_3$, and silicate from 31 to 32 mg/L as SiO_2 (**Table 4-1**). These ranges represent the 10th to 90th percentiles of the measured values. Throughout the testing phase, alkalinity (10th to 90th percentile = 65 to 80 mg/L as $CaCO_3$), hardness (62 to 69 mg/L as $CaCO_3$), and silicate (29 to 34 mg/L as SiO_2) remained similar to concentrations observed during the acclimation phase. Except for pH (see **Section 4.2.2**) and turbidity (See **Section 4.2.4**), effluent water quality generally remained comparable to influent water quality throughout the evaluation period (**Appendix E**).

Table 4-1 Summary of Influent Water Quality

Parameter	Acclimation Period		Testing Period
	Conditioning 1 and 2 Median (10th-90th percentile)	Conditioning 3 Median (10th-90th percentile)	Testing Median (10th-90th percentile)
Total Alkalinity (mg/L as $CaCO_3$)	64 (61 – 66)	71 (67 – 74)	73 (65 - 80)
Total Hardness (mg/L as $CaCO_3$)	64 (61 - 65)	62 (60 - 68)	67 (62 - 69)
pH (S.U.)	8.6 (8.5 - 8.8)	8.8 (8.7 - 8.9)	Control = 8.7 (8.2 - 8.9) 1.0 mg/L as PO_4 = 8.5 (7.9 - 8.7) 3.0 mg/L as PO_4 = 8.3 (7.6 - 8.7)
Turbidity (NTU)	0.32 (0.24 - 0.39)	0.19 (0.12 - 0.32)	Control = 0.19 (0.13 - 0.29) 1.0 mg/L as PO_4 = 0.19 (0.14 - 0.32) 3.0 mg/L as PO_4 = 0.20 (0.13 - 0.33)
Temperature (°F)	56 (54 - 58)	56 (55 - 58)	56 (56 - 60)
Calcium (mg/L as Ca)	16 (15 - 16)	16 (15 – 17)	17 (16 – 18)
Magnesium (mg/L as Mg)	5.6 (5.3 – 6.0)	5.7 (5.5 - 6.2)	5.7 (5.3 - 6.0)
Chloride (mg/L as Cl)	29 (27 – 33)	26 (25 – 28)	31 (26 – 32)
Sulfate (mg/L as SO_4)	4.1 (2.1 – 4.5)	3.9 (2.9 - 5.1)	3.0 (2.3 – 4.0)
Silicate (mg/L as SiO_2)	32 (31 - 32)	32 (31 - 32)	31 (29 – 34)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.002)	n.d. (n.d. - 0.17)	2.0 (n.d. - 2.3)
Total Chlorine (mg/L as Cl_2)	2.4 (2.0 - 2.6)	2.4 (2.1 - 2.6)	2.4 (2.1 - 2.6)
Free Ammonia (mg/L as NH_3-N)	n.d. (n.d. – 0.10)	0.13 (0.046 – 0.21)	0.058 (0.0016 – 0.17)
Total Ammonia (mg/L as NH_3-N)	0.47 (0.45 - 0.52)	0.59 (0.50 - 0.64)	0.51 (0.44 - 0.58)
Orthophosphate (mg/L as PO_4)	No phosphate used	No phosphate used	Control = No phosphate used 1.0 mg/L as PO_4 = 1.2 (0.24 - 1.6) 3.0 mg/L as PO_4 = 2.9 (0.25 - 3.4)

Note:
1 – Below detection limit
Key: S.U. – standard units, NTU – Nephelometric Turbidity Units, °F – degrees Fahrenheit, Ca – calcium, Mg – magnesium, Cl – chloride, SO_4 – sulfate, Cl_2 – chlorine, NH_3-N – ammonia-nitrogen, n.d. – non-detect
Unless otherwise noted, influent water quality represents that measured for the control skid. Presented medians and ranges do not vary significantly among the skids unless noted in the table.

4.2.2 pH

In the acclimation phase, prior to PFAS treatment addition, influent pH ranged from 8.7 to 8.9 in the 10th to 90th percentile. Following the startup of the PFAS treatment system on October 11, 2024, pH in the influent water became highly variable through May 2025, with 10th to 90th percentile values ranging from 8.1 to 8.9 S.U (**Figure 4-1**). This variability was attributed to a pumping issue with the caustic soda feed.

This increased variability in pH is important because pH strongly influences corrosion processes and metals release in distribution systems. Fluctuations toward lower pH conditions can reduce the stability of protective pipe scales and increase the potential for lead and copper release (See **Sections 4.3, 4.4,**

and 4.6). As a result, periods of pH instability may contribute to increased short-term metals release, highlighting the importance of maintaining a stable finished water pH for corrosion control.

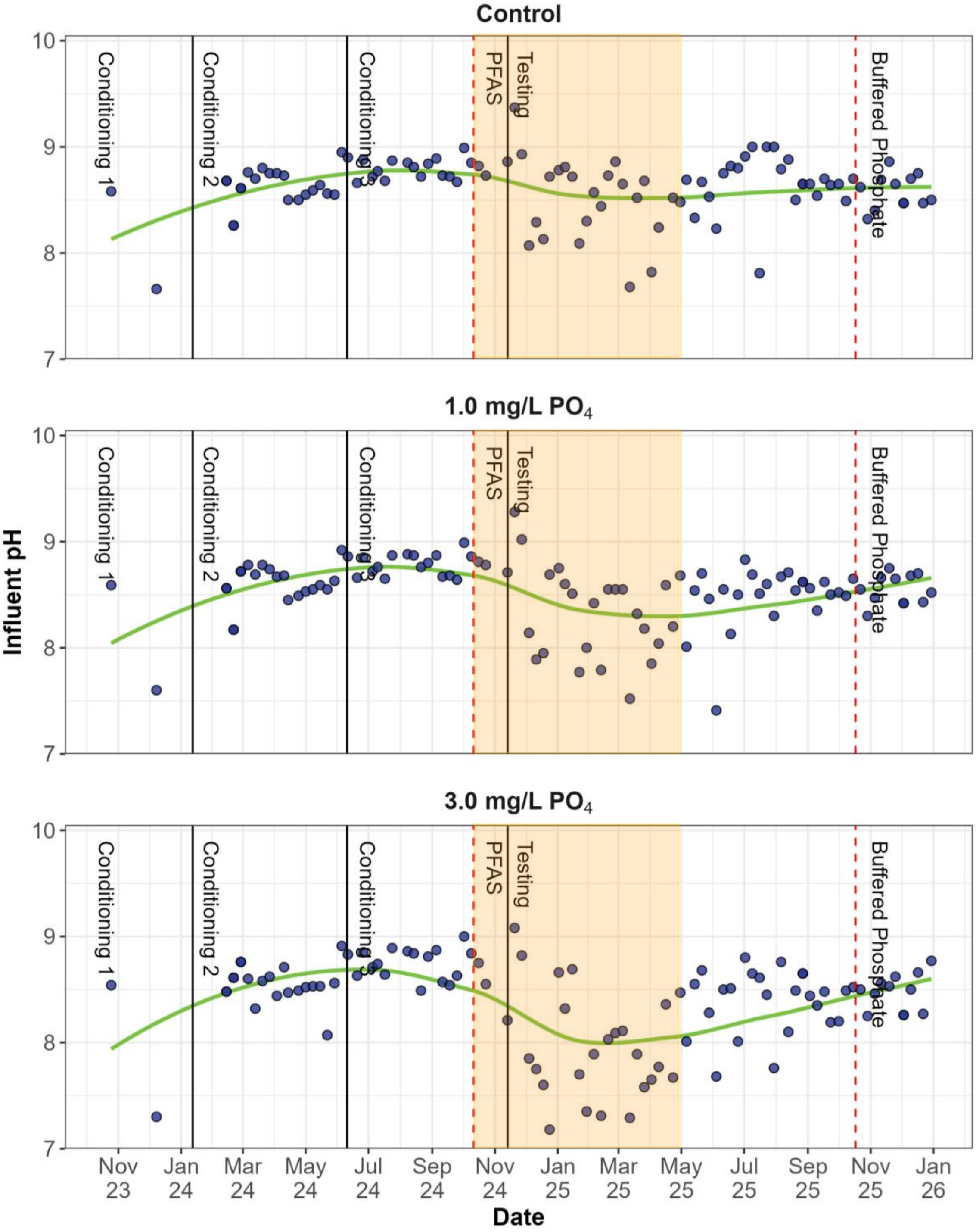


Figure 4-1 Influent Water Quality: pH

Note: The blue points represent raw data. The green lines represent the data trends predicted using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

Orthophosphate treatment using phosphoric acid caused a measurable decrease in influent pH in the pipe loop systems (**Figure 4-2**). The pH decreased by approximately 0.2 S.U. (95% confidence interval = 0.1 to 0.3, p-value less than [<] 0.05) in the skid receiving 1.0 mg/L as PO_4 and by 0.4 S.U. (95% confidence interval = 0.3 to 0.5, p-value <0.05) in the skid receiving 3.0 mg/L as PO_4 (**Appendix E, Figure E-1**). While there was no practical way to adjust pH within the pipe loop setup, pH control could be implemented at full scale if phosphoric acid were selected for corrosion control. To minimize the pH reduction observed in the pipe loops, a buffered orthophosphate product (Carus 4500, pH 5.1-6.1) was substituted on October 17, 2025.

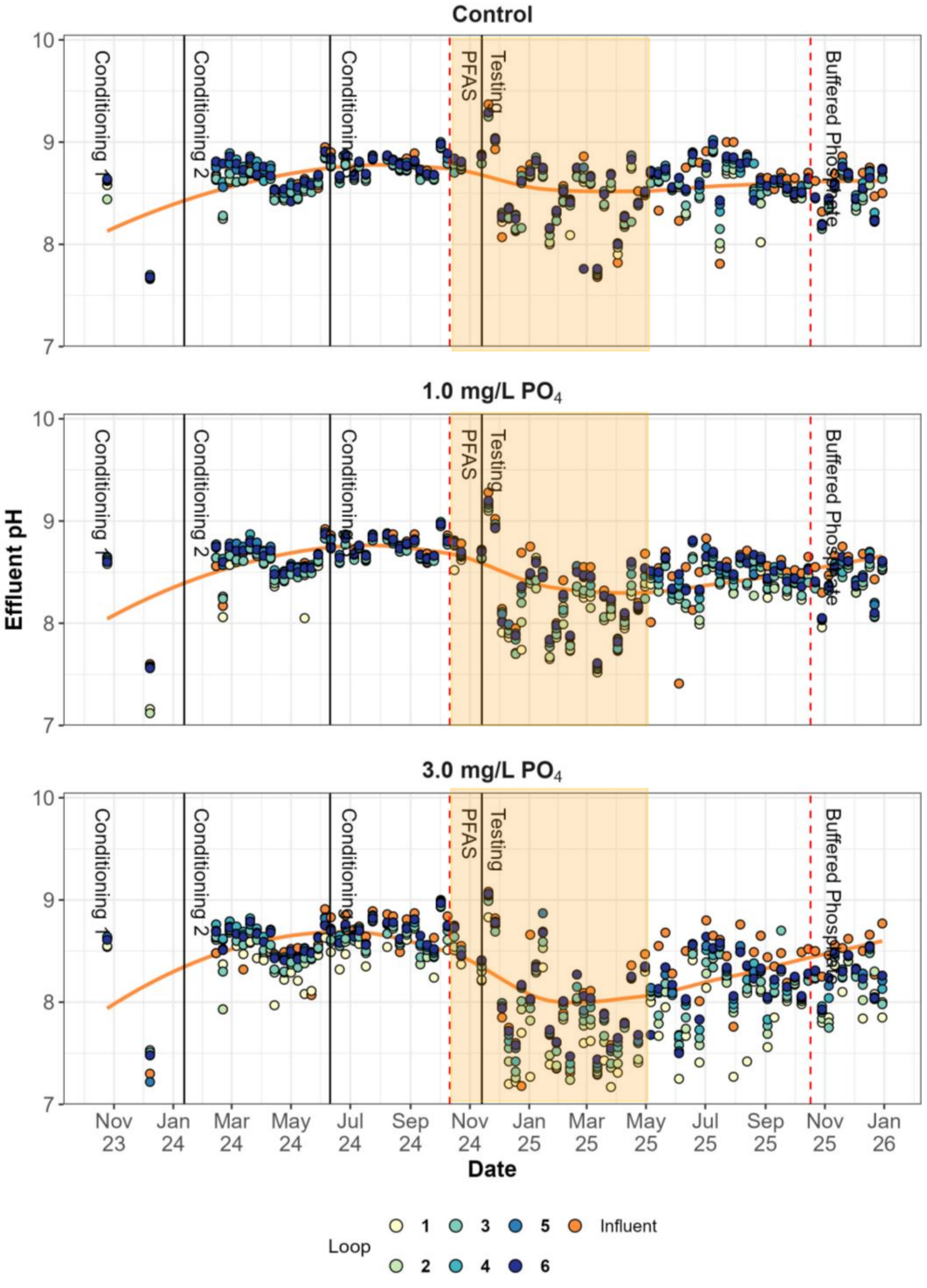


Figure 4-2 Effluent Water Quality: pH

Note: The points represent raw data. The orange points represent influent pH. The orange line represent the data trends of influent pH predicted using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

4.2.3 Orthophosphate Residual

The pipe loops were operated to target orthophosphate residuals of 1.0 mg/L and 3.0 mg/L as PO_4, with a target deviation of ± 0.3 mg/L as PO_4 during the testing phase. Over the course of testing, the median influent orthophosphate concentrations were 1.2 mg/L as PO_4 (10th-90th percentile: 0.2 to 1.6 mg/L as PO_4) for the skid receiving 1.0 mg/L as PO_4 and 2.9 mg/L as PO_4 (0.2 to 3.4 mg/L as PO_4) for the skid receiving 3.0 mg/L as PO_4. Occasional short-term drops or spikes in orthophosphate were observed; particularly, influent orthophosphate concentrations were below 0.5 mg/L as PO_4 between May and July 2025 (**Figure 4-3**). In contrast, effluent orthophosphate concentrations from the pipe loops were generally within the target ranges. The low orthophosphate measurements observed in influent samples between May and July 2025 were attributed to sampling error. During this period, significant staff turnover occurred, which may have contributed to inconsistencies in sampling and sample handling.

Between May and September, effluent orthophosphate concentrations in the lead loops under the 1.0 mg/L as PO_4 condition were often higher than influent concentrations (**Figure 4-3**). However, elevated effluent concentrations were not consistently observed in the same loops. This variability was attributed to uneven flow distribution across the loops in the 1.0 mg/L as PO_4 dosing skid. The flow imbalance issue was addressed in October 2025.

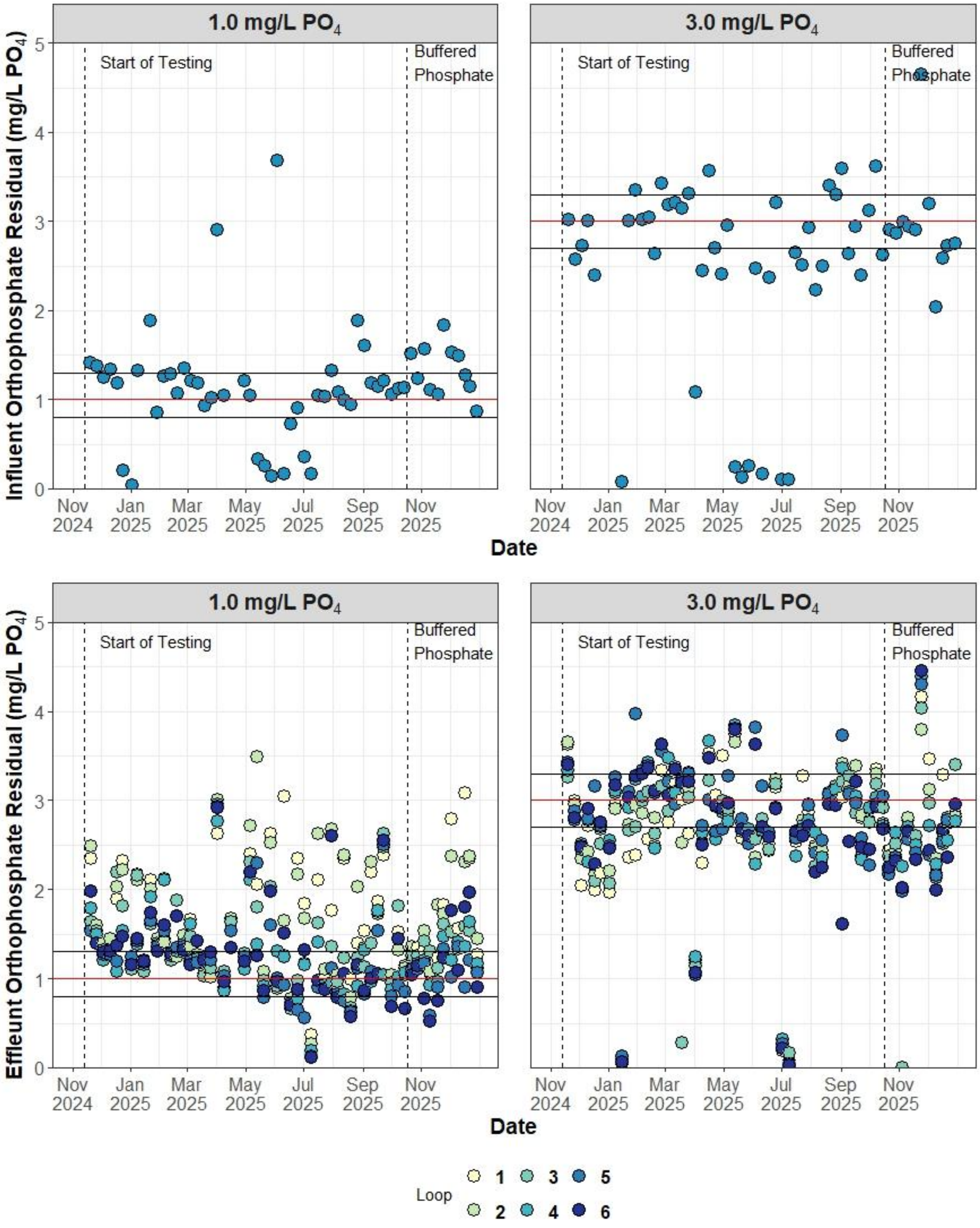


Figure 4-3 Influent and Effluent Orthophosphate Residual

Note: The red lines indicate the target orthophosphate residual concentrations of 1.0 and 3.0 mg/L as PO_4, while the black horizontal lines represent the variability goal around the target residual range.

4.2.4 Turbidity

During the acclimation phase, influent turbidity in the orthophosphate-treated loops was typically similar to that observed in the control skid (**Figure 4-4**). A temporary spike in influent turbidity was observed in the orthophosphate skids between the weeks of December 18 and 24, 2025. This increase was likely associated with a 0.5 to 1.5 S.U. decrease in pH combined with variable orthophosphate concentrations in the influent water (ranging from <0.2 to 2.4 mg/L as PO_4). Other spikes in influent turbidity were observed from June to August 2025; however, the cause could not be identified. These events may be associated with highly variable full-scale finished water pH or fluctuations in orthophosphate dosing during the same period. Influent turbidity in all systems gradually decreased and returned to levels similar to baseline conditions.

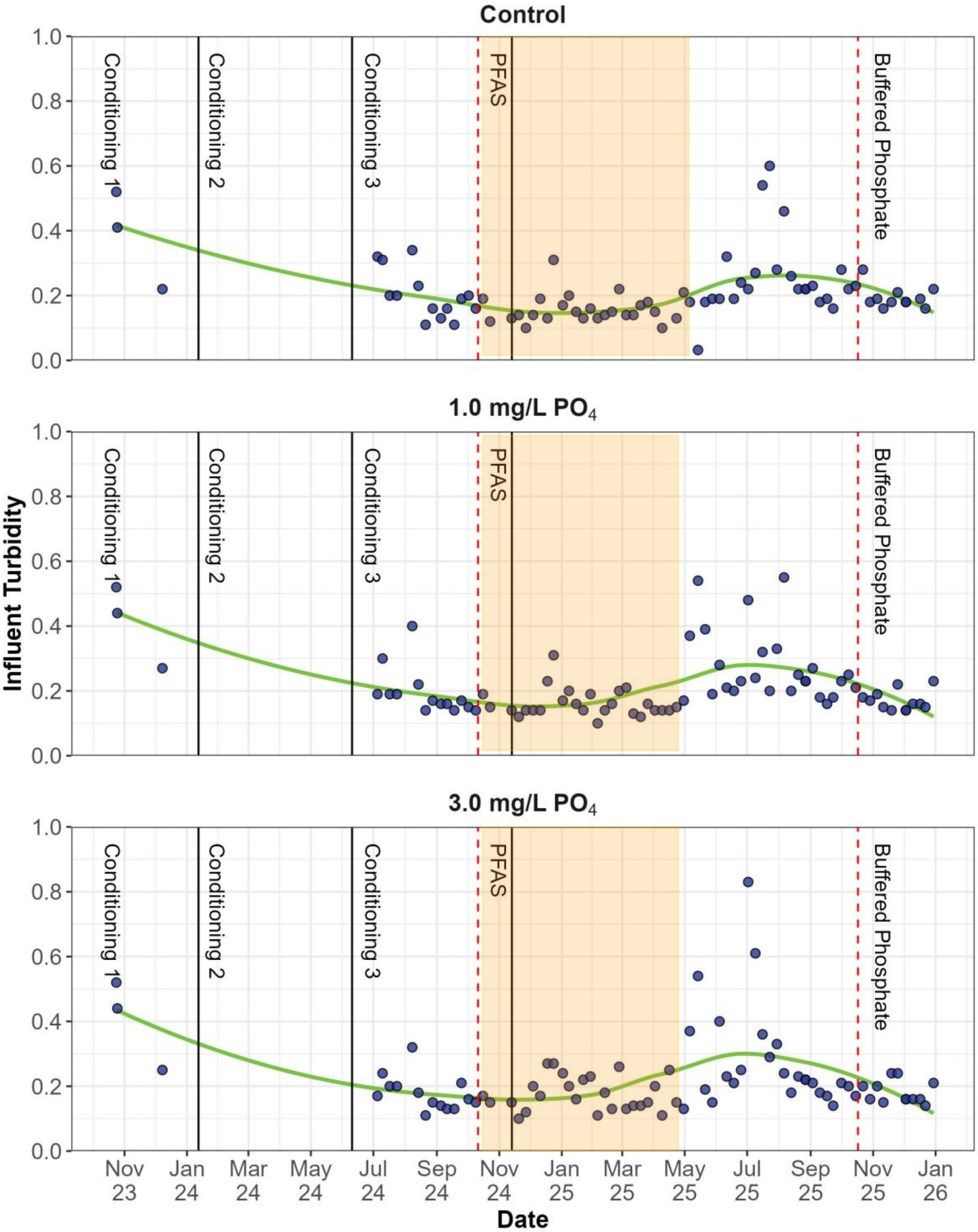


Figure 4-4 Influent Water Quality: Turbidity

Note: The blue points represent raw data. The green lines represent the data trends predicted using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

Influent turbidity in the testing phase typically remained similar between the orthophosphate-treated and untreated skids (p-value = 0.89 to 0.92, 95% confidence interval of slope = 0.91 to 1.1). Median turbidity values in the final seven consecutive samples of the testing phase ranged from 0.16 to 0.19 NTU (**Figure 4-5**).

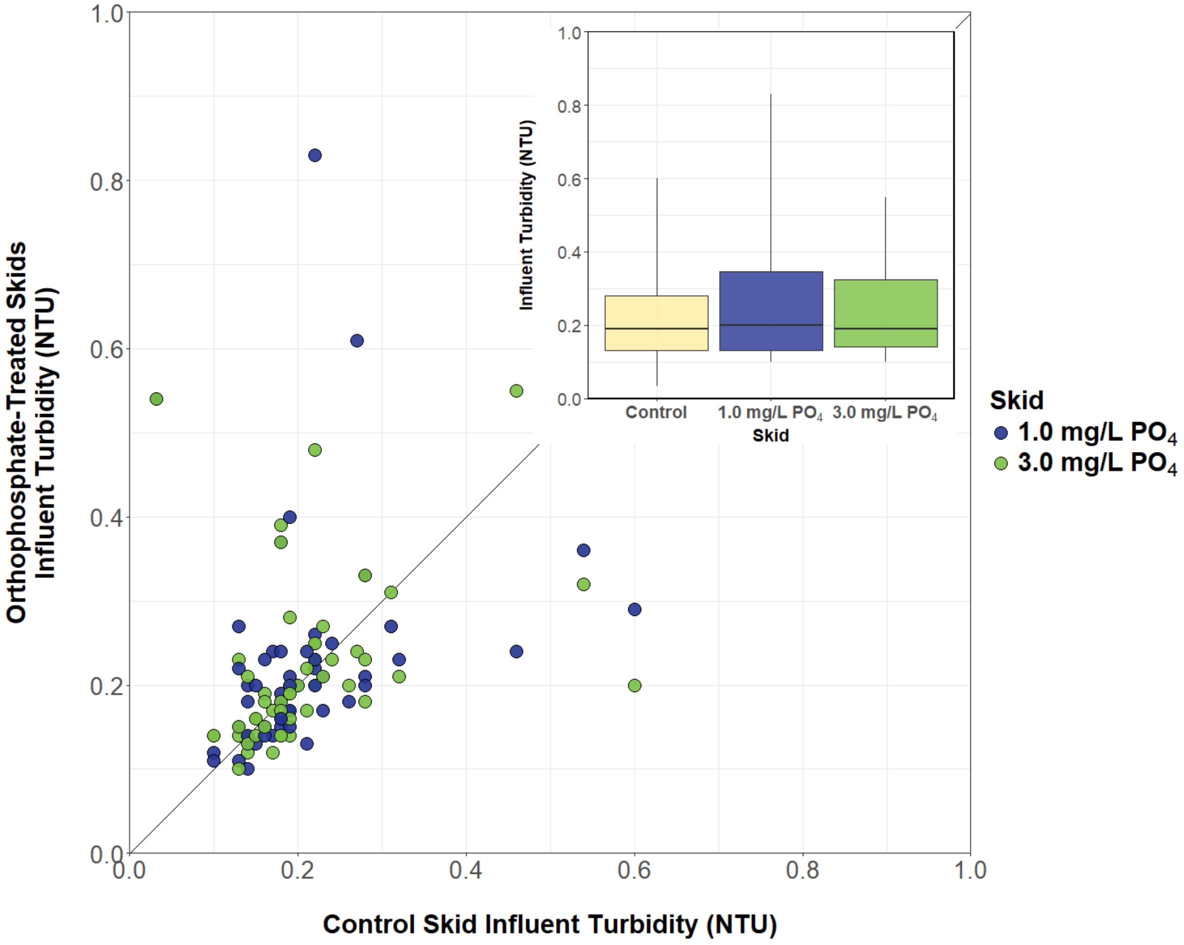


Figure 4-5 Differences in Influent Turbidity Distributions between Orthophosphate and Control Conditions.
Note: In the box plots, the horizontal line denotes the median, boxes represent the 10th and 90th percentiles, and vertical lines indicate the minimum and maximum observed values. Boxes overlap the whiskers when percentile ranges are similar to the minimum and maximum.

In contrast, effluent turbidity remained higher in the phosphate-treated systems for the copper pipes with lead solder only (p-value <0.05), indicating continued mobilization or formation of particulate material within these treated pipe loops (**Figure 4-6**). At an orthophosphate dose of 1.0 mg/L as PO_4, turbidity was estimated to be approximately 12% higher than that of the control, while at 3.0 mg/L as PO_4, turbidity was approximately 23% higher. These conditions may have promoted the formation of particulate material, resulting in elevated turbidity (See **Section 4.6**). In a bench-scale experiment using new copper pipes with lead–tin solder, Nguyen et al. (2011) observed similar behavior of increased particle formation in the presence of orthophosphate, attributed to the release of lead–tin particles and enhanced tin corrosion.

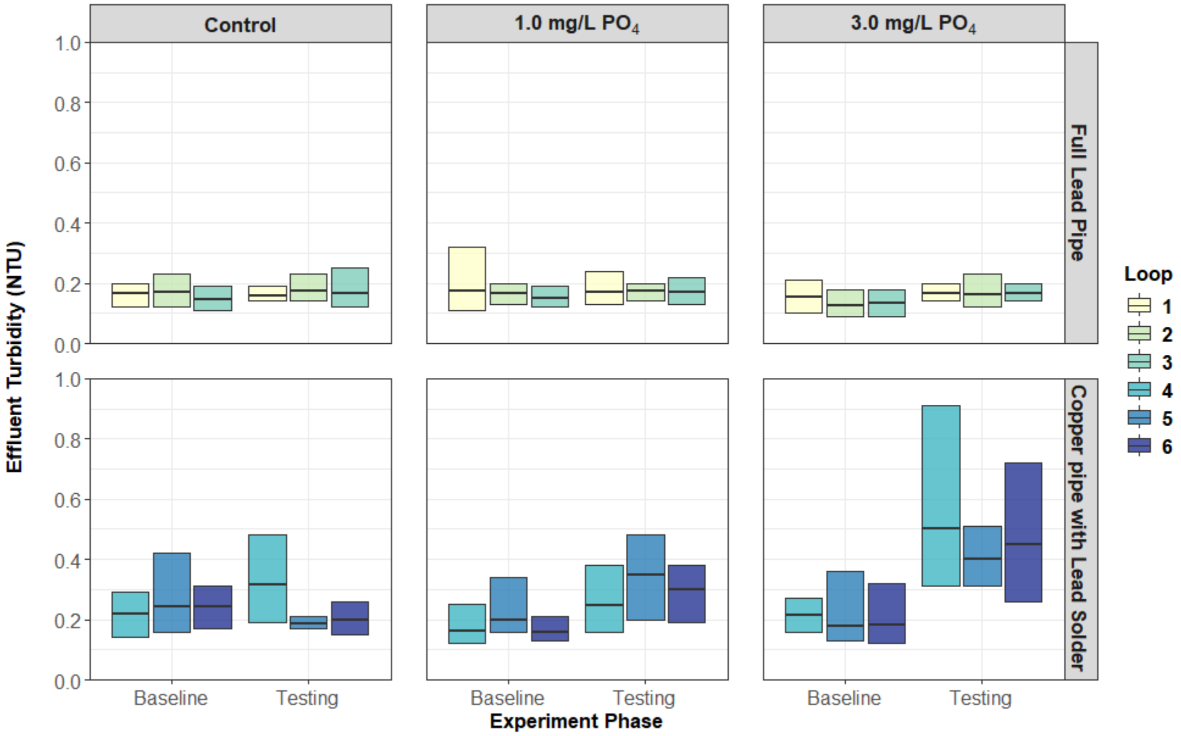


Figure 4-6 Effluent Water Quality: Turbidity

Note: The horizontal line denotes the median, boxes represent the 10th and 90th percentiles, and vertical lines indicate the minimum and maximum observed values. Boxes overlap the whiskers when percentile ranges are similar to the minimum and maximum.

4.3 Lead Release from Lead Pipes

In Conditioning Phase 3, the median total lead concentrations at the end of the phase ranged between 4.7 to 9.0 µg/L across all pipe loops (**Table 4-2**). These values are consistent with lead concentrations observed during WWW's most recent three sampling rounds, indicating that lead release from the pipe loops is representative of system conditions. There was one pipe, Loop 3 on the skid that would receive 3.0 mg/L as PO_4, with a median total lead concentration that was approximately 30% less than the average of the last seven lead concentrations measured in all other loops (4.7 vs 6.4 µg/L). Therefore, steady-state lead release at the end of the testing phase was compared to the baseline concentrations determined in Conditioning Phase 3. This comparison was performed separately for each pipe loop to assess the relative change in lead release under the test conditions.

Table 4-2 Comparison of Steady-State Total Lead Release from Lead Pipes during Conditioning Phase 3 and the Testing Phase

Experimental Condition	Loop	Conditioning Phase 3- Median Total Lead Release (10th to 90th percentile) (µg/L)	Testing Phase- Median Total Lead Release (10th to 90th percentile) (µg/L)
Control	1	9.0 (7.4 to 11)	9.4 (6.1 to 12)
Control	2	7.4 (6.7 to 8.4)	8.5 (6.9 to 14)
Control	3	5.9 (5.5 to 6.5)	7.5 (5.6 to 13)
1.0 mg/L PO_4	1	8.6 (7.4 to 10)	5.4 (3.4 to 6.2)
1.0 mg/L PO_4	2	6.9 (6.1 to 7.6)	6.1 (3,0 to 6.8)
1.0 mg/L PO_4	3	6.3 (5.8 to 7.2)	5.6 (3.0 to 6.3)
3.0 mg/L PO_4	1	6.5 (5.5 to 7.0)	4.4 (2.5 to 5.3)
3.0 mg/L PO_4	2	8.9 (7.6 to 10)	5.9 (1.5 to 6.4)
3.0 mg/L PO_4	3	4.7 (4.4 to 5.5)	2.0 (1.5 to 3.9)

Note: Reported lead concentrations represent the median concentrations of the last 7 weekly samples collected during each phase.

After transitioning to the testing phase, lead concentrations in the Control skid began to rise above the baseline established during Conditioning Phase 3, likely due to the decrease in pH following startup of the PFAS treatment system (**Figure 4-7**). Additionally, highly variable pH resulted in high lead concentrations between 20 to 150 µg/L between February to May 2025 (**Figure E-3, Appendix E**). Concentrations did not return to the levels observed during Conditioning Phase 3 for two of the control loops. By the end of the study phase, median lead concentrations in the Control skid were up to 27% higher than during Conditioning Phase 3. Moreover, the control loops exhibited greater variability in total lead release, as evidenced by the wider spread between the 10th and 90th percentiles (**Figure 4-8**).

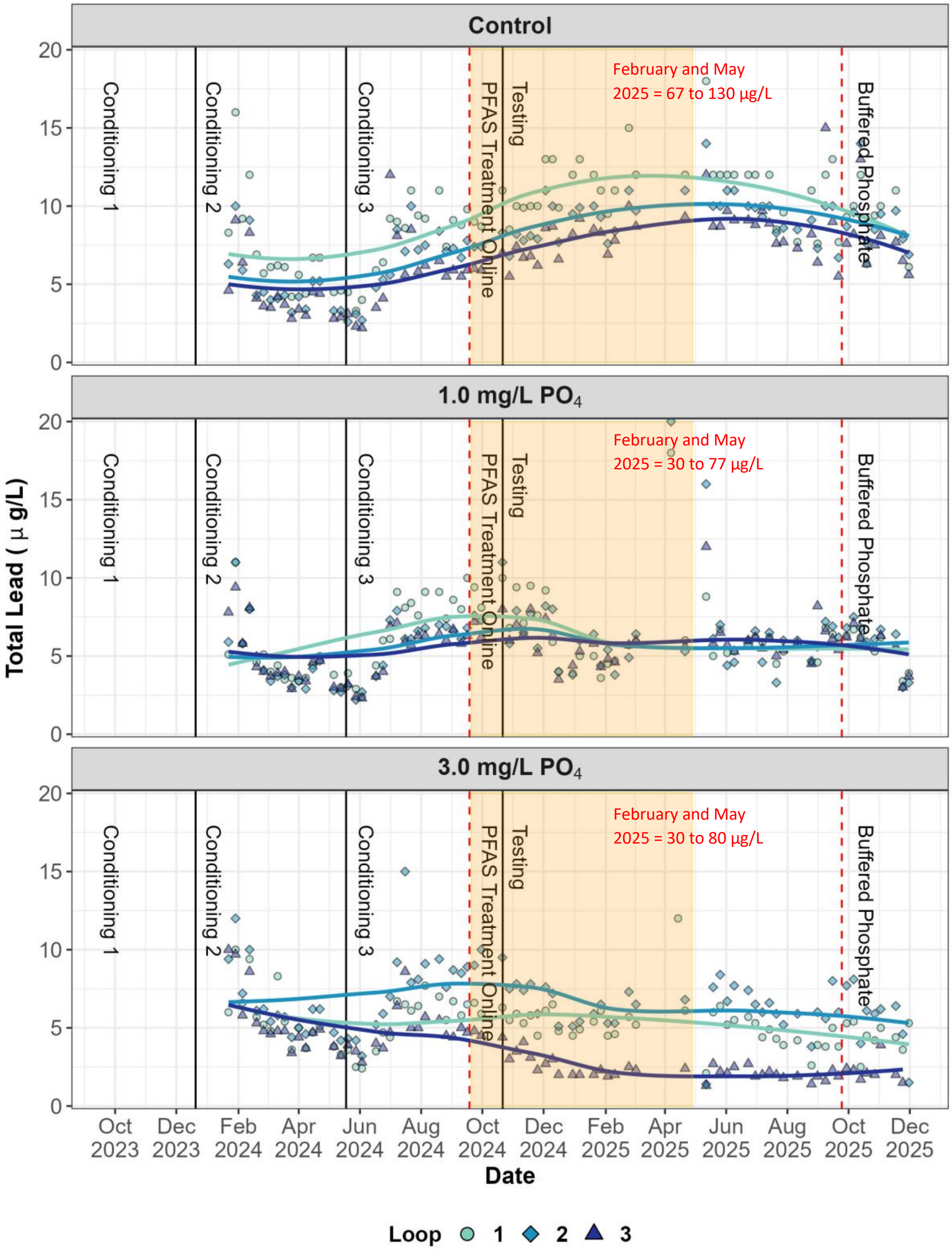


Figure 4-7 Lead Release from Harvested Lead Pipes

Note: Points represent raw data, and lines indicate trends estimate using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

In contrast, orthophosphate treatment reduced variability in total lead concentrations (**Figure 4-8**). Orthophosphate treatment also reduced total lead release relative to baseline conditions (**Figure 4-7**). In addition, total lead release was primarily dissolved, with particulate lead lower under orthophosphate treatment (**Appendix E**, **Figure E-4**). This indicates that the change in water chemistry associated with orthophosphate addition did not physically destabilize the existing pipe scale in a way that would promote the release of lead-containing particles. The predominance of dissolved lead also indicates that lead release with orthophosphate treatment is largely governed by solubility processes rather than particulate scale detachment. Under these conditions, lead concentrations may be more strongly influenced by water chemistry parameters such as orthophosphate residual and pH. As a result, optimizing orthophosphate dose or fine-tuning pH can be expected to influence lead concentrations in a more predictable manner.

At a dose of 1.0 mg/L as PO_4, median lead concentrations ranged from 5.4 to 6.1 µg/L (**Figure 4-8**). Under this condition, lead release was reduced by approximately 11% to 32% of the baseline, corresponding to relative a reduction in lead concentrations of 0.7 to 3.2 µg/L. At a dose of 3.0 mg/L as PO_4, median lead concentrations ranged from 2.0 to 5.9 µg/L with 32 to 57 % lower lead concentrations than the baseline (**Figure 4-8**). Lead release at 3.0 mg/L as PO_4 was approximately 8% lower than at 1.0 mg/L as PO_4, resulting in an additional reduction of 2.1 to 3.0 µg/L ($p\text{-value} < 0.05$). The 90th percentile lead concentrations under both orthophosphate treatment levels remained well below the upcoming 10 µg/L LCRI lead action level, with observed medians ranging from 3.9 to 6.8 µg/L.

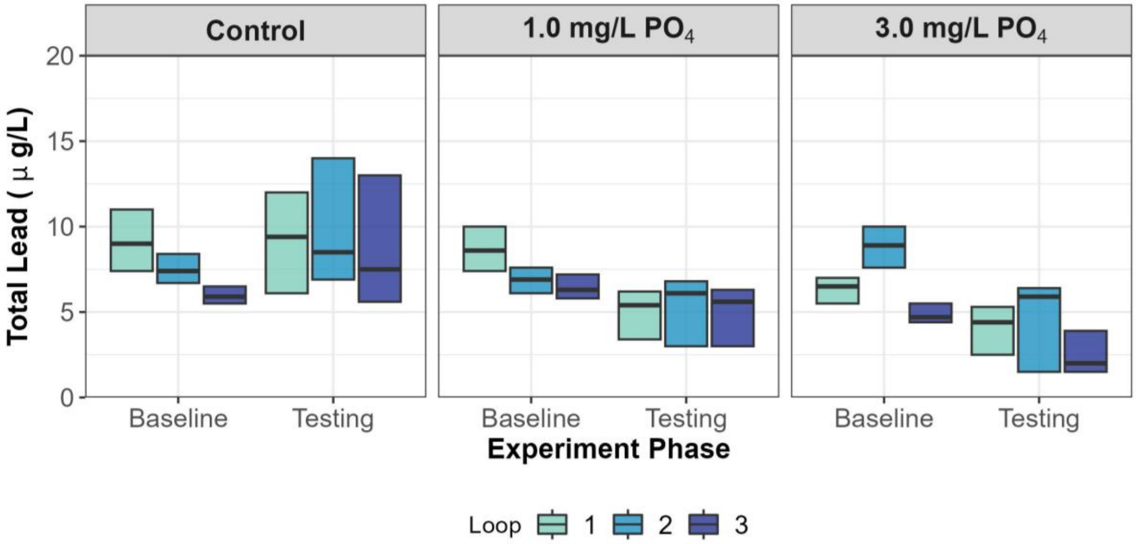


Figure 4-8 Comparison of Lead Release During Conditioning Phase 3 (Baseline) and the Testing Phase from Lead Pipes

Note: The horizontal line denotes the median, boxes represent the 10th and 90th percentiles, and vertical lines indicate the minimum and maximum observed values in the last 7 consecutive weekly samples. Boxes overlap the whiskers when percentile ranges are similar to the minimum and maximum.

4.4 Lead Pipe Scale Analysis

Pipe scale characterization was performed on four harvested temporary test sections at the end of the testing phase (approximately 59 weeks of orthophosphate treatment): two from the 1.0 mg/L PO_4

condition and two from the 3.0 mg/L PO_4 condition. The results were compared to previously characterized harvested LSL scale from the distribution system to evaluate similarities in mineralogy and scale development. A detailed scale analysis is provided in **Appendix F**.

Consistent with harvested LSL scales from the distribution system, scale material from all four test sections was predominantly amorphous. The outer layers were characterized by poorly crystalline, heterogeneous deposits rather than well-defined crystalline structures. Elemental analysis indicated that these amorphous layers contained aluminum and silicon, likely derived from treatment residuals. Manganese was detected across all test sections in one pipe from each test condition (one from 1 mg/L PO_4 and one from 3.0 mg/L PO_4). While not identified as a dominant mineral phase, its consistent detection indicates that it is an important secondary component of the scale. Phosphorus was detected in the scales of all four pipes via ICP-MS, consistent with orthophosphate addition during the study period. While phosphorus was present, its incorporation into discrete crystalline lead phosphate phases was limited.

The dominant crystalline mineral phases identified in the coupons were the lead(II) carbonates, cerussite ($PbCO_3$) and hydrocerussite [$Pb_3(CO_3)_2(OH)_2$]. In addition, iron oxide, primarily magnetite (Fe_3O_4), was identified in the pipe scale. The presence of cerussite and hydrocerussite is consistent with carbonate-controlled lead scale formation under conditions of moderate alkalinity and high pH. Lead phosphate, specifically hydroxypyromorphite [$Pb_5(PO_4)_3OH$], was identified as a minor mineral phase in Loop 1 (Pipe 2A in scale analysis report) receiving 3.0 mg/L PO_4. No well-defined lead phosphate minerals were identified in the remaining coupons.

4.5 Lead Release from Copper Pipes with Lead Solder

Median lead release from new copper pipes with new lead solder at the end of conditioning ranged from 140 to 280 µg/L (**Table 4-3**). Lead release from the copper pipes with lead solder was higher than what is typically observed in compliance tap samples. This result was expected because the pipe loops contain a much greater amount of exposed lead solder than is normally found in household plumbing. These higher lead levels were intentionally created to make the system more sensitive and allow a clearer evaluation of how different treatment conditions affect lead release.

Table 4-3 Comparison of Steady-State Total Lead Release from Copper Pipes with Lead Solder during Conditioning Phase 3 and the Testing Phase

Experimental Condtion	Loop	Conditioning Phase 3- Median Total Lead Release (10th to 90th percentile) (µg/L)	Testing Phase- Median Total Lead Release (10th to 90th percentile) (µg/L)
Control	4	280 (190 to 330)	260 (120 to 350)
Control	5	160 (130 to 210)	81 (49 to 170)
Control	6	180 (150 to 230)	110 (89 to 280)
1.0 mg/L PO_4	4	180 (130 to 250)	55 (40 to 100)
1.0 mg/L PO_4	5	170 (150 to 250)	120 (88 to 190)
1.0 mg/L PO_4	6	160 (130 to 200)	90 (74 to 130)
3.0 mg/L PO_4	4	240 (230 to 320)	95 (40 to 210)
3.0 mg/L PO_4	5	210 (160 to 220)	67 (45 to 210)
3.0 mg/L PO_4	6	140 (110 to 180)	79 (40 to 150)

Note: Reported lead concentrations represent the median concentrations of the last 7 samples collected during each phase.

Median total lead release at the end of the testing phase was lower than at the end of the conditioning phase, with reductions of up to 49% in the control system and up to 69% in the orthophosphate-treated systems. The notably lower lead concentrations observed in the control loops during testing in comparison to conditioning (range of medians = 160 to 280 µg/L versus 81 to 260 µg/L) suggests that continued exposure to the source water promoted the development of a more protective pipe scale over time in some of the loops, resulting in reduced lead release by the end of the experiment (**Figure 4-9**). Loop 4 in the control skid had similar lead levels during acclimation and testing. Given the substantially lower lead levels in the control skid, direct comparison of lead concentrations at the acclimation and testing phases of each pipe would not be able to separate the confounding effects of the additional passivation over time. Therefore, the ratio of median lead concentrations between the control and phosphate-added skids at the end of the testing phase was evaluated to more effectively assess relative treatment performance.

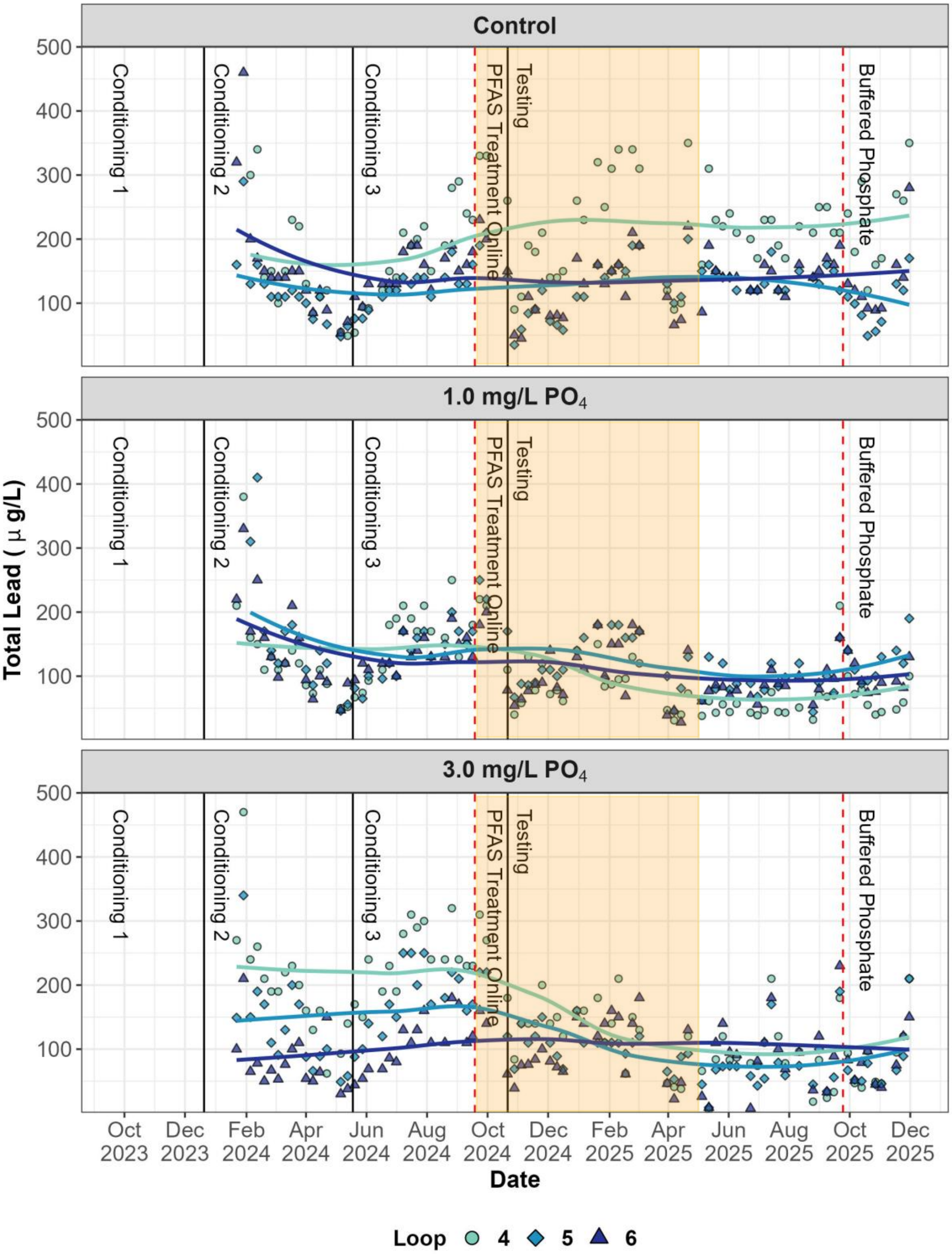


Figure 4-9 Lead Release from New Copper Pipes with Lead Solder

Note: Points represent raw data, and lines indicate trends estimated using non-parametric LOESS models. Elevated lead concentrations from new lead solder present the worst case. For clarity and readability, 4 extreme lead concentrations (> 500 µg/L) in the Control and 1.0 mg/L PO_4 Skids between January to February 2024 were not shown the figure. The orange box shows the period where pH variability was high due to the pumping issue.

Orthophosphate treatment reduced total lead release relative to the control, with an estimated reduction of approximately 30% with 1.0 mg/L as PO_4 dosed and approximately 40% with 3.0 mg/L as PO_4 dosed (**Figure 4-10**). Despite the lower median observed at the higher orthophosphate dose, total lead release was not significantly different between the 1.0 and 3.0 mg/L as PO_4 orthophosphate treatments (p-value = 0.43, ratio of medians = 0.92, 95% CI = 0.7 to 1.2). However, the higher orthophosphate dose resulted in a larger variability in total lead concentrations across the pipe loops (**Figure 4-10**).

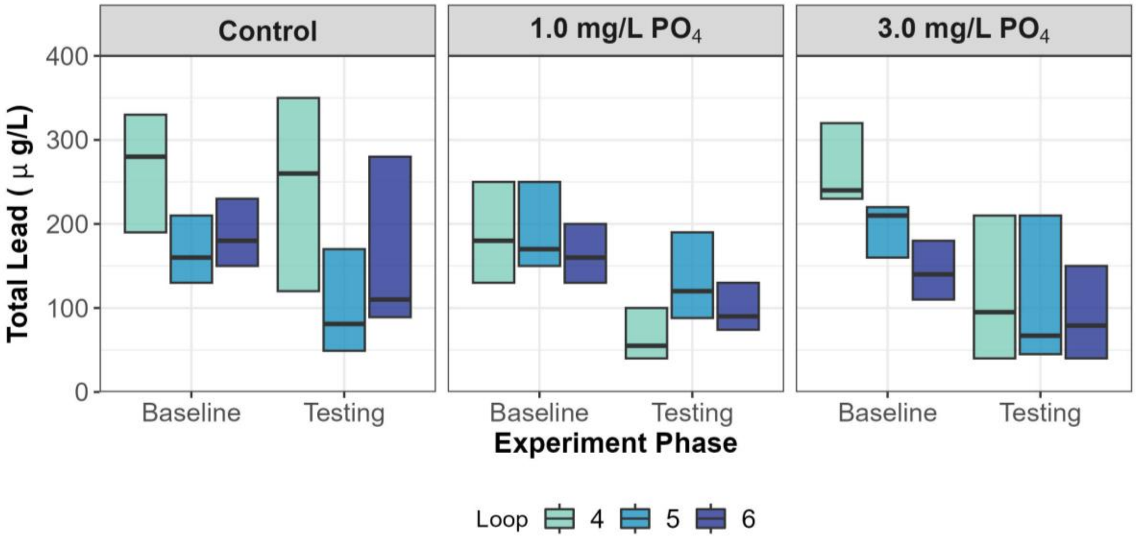


Figure 4-10 Comparison of Lead Release During Conditioning Phase 3 (Baseline) and the Testing Phase from Copper Pipes with Lead Solder

Note: The horizontal line denotes the median, boxes represent the 10th and 90th percentiles, and vertical lines indicate the minimum and maximum observed values in the last 7 consecutive weekly samples. Boxes overlap the whiskers when percentile ranges are similar to the minimum and maximum.

Notably, the 3.0 mg/L as PO_4 treatment resulted in a higher particulate lead fraction compared to the 1.0 mg/L as PO_4 treatment (**Figure 4-11**), which may have also resulted in higher turbidity (**Figure 4-6**). Increased particulate and colloidal lead may have important implications for lead control, as these forms can be more mobile, contribute to episodic lead spikes, and may not be effectively removed by some point-of-use (POU) filters, particularly those designed primarily for dissolved lead removal.

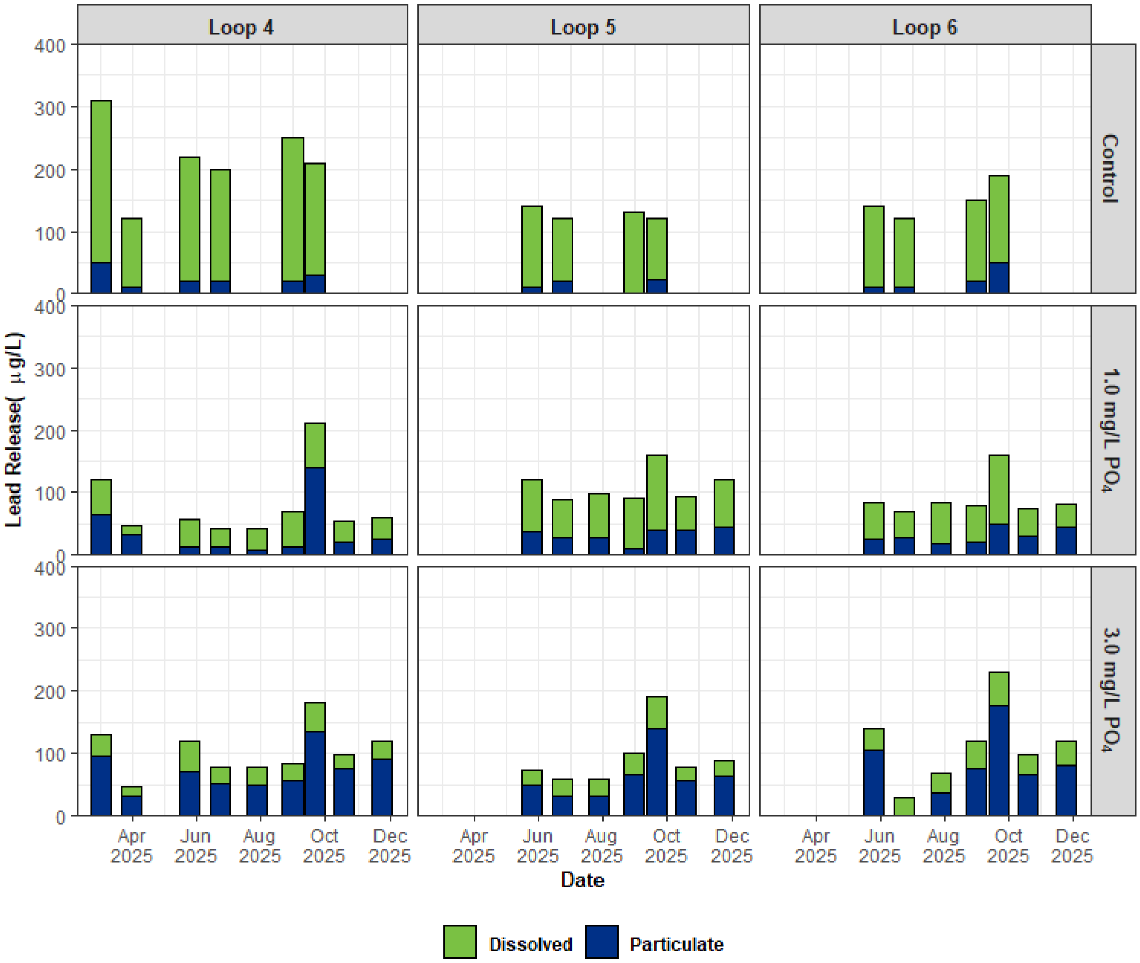


Figure 4-11 Dissolved and Particulate Lead from Copper Pipes with Lead Solder Under Orthophosphate and Control Conditions

4.6 Copper Release from Copper Pipes with Lead Solder

Median copper release from new copper pipes with new lead solder ranged from 12 to 19 µg/L at the end of conditioning (**Table 4-4**). These values are consistent with copper concentrations observed during WWW's most recent three sampling rounds and 1st liter samples collected in 2022 and 2024, indicating that copper release from the pipe loops is representative of system conditions.

Table 4-4 Comparison of Steady-State Total Copper Release from Copper Pipes with Lead Solder during Conditioning Phase 3 and the Testing Phase

Experimental Condtion	Loop	Conditioning Phase 3- Median Total Copper Release (10th to 90th percentile) (µg/L)	Testing Phase- Median Total Copper Release (10th to 90th percentile) (µg/L)
Control	4	12 (10 to 14)	9.9 (6.9 to 18)
Control	5	13 (12 to 17)	10 (5.6 to 17)
Control	6	14 (13 to 18)	12 (8.3 to 20)
1.0 mg/L PO_4	4	13 (10 to 14)	12 (9.7 to 22)
1.0 mg/L PO_4	5	14 (12 to 18)	12 (10 to 25)
1.0 mg/L PO_4	6	15 (11 to 17)	13 (9.3 to 20)
3.0 mg/L PO_4	4	17 (13 to 19)	19 (14 to 37)
3.0 mg/L PO_4	5	16 (14 to 20)	19 (14 to 38)
3.0 mg/L PO_4	6	19 (15 to 21)	18 (14 to 29)

Note: Reported copper concentrations represent the median concentrations of the last 7 samples collected during each phase.

Copper concentrations increased sharply at the start of the testing phase (**Figure 4-12**). This increase could not be directly attributed to test conditions or operational changes within the pilot system. During this period, influent water pH from the full-scale WTP was highly variable, which likely destabilized existing copper pipe scale and resulted in transient spikes in effluent copper concentrations, with maximum values observed up to approximately 140 µg/L.

The effect was more apparent in the orthophosphate-treated skids, where the addition of orthophosphate resulted in a larger pH decrease relative to the control (**Appendix E, Figure E-1**). This response was particularly pronounced at the 3.0 mg/L PO_4 dose, resulting in the highest copper concentrations observed. As influent pH variability was addressed and stabilized, copper concentrations declined across all skids (**Figure 4-12**). However, median copper levels in the 3.0 mg/L PO_4 skid did not return to pre-pH disturbance concentrations (18-19 compared to 16-19 pre-pH disturbance), likely due to the magnitude of the disturbance from the pH shift and the limited time available for re-stabilization during the short testing period. Notably, copper concentrations remained very low overall, regardless of treatment, suggesting that effective copper corrosion control may rely more on maintaining consistent water quality than on the presence of orthophosphate.

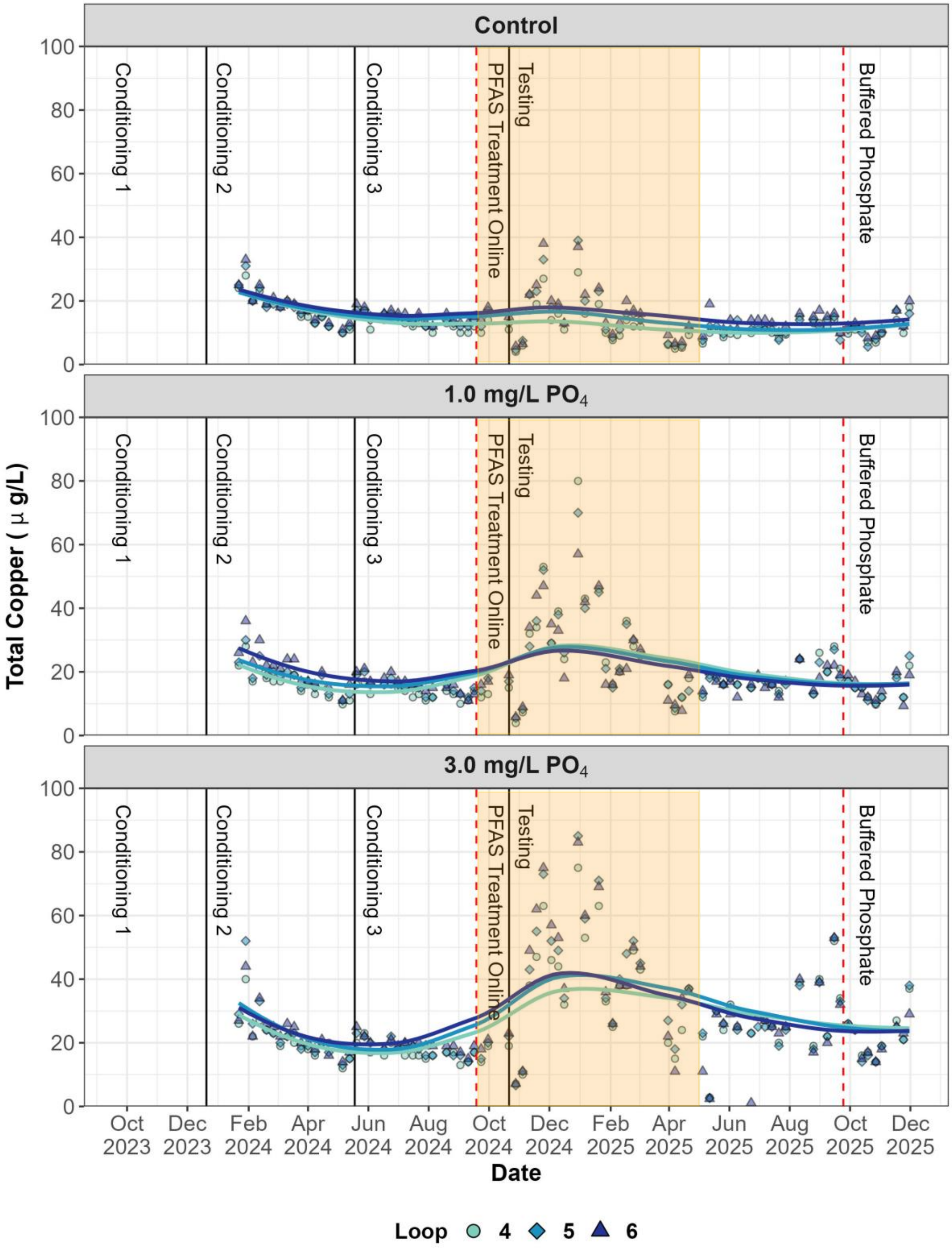


Figure 4-12 Copper Release from New Copper Pipes with Lead Solder

Note: Points represent raw data, and lines indicate trends predicted using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

By the end of the testing phase, copper concentrations in the control skid (median = 12 µg/L; 10th–90th percentile = 7–21 µg/L) and the skid receiving 1.0 mg/L as PO_4 (median = 18 µg/L; 10th–90th percentile = 11–37 µg/L) returned to levels similar to those observed during the acclimation period (**Figure 4-13**). In contrast, the skid receiving 3.0 mg/L as PO_4 exhibited higher copper concentrations at the end of testing (median = 26 µg/L; 10th–90th percentile = 15–53 µg/L). Due to the coincident timing of orthophosphate addition and substantial influent pH variability at the beginning of the testing phase, the individual effects of orthophosphate treatment and pH on copper release could not be independently resolved. However, copper concentrations remained well below the LCR or LCRI copper action level (1,300 µg/L). Therefore, orthophosphate addition is not anticipated to adversely impact copper corrosion compliance.

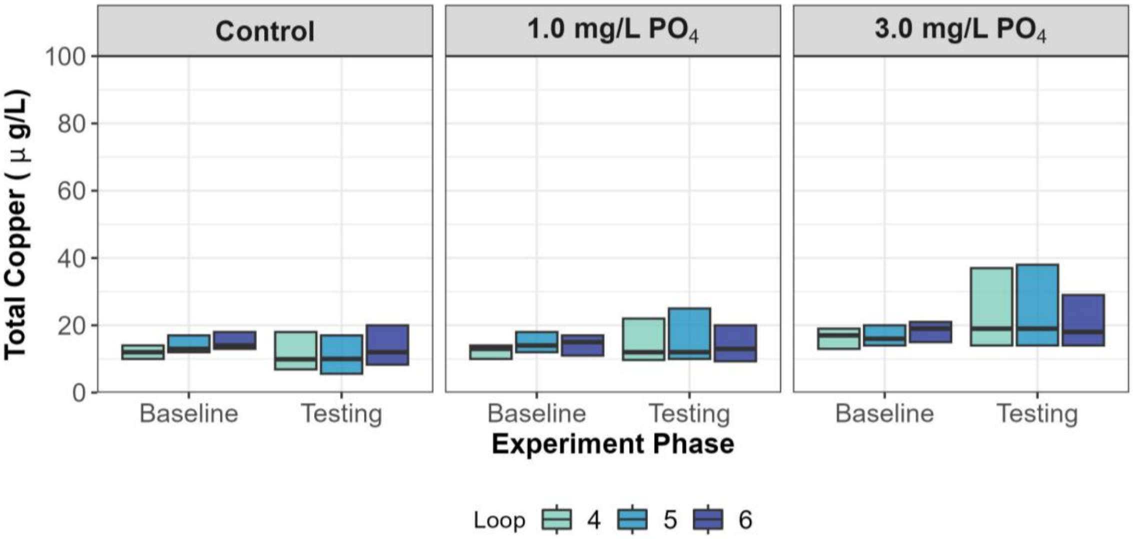


Figure 4-13 Comparison of Copper Release During Conditioning 3 and Testing from Copper Pipes with Lead Solder

Note: The horizontal line denotes the median, boxes represent the 10th and 90th percentiles, and vertical lines indicate the minimum and maximum observed values. Boxes overlap the whiskers when percentile ranges are similar to the minimum and maximum.

4.7 Summary of Pipe Loop Results

Dosing orthophosphate did not significantly impact key water quality parameters such as total alkalinity, total hardness, silicate, chloride, and sulfate. At the start of the testing phase, variable influent pH and orthophosphate dosing resulted in spikes in turbidity and metal concentrations. Elevated turbidity can indicate the mobilization of particulate-bound lead and copper, which contributes to increased total metal concentrations even when dissolved levels are low. Sporadic turbidity spikes suggest that pipe scales were destabilized, particularly during periods of pH depression or fluctuating phosphate dosing. These observations highlight the importance of maintaining a stable pH and consistent orthophosphate residuals to promote the formation of adherent, passivating scales, minimize particulate release, and maintain overall metal stabilization in the distribution system.

For harvested lead pipes, orthophosphate treatment at 1.0 mg/L as PO_4 reduced lead release by approximately 11 to 37% of the baseline levels. Treatment at 3.0 mg/L as PO4 reduced lead release by approximately 32 to 57% compared to the baseline. In addition, the 3.0 mg/L as PO_4 treatment reduced lead by approximately 8% compared to 1.0 mg/L as PO_4. Despite these differences between the two orthophosphate doses, 90th percentile lead concentrations from the last seven consecutive weekly samples under both orthophosphate treatment levels remained well below the upcoming LCRI action level of 10 µg/L, with observed concentrations ranging from 3.9 to 6.8 µg/L.

Overall, pipe coupon mineralogy under both 1.0 mg/L and 3.0 mg/L PO_4 conditions was broadly similar to harvested LSL scales from the distribution system, with predominantly amorphous surface layers and dominant lead carbonate minerals (cerussite and hydrocerussite), along with iron oxide (magnetite). Phosphorus was present in all scales; however, crystalline hydroxypyromorphite was only detected as a minor phase in one 3 mg/L PO_4 coupon. The limited occurrence of crystalline lead phosphate minerals, even under 3 mg/L PO_4 dosing, may be attributed to several factors:

- High pH and Moderate Alkalinity: Under the finished water conditions evaluated, carbonate equilibria favor the stability of lead carbonate phases such as cerussite and hydrocerussite. orthophosphate may adsorb to existing scale surfaces or incorporate into amorphous layers rather than forming discrete crystalline phosphate minerals.
- Short Experimental Duration: Formation of the well-crystalline lead phosphate solid hydroxypyromorphite can require extended contact time to allow for the gradual transformation to more stable phosphate minerals. In early-stage orthophosphate addition, phosphorus is often incorporated into amorphous or poorly crystalline phases before transforming into identifiable crystalline phosphate minerals. Therefore, the limited detection of crystalline lead phosphate phases likely reflects kinetic constraints rather than an absence of phosphate interaction with the scale.
- Detection Level of Crystalline Phases: In order to be detectable by XRD, a crystalline solid usually needs to represent about 5% by mass of the materials in a sample. While crystalline lead phosphate solids may have formed, for the duration of the test phase, they may not have yet been detectable in most scales. Even once lead phosphate solids do form on pipes that originally contained lead carbonate solids, the lead carbonate solids can remain as the predominant solids with a relatively thin layer of lead phosphate solids in contact with the water and controlling lead concentrations at relatively low values.

For lead release in copper pipes with lead solder, orthophosphate treatment reduced total lead release relative to the control condition, with an estimated reduction of approximately 30% at 1.0 mg/L as PO_4 and approximately 40% at 3.0 mg/L as PO_4. Although a lower median total lead concentration was observed at the higher orthophosphate dose, the difference in total lead release between the 1.0 and 3.0 mg/L as PO_4 treatment levels was not significantly different (Wilcoxon p-value = 0.69). Therefore, it is not anticipated that a dose of orthophosphate above 1.0 mg/L will provide significant long-term benefits to mitigating lead release from galvanic corrosion. Furthermore, the higher orthophosphate dose resulted in an increased fraction of particulate lead relative to total lead. Particulate and colloidal lead can be more difficult to remove, contribute to episodic spikes, and may not be effectively captured by POU filters designed for dissolved lead reduction.

Copper concentrations remained well below the LCR and upcoming LCRI action level of 1,300 µg/L, indicating that orthophosphate addition is not expected to adversely impact copper corrosion compliance. Copper concentrations spiked at the start of testing, likely due to influent pH variability that likely destabilized copper pipe scale, with larger increases in the orthophosphate-treated skids, particularly at 3.0 mg/L as PO_4. As pH stabilized, copper levels declined across all skids. By the end of testing, median copper concentrations were 12 µg/L (10th – 90th percentile: 7–21 µg/L) in the control skid, 18 µg/L (10th – 90th percentile: 11–37 µg/L) in the skid receiving 1.0 mg/L as PO_4, and 26 µg/L (10th – 90th percentile: 15–53 µg/L) in the skid receiving 3.0 mg/L as PO_4.

5.0 Summary and Recommendations

5.1 Summary and Key Considerations

Following WWW's transition to a new WTP, most water quality parameters remained similar. Alkalinity and hardness remained similar to pre-transition levels. While chloride and sulfate concentrations decreased, the CSMR increased under the New WTP, ranging from 5.8 to 29 compared to 1.6 to 7.5 at the Old WTP. The increase in CSMR indicates a heightened potential for galvanic corrosion within WWW's distribution system.

While WWW has maintained compliance with the LCR since 2015, changes to finished water quality as well as the more stringent upcoming LCRI regulation prompted proactive evaluation of potential impacts using sequential samples collected in 2022 and 2024. Lead and copper concentrations were lower under the New WTP water quality. These results suggest that the New WTP did not negatively impact lead and copper corrosion from sites with LSLs.

However, the more stringent sampling requirements under the LCRI resulted in higher reported lead levels when the 5th liter is used for compliance. In this limited study, 5th liter concentrations were an estimated 4.2 times greater than the 1st liter concentrations on average, with a 90th percentile concentration of 19.2 µg/L. Note that this dataset is limited. While it is useful for estimating the direction of potential impacts, it does not provide a definitive magnitude of lead concentrations in compliance samples.

To characterize existing lead corrosion scales, pipe scale analyses were performed on four harvested LSLs in the distribution system, including one collected in 2022, two collected in 2024, and one collected in 2025. The analysis yielded the following results:

- The most dominant crystalline phases in the 2022 and 2024 pipe segments were the lead carbonate solids cerussite and hydrocerussite. These were also present in the 2025 pipe segments, along with calcite and magnetite. Amorphous (i.e., non-crystalline and consequently not identifiable by XRD) materials were also abundant in the pipe scales.
- Calcite was the most dominant mineral present in the 2025 pipe segments.
- Aluminum was consistently found in the pipe scale. Some pipes also contained silicon, manganese, zinc, phosphorus, and calcium, likely reflecting contributions from treatment chemicals (e.g., silicate, aluminum coagulant) and source water (e.g., phosphorus, manganese, calcium).

The results of the pipe scale analysis from harvested LSLs in the distribution system did not display any significant differences in the pipe scales that could be due to the new WTP.

To address the increase in CSMR, potential increase in 90th percentile lead concentrations associated with LCRI's 5th liter sampling, and identify ways to reduce lead release, the pipe loop study evaluated orthophosphate addition as a corrosion control strategy using WWW's finished water in a controlled pipe loop system. Specifically, the study compared orthophosphate doses of 1.0 and 3.0 mg/L as PO_4

against existing treatment, assessed changes in lead and copper release from harvested lead service lines and simulated premise plumbing, characterized corrosion scale mineralogy, and identified any water quality impacts associated with orthophosphate addition.

Table 5-1 presents a summary of findings from the pipe loop study and key considerations for WWW. Orthophosphate at 1.0 mg/L as PO_4 improved lead release in both harvested lead pipes and copper pipes with lead solder. Increasing the dose to 3.0 mg/L as PO_4 provided only marginal additional benefits and increased turbidity in copper pipes with lead solder. This increase in lead particulates and turbidity may be related to characteristics of the experimental pipe construction, particularly the larger exposed solder surface area than would typically occur in premises plumbing, or destabilization of pipe scale from highly variable pH between October 2024 to May 2025. As a result, the observed turbidity response may reflect study-specific conditions rather than an effect that would necessarily be expected during full-scale orthophosphate addition. However, it may be prudent to evaluate turbidity and related water quality parameters through monitoring if orthophosphate treatment is implemented. In the lead pipe loops, mineralogy of the pipe coupons from both 1.0 mg/L and 3.0 mg/L PO_4 conditions was similar to LSL harvested from the distribution system, consisting primarily of amorphous surface layers with dominant lead carbonate phases (cerussite and hydrocerussite) and iron oxide (magnetite). Phosphorus was detected in all scales; however, crystalline hydroxypyromorphite was identified only as a minor phase in one coupon receiving 3.0 mg/L PO_4.

These results indicate that while orthophosphate was incorporated into the scale, short-term exposure during the testing resulted in limited conversion of carbonate minerals to stable crystalline lead phosphate phases. Longer-term contact time may be necessary to promote transformation of the top layer toward more protective phosphate-based mineralogy. However, this transformation does not always occur fully in distribution systems (Tully, DeSantis and Schock, 2019). Even so, low lead concentrations have been observed even when complete mineralogical transformation does not occur (Aghasadeghi et al., 2021; Tully, DeSantis and Schock, 2019).

While orthophosphate improved lead and copper control in the pipe loops, its addition can affect other water quality and operational aspects of the water and wastewater system. Orthophosphate added at the water treatment plant may need to be removed at wastewater treatment plants to protect receiving waters from excess nutrient loading. Phosphorus can also promote biological growth, as it is a limiting nutrient for algae in many aquatic systems. All of these factors should be considered alongside the corrosion control benefits of orthophosphate when determining whether to implement phosphate treatment and when selecting an appropriate target dose.

Table 5-1 Summary and Key Considerations from the Pipe Loop Study

Parameter	Harvested Lead Pipes	Copper Pipe with Lead Solder	Key Considerations
pH	Phosphoric acid decreased pH by approximately 0.2 S.U. in the 1.0 mg/L as PO_4 skid and by 0.4 S.U. in the 3.0 mg/L as PO_4 skid		Full-scale phosphoric acid implementation may require pH control; existing WTP can support pH adjustment.
Turbidity	No impact of orthophosphate	Compared to the control, effluent turbidity was 12% and 23% higher in with 1.0 and 3.0 mg/L as PO_4, respectively.	Increasing orthophosphate above 1.0 mg/L as PO_4 can result in increased turbidity and associated lead particle release (see **Section 4.4**)
Lead Release	Lead release was reduced by 11% to 37% of the baseline at 1.0 mg/L as PO_4 (median lead = 5.4 to 6.1 µg/L), with a further ~8% reduction at 3.0 mg/L as PO_4 (median lead = 2.0 to 5.9 µg/L). Median lead concentrations under the control ranged between 7.5 to 9.4 µg/L (90th percentile = 12 to 14 µg/L). Under orthophosphate treatment, median lead concentrations ranged between 2.0 to 6.2 µg/L and were well below the 10 µg/L LCRI action level at both orthophosphate doses (90th percentile= 3.9 to 6.8 µg/L), indicating minimal benefit from orthophosphate dosing above 3.0 mg/L as PO_4.	Total lead release decreased by approximately 30% at 1.0 mg/L and 40% at 3.0 mg/L as PO_4; the difference between doses was not statistically significant. 3.0 mg/L as PO_4 increased the particulate lead fraction relative to 1.0 mg/L as PO_4.	Orthophosphate at 1.0 mg/L as PO_4 decreased lead in comparison to the control condition. However, a 3.0 mg/L as PO_4 dose increased particulate lead from copper pipes with lead solder.
Copper Release	Not applicable	1.0 mg/L as PO_4 did not significantly impact copper concentrations 3.0 mg/L as PO_4 resulted in higher copper concentrations with larger variability likely due to the variable pH seen in the full scale WTP and larger pH depression experienced with phosphoric acid addition.	Orthophosphate provided little benefit to copper corrosion control in the pipe loop study.

5.2 Recommendations

Based on the results of the pipe loop study, CDM Smith recommends the following:

- To further evaluate lead phosphate scale formation and better understand the long-term mechanism of lead corrosion control, it is recommended to conduct additional pipe loop scale analyses in April to June of 2026.
- To reduce lead concentrations at the tap, it is recommended to add orthophosphate and maintain a residual of 1.0 mg/L as PO_4 at the entry point. This can be done gradually following the development of a transition plan.
- It is recommended to design the phosphate chemical system for full-scale implementation for a dose of 3.0 mg/L as PO_4 in the event that the orthophosphate dose needs to be increased. Conceptual design for this improvement is not included as part of this project and may be undertaken separately in the future.
- WWW is recommended to develop a full-scale transition plan to enable phased orthophosphate implementation and monitor water quality impacts.
- It is recommended to maintain the pipe loops under the current flow and stagnation patterns, with minimal sampling (e.g., once per month) to serve as a sentinel monitoring system if orthophosphate is implemented. Maintaining these loops provides a practical way to track potential changes in metal release over time. Because the loops contain already conditioned pipes, they represent a valuable resource for ongoing monitoring and evaluation of corrosion control performance.
- WWW may consider using the existing pipe loops to evaluate the impact of removing the sodium silicate on corrosion control and metal release.

6.0 References

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Appendix A Desktop Modeling Analysis

CDM Smith

Technical Memorandum - DRAFT

To: *Wausau Water Works*

From: *CDM Smith*

Date: *August 21, 2023*

Subject: *TM2 – Desktop Modeling Analysis*

Wausau Water Works (WWW) retained CDM Smith to evaluate corrosion control treatment (CCT) options and prepare a recommendations report. CDM Smith reviewed data from WWW in a Technical Memorandum 1 – Data Collection. CDM Smith reviewed existing (from the WTP previously in use) and recently collected (from the new WTP, data available starting in January 2023 up to May 2023) raw and treated (finished) water quality data for the treatment and distribution system and completed a desktop review of corrosion control alternatives.

Introduction

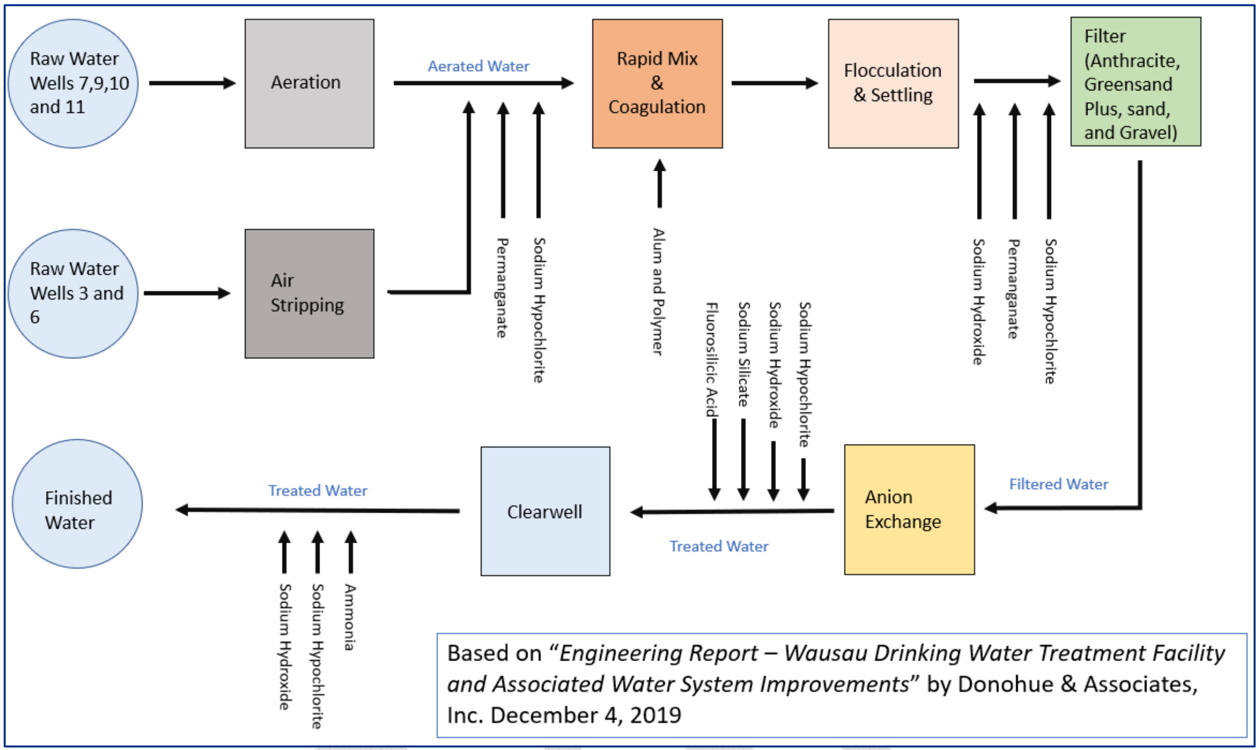
Purpose

As part of this evaluation, CDM Smith:

- reviewed historical water quality data and information;
- conducted a desktop water quality review, including a lead solubility review for the new finished water quality; and
- developed recommendations for next testing steps.

Water System Description

WWW has transitioned to a new Potable Water Treatment Facility that includes significant process changes that may change finished water chemistry, shown in the process flow diagram in **Figure 1**. This new facility went online on December 20th, 2022. Associated water chemistry changes may impact the effectiveness of existing CCT. The Wisconsin Department of Natural Resources (WDNR) required the WWW to complete a demonstrative CCT study using the new finished water and then submit a report identifying the optimal CCT strategy.



Based on "*Engineering Report – Wausau Drinking Water Treatment Facility and Associated Water System Improvements*" by Donohue & Associates, Inc. December 4, 2019

Figure 1. Process flow diagram for WWW new water treatment facility.

Review of Existing Water Quality Data and Information

Historical Lead Results

The results from the LCR first liter sampling from 1999 through 2020 are summarized in **Error! Reference source not found.**. Note that the Utility exceeded the action level (15 µg/L) three times since 1992, though it should be noted that the 2006 sampling event only included one sample site (while other years typically included from 10 to 60 sites). The Lead and Copper Rule Revisions (LCRR)[1] will impose a new trigger limit of 10 µg/L sampled from the fifth liter for lead service lines, taking effect in 2024. Exceeding the trigger limit requires WWW to establish an annual goal for LSL replacements with the WDNR. Additionally, the change to sampling from the fifth liter instead of the first liter is anticipated to increase the lead sampling results. While WWW only has one action level exceedance from a regular sampling period (1992), there are a few sampling periods that were above the proposed trigger level in the first liter sampling (which at many sample sites will be

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[1] https://www.epa.gov/ground-water-and-drinking-water/proposed-revisions-lead-and-copper-rule

lower than the water sampled from the fifth liter). The action level concentration limit of 15 µg/L and trigger level of 10 µg/L are indicated on **Figure 2** for comparison with the monitoring results.

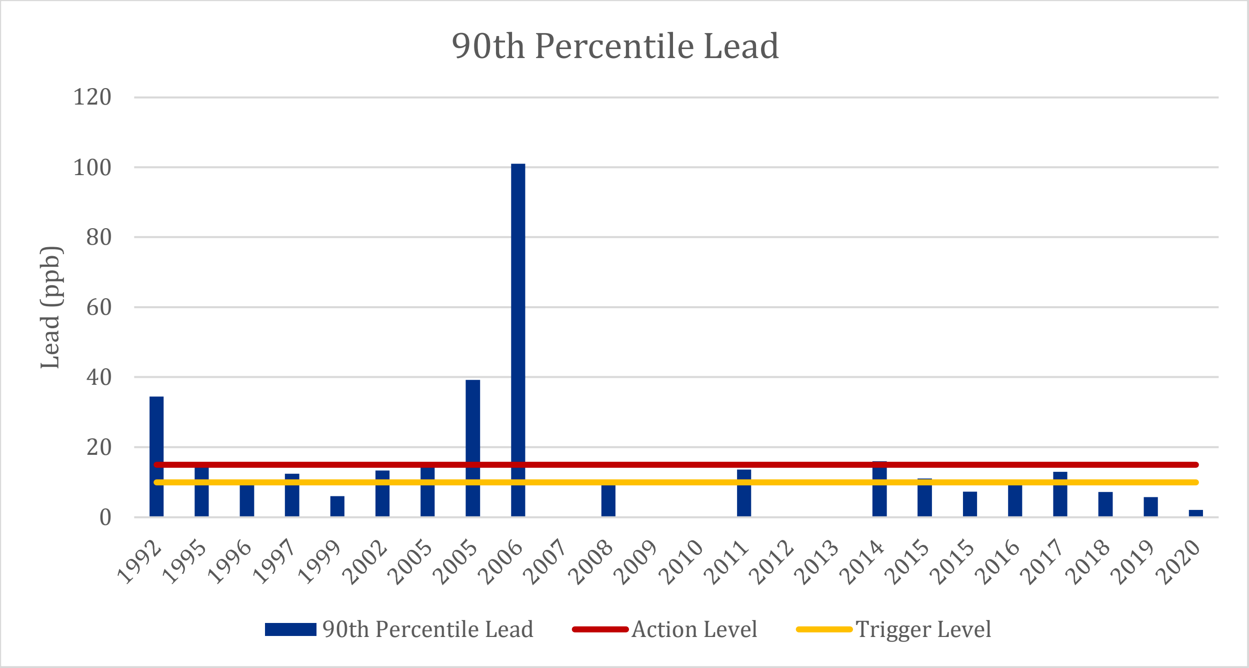

Figure 2. Lead compliance sampling (first liter) for sampling periods from 1992 to 2020. The action level and proposed trigger levels are shown in red and gold lines, respectively. The LCRR changes lead sampling from the first liter to the fifth liter, which is expected to increase the measured lead concentration for most utilities.

The LCRR also change the procedures for compliance sampling. Under the new revisions, samples from lead service lines are collected from the fifth liter of water rather than the first liter from the tap. **Figure 3** shows recent sequential sampling results. In the samples shown, the median concentration of lead in the fifth liter is 7 µg/L while the median of the first liter is 2 µg/L, indicating that WWW may encounter samples that are above the action level in the 5th liter, but were not above the action level the first liter. This change to the sampling procedure is likely to result in a higher 90th percentile of lead levels in future sampling periods. Additionally, the lead levels in a sequential sample may reach their peak in liters after the fifth liter (Site 4 as an example).

While this is not significant from a compliance perspective, conditions like this should still be monitored for corrosion control treatment optimization.

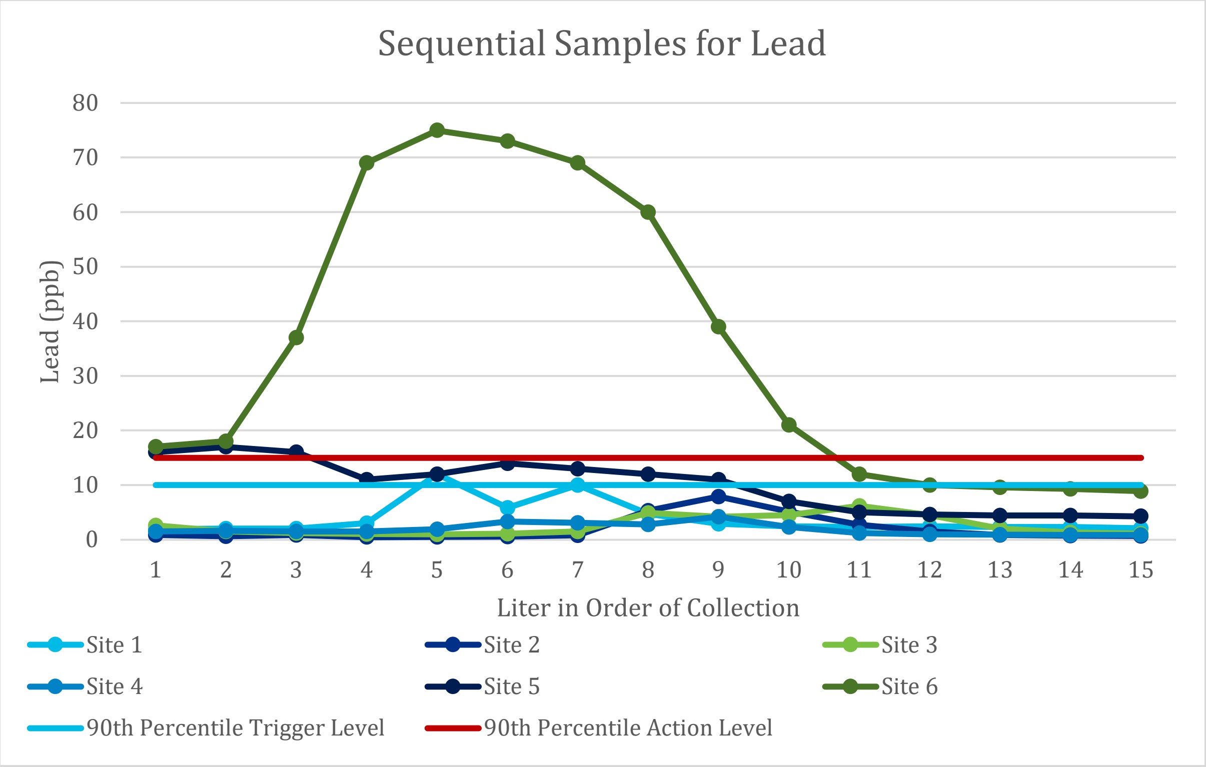

Figure 3. Sequential sampling results for lead. Action level and trigger levels are shown in red and gold,

Historical Copper Results

WWW has maintained copper levels well below the LCR action level. The 90th percentile for copper has been well below the 1300 µg/L action level. Thus, this evaluation does not include consideration of approaches to minimizing copper solubility.

Water Quality Data From the Previous WTP

Table 1 summarizes WWW's water quality from the previous WTP. Data was provided for 2021 and 2022 for raw and finished water, except for some raw water (source water is groundwater) parameters for which data was only available for 2017 (calcium, alkalinity, and TDS).

Table 1. Raw and Finished Water Quality Data

	TDS[2] (mg/L)	pH	Alkalinity (mg/L)	Calcium (mg/L)	Temperature (°C)	Chloride (mg/L)	Sulfate (mg/L)	Magnesium (mg/L)	TOC (mg/L)	Turbidity (NTU)
	Raw Water									
Average	210	7.25	64	19	N/A	N/A	N/A	6	5	2.7
	Finished Water									
Average	129	8.70	83	26	N/A	31	12	4.7	N/A	N/A

pH and Alkalinity

The nature and formation of lead corrosion products is strongly influenced by alkalinity and pH. Alkalinity, as a measurement, is pH dependent and mostly comes from carbonate and bicarbonate ions in the water. However, it can be used as a surrogate measurement for dissolved inorganic carbon (DIC). DIC indicates the amount of carbonate species available to react with lead to form lead carbonate scale. In the absence of orthophosphate corrosion control, lead carbonates are a dominant factor controlling lead release. Alkalinity is also an indicator of how stable the pH of the treated water will be under varying quality conditions. Water with higher alkalinity will have more buffering capacity and more stable pH. Alkalinity affects both the stability of the treated water pH in the distribution system and how difficult it would be to alter the pH in the treatment process.

Typically, it is recommended that pH swings do not exceed 0.2 units from day to day. Daily data were not provided for pH, but **Figure 4** shows monthly pH data for raw water, finished water, and the distributed water. The moderately high alkalinity indicates that the water provides good pH buffering. Overall, WWW experiences relatively consistent pH in raw and finished water; the difference in pH only exceeds 0.2 in a few cases for raw and distributed water and only once for finished water.[3]

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[2] Total dissolved solids (TDS) was not provided in the data by the Utility, but it was calculated from the conductivity data provided using a multiplier of 0.55, based on the findings from Rusydi:
(Anna F Rusydi 2018 IOP Conf. Ser.: Earth Environ. Sci. 118 012019)

[3] With limited data available, it is difficult to determine whether this swing is due to sampling error instead of a change in the water pH.

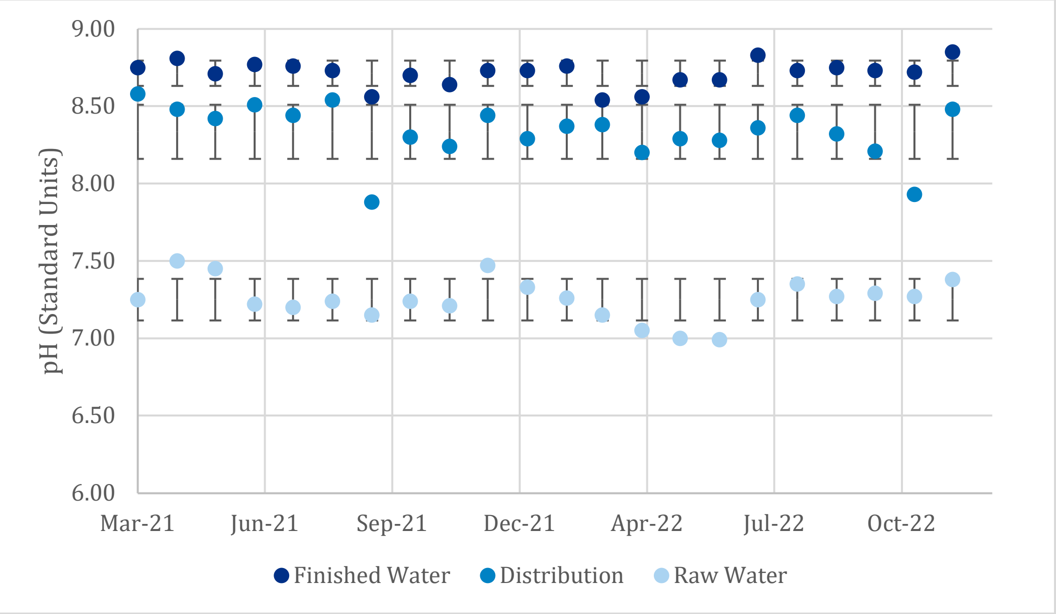

Figure 4. Finished water pH from 2021 through 2022. Standard deviation is shown for each data set.

Average alkalinity in the finished water (at the system entry point) is 83 mg/L, indicating a moderately high alkalinity water. This alkalinity level is normally associated with stable pH in the distribution system, and it is less likely that the distribution system has localized pH changes that could cause localized lead releases. This data for alkalinity is shown in **Figure 5**.

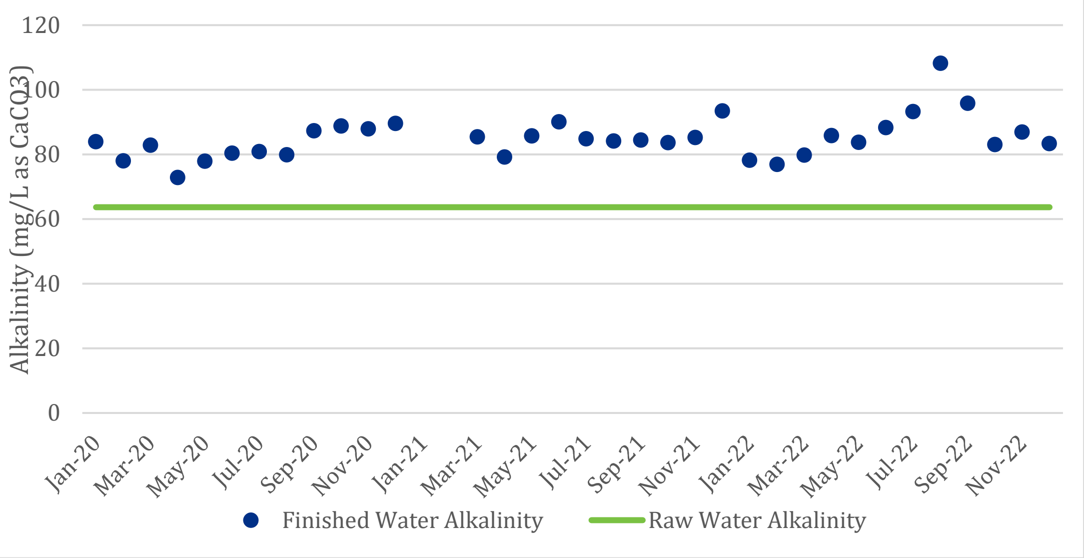

Figure 5. Finished water alkalinity from 2020 through 2022. Note that raw water alkalinity data was only given for one sampling event in 2017, and the average of the value from each well is shown here as a line for reference.

Chloride and Sulfate

Past industry research has shown that as the chloride to sulfate mass ratio (CSMR) approaches 0.4 to 0.6 and above, galvanic corrosion may be promoted, which may increase lead concentrations[4]. WWW's finished water data indicates chloride levels at about 47 mg/L and sulfate levels at about 10 mg/L. This equates of a CSMR of more than four, and this ratio is within the region of potentially higher lead concentrations. Water treatment changes that increase this ratio could increase lead release, and the finished water data from January through May of 2023 from the new WTP indicate a CSMR of 22 (data show average chloride at 61 mg/L and sulfate at 2.8 mg/L, increased from the previous WTP likely due to the new ion exchange process, which can remove sulfate). However, higher alkalinity in the water and the use of corrosion inhibitors could work towards mitigating the impact of this ratio on lead levels.

Iron

The secondary maximum contaminant level (SMCL) for iron is 0.3 mg/L, which is designed to mitigate red water occurrences. Data were not provided for iron, but note that higher iron levels in distribution could indicate corrosion of other materials such as lead and copper in the distribution piping. Particulate iron can also carry lead.

Hardness

This parameter impacts how likely the water is to form a calcium carbonate scale on the pipe walls, which can nominally provide protection against lead solubility. However, the effect of hardness in preventing corrosion is limited and therefore is no longer accepted by the EPA as a means of corrosion control. WWW's average finished water hardness is 88 mg/L (from 2020-2022 data), which is considered as moderately hard water.

Silicate

WWW adds sodium silicate to the system as a means of corrosion control via pH stabilization. **Figure 6** shows the silicate residual in the finished water from 2020 through 2022. This residual is around 35 mg/L with some variation between 30 and 40 mg/L. This parameter is not considered to have a direct impact on corrosion or lead release[5] and is not used as an input in the desktop model.

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[4] *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems*, EPA, March 2016.

[5] Li, Bofu, et al. "Effectiveness of sodium silicates for lead corrosion control: A critical review of current data." Environmental Science & Technology Letters 8.11 (2021): 932-939.

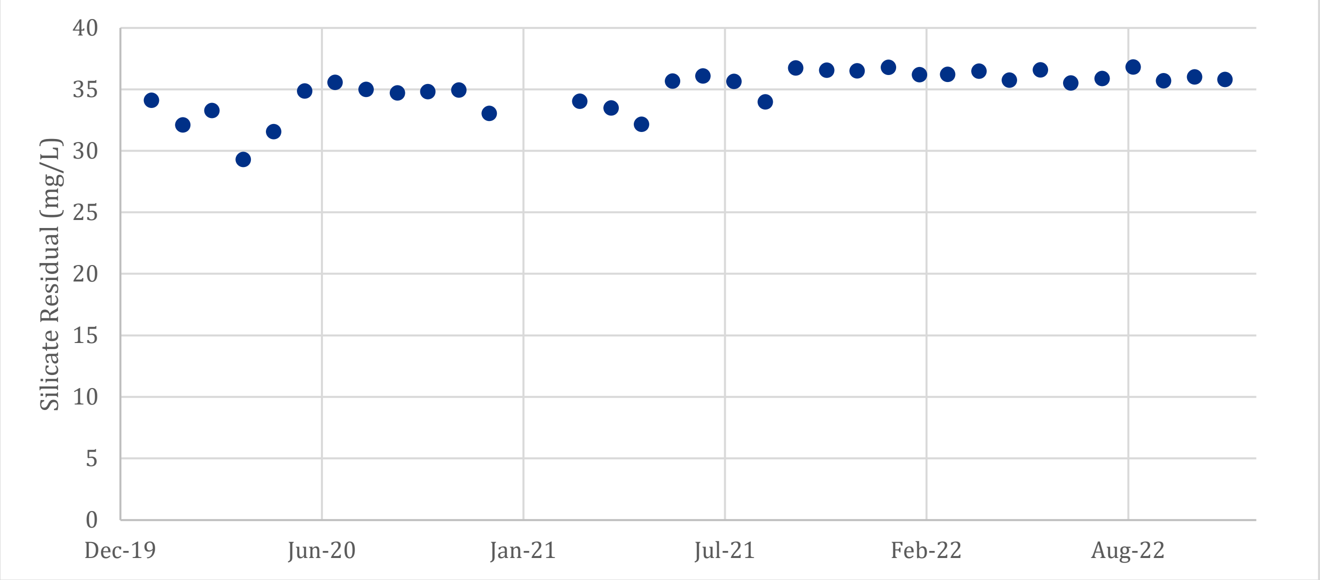

Figure 6. Silicate residual in finished water from 2020 through 2022.

Scale Analysis

A piece of lead pipe was harvested from a lead service line taken from the distribution system. This lead pipe coupon was sent to Dr. Dan Giammar at Washington University for scale analysis. The findings of Dr. Giammar's analysis are summarized below, and the full report is attached to this document .

Corrosion scale from a segment of one harvested lead service line was examined via X-ray diffraction (XRD), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS). Additionally, the elemental composition of scale was analyzed via inductively coupled plasma mass spectrometry (ICP-MS).

The pipe segment had two distinct layers of scale, determined via the color change between one scale layer to the next. Similar to other water systems treated with sodium silicate, the lead mineral phases found in corrosion scale were lead (II) carbonates and lead (IV) oxides. The top layer was brown and rough, and composed of a mixture of two lead (II) carbonates: hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and cerussite ($PbCO_3$). The broad XRD peaks and elemental analysis via ICP-MS of the top scale layer suggest that an amorphous layer containing calcium (Ca), aluminum (Al), iron (Fe), and manganese (Mn) were present.

The bottom layer was white and compact and contained a mixture of the lead (II) carbonates cerussite and hydrocerussite, as well as a small amount of the lead (IV) oxide litharge (PbO). Cerussite was the most dominant lead mineral phase in the bottom layer. Concentrations of calcium, iron, and aluminum, but not manganese, were detected on the bottom layer.

Desktop Review of Water Quality and Corrosion Control Alternatives

Desktop analysis using the water quality data provided from the distribution system was used to calculate corrosion indices and lead solubility for the WWW's treated water conditions. Lead solubility was modeled at varying pH and with modeled orthophosphate addition. The model was created using the finished water quality data from the new WTP. **Table 2** shows that the finished water data sets are very similar, with the exception of chloride and sulfate.

Table 2. Comparison of Previous Average Finished Water Quality and New WTP Average Finished Water Quality

	TDS (mg/L)	pH	Alkalinity (mg/L)	Calcium (mg/L)	Temperature (°C)	Chloride (mg/L)	Sulfate (mg/L)	Magnesium (mg/L)	TOC (mg/L)	Turbidity (NTU)
	New WTP Finished Water									
Average	122	8.55	81	16	N/A	61	2.8	5.7	5.7	N/A
	Previous Finished Water									
Average	129[6]	8.70	83	26	N/A	31	12	4.7	N/A	N/A

Modeling Software

Water!Pro Version 6.90 was used in this analysis. This is a commercially available computer modeling package based in Excel. It calculates the three major corrosion indices (CCPP, LSI, and Ryznar Stability Index) and estimates lead and copper solubility. Both the existing water composition and the impact of potential corrosion control treatment changes can be modeled. It also provides recommended ranges for target corrosion indices. The EPA lists Water!Pro in its OCCT guidelines as an available model for evaluating corrosivity of water and predicting the impact of treatment changes on corrosivity and lead solubility.

Modeled Water Quality

Data from January through May of 2023 for new WTP finished water were used for the model as shown in **Table 3**. Note, the only temperature data from the finished water was from January and collected at the entry point.

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[6] Total dissolved solids (TDS) was not provided in the data by the Utility, but it was calculated from the conductivity data provided using a multiplier of 0.55, based on the findings from Rusydi:
(Anna F Rusydi 2018 IOP Conf. Ser.: Earth Environ. Sci. 118 012019)

Table 3. Water Quality Data Used for the Modeling

	pH	TDS (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Temperature (°C)	Calcium (mg/L)	Chloride[7] (mg/L)	Sulfate[6] (mg/L)	Magnesium (mg/L)
Existing Finished Water	8.55	122	81	10.8	16	61	2.8	5.7

Modeling Results

Water!Pro modeling[8] was conducted to estimate the impact on lead solubility of orthophosphate doses between 0 to 3 mg/L as PO_4 at pH between 7.4 to 8.5, as shown in **Figure 7**. Thermodynamic models can estimate dissolved lead concentrations and predict lead mineral phases but cannot account for the contribution of lead particles to total lead concentrations. Note that these solubility values are not predictions of actual dissolved lead concentrations in tap water or in water stagnated in lead service lines; they are used to create quantitative comparisons between modeled conditions to show relative changes in lead solubility associated with changes in pH and orthophosphate concentration.

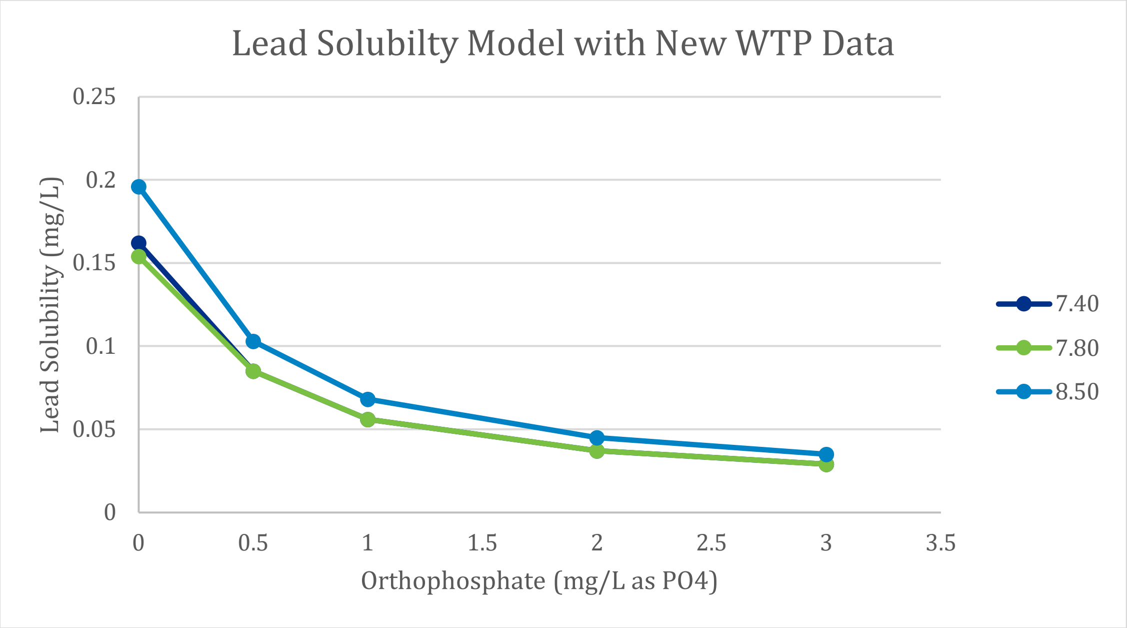

Figure 7. Lead solubility model at varying pH values with orthophosphate addition.

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[7] While the chloride to sulfate ratio is known to affect lead corrosion, WaterPro Models do not take into account the impact of chloride to sulfate ratio when calculating lead solubility.

[8] Results were confirmed in with a MINEQL+ analysis by Dr. Dan Giammar. The results of the MINEQL+ analysis match the trends of the WaterPro modeling, thought the magnitude of the values between models is different.

While lowering pH is predicted to reduce lead solubility, the effect of orthophosphate is far more effective. At the current pH of 8.5, lead solubility decreases by 50% at a 0.5 mg/L orthophosphate dose. Up to 75% decrease is seen at a 2 mg/L orthophosphate dose.

Lead solubility continues to decrease at all pH levels as orthophosphate increases, but this decrease is most substantial up to a dose of 1.0 mg/L as PO_4. Increasing the dose at pH 8.5 from 2 mg/L to 3 mg/L only shows about 20% decrease in lead solubility.

It is important to note that while thermodynamic models predict low lead solubility at pH 8.5 and 1 mg/L of orthophosphate, one study noted higher dissolved and total lead concentrations at pH 8.5 compared to either pH 8.0 or 9.0 in a recirculating pipe loop. It may be worthwhile to explore simultaneously lowering pH to 7.8 and adding 1 mg/L of orthophosphate. Thermodynamic modelling suggests that this will also reduce lead by 17% compared to a pH of 8.5.

Limitations of Modeling

Impact of Chloride to Sulfate Ratio

Water quality studies have identified issues with lead corrosion in utilities with high chloride to sulfate ratio due to increased galvanic corrosion. The new water quality from the new plant has a substantially higher chloride to sulfate mass ratio (CSMR). This impact is believed to me more significant for galvanic corrosion at connections between dissimilar metals, such as in the use of lead solder on copper pipe or in partial service line replacements using an electrically conductive brass coupling. WWW is working with WDNR to conduct additional sampling and testing as a result of this change. CDM Smith's study is focused on long-term corrosion control optimization.

Particulate Lead

The modeling conducted focuses on dissolved lead and lead solubility but does not offer insight into the release of particulate lead. A pipe loop study can better assess how water chemistry changes may destabilize a pipe scale in a way that could increase the release of particulate lead.

Conclusions and Recommended Next Steps:

Based on our initial desktop analysis, the Lead and Copper Rule Revisions will likely put Wausau above the trigger level for lead and thus require additional actions to mitigate lead release into drinking water. Based upon our analysis, the following conclusions and next steps are recommended:

- **Lead Service Line Inventory and Planning:** WWW recently completed the development of a LSLR plan and is initiating efforts to replace all LSLs within 15 years. Moving forward with these plans will help to protect public health and make it easier for WWW to maintain compliance with current and future lead regulations.

- **Consider Implementing Orthophosphate Addition for Corrosion Control:** Based on this desktop analysis, it is recommended that WWW use pipe loops to study adding orthophosphate for corrosion control at doses of 1.0 mg/L and 3.0 mg/L at the current target pH 8.5 (targeted at system entry point). Discontinuing the use of silicates was discussed as a potential test condition for this pipe loop study, but it was determined that it is best to analyze varied levels of orthophosphate first, without other treatment changes. Later on, a test condition may be altered to demonstrate the effects of lowering the pH by removing the silicates, which currently act to buffer the pH.

- **Long-Term Monitoring:** WWW should continue to monitor and maintain consistent finished water pH and chorine residual throughout the distribution system, and other water quality parameters at the system entry point and in the distribution system on a consistent basis to ensure that the parameters are stable and not experiencing significant drifts. Continuing to collect sequential sampling profiles and performing occasional scale analysis of harvested pipes are also recommended.
- **Available Monitoring During the Transition to New WTP:** WWW should continue investigative monitoring as required by the WDNR for utilities that are making major treatment changes. This includes sampling for alkalinity, calcium, chloride, free and total chlorine, conductivity, hardness, iron, manganese, orthophosphate, pH, phosphorus, silica, sulfate, and water temperature at the entry point and in the distribution system. This also includes sampling for lead and copper in the distribution system.

This analysis is focused on mitigating lead releases. However, the corrosion control treatment method should be evaluated for copper and iron corrosion to minimize any unintended consequences.

Appendix A – Scale Analysis

Characterization of Scale of Lead Pipe Segment from Wausau,Wisconsin

Yao Ma and Daniel Giammar
Washington University in St. Louis
September 20, 2022

Introduction

This report summarizes the characterization of the lead pipe segment received from Wausau, Wisconsin in July 2022.

The pipe was cut open, photographed, and prepared for analysis of the corrosion scales. Analysis of the corrosion scales used scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS), X-ray powder diffraction (XRD), and inductively coupled plasma mass spectrometry (ICP-MS). The quantitative and qualitative information obtained from the scale analysis of the pipe is compiled and presented below.

Method for pipe scale analysis:

The scale analysis involved the examination of a cross section and transverse section of the pipe segment. To prepare a cross section, one end of the pipe was filled with a mixture of hardener and epoxy resin (18 wt.%). Once the epoxy had cured, this section was cut from the rest of the segment and polished using sandpapers of increasingly fine grit (up to 1200 grit). The polishing was done with mineral oil on the sandpaper to minimize the generation of airborne particles. The polished sample was sonicated in ethanol to remove residual mineral oil and pipe particles prior to SEM-EDS analysis. The pipe was analyzed using a Thermo Fisher Quattro S E-SEM for imaging. Energy dispersive X-ray (EDS) spectroscopy with the SEM was used to semi-quantitatively determine the elemental composition of the pipe scales. For X-ray diffraction (XRD) characterization and inductively coupled plasma mass spectrometry (ICP-MS) analysis, scales were collected by scraping them off of the inner surface of a transverse section with a stainless-steel spatula. Two different layers of scale were scraped off the inner pipe surface. The different layers were visually distinguished by their colors. The top layer could be removed by relatively gentle scraping. The bottom layer required more force to remove, and its removal also removed some of the underlying lead pipe. Portions of the ground up scale were characterized by XRD on a Bruker d8 Advance X-ray diffractometer with Cu Ka radiation. MTI 1-inch low background Si was used as a sample holder. Other portions of the powdered scales were weighed and then digested in a mixture concentrated hydrochloric and nitric acids (3:1 by volume) at 100°C for two hours in preparation for quantitative analysis of their elemental composition using a NexION 2000 ICP-MS.

Results:

Figure 1. Photograph of the transverse sections of the pipe segment. In this image, a portion of the top layer scale has been removed, which exposes the bottom layer scale.

The pipe segment had two different layers of scale (Figure 1): a brownish and rough top layer and a white and compact bottom layer.

While the layers viewed for the transverse section of the pipe could be clearly distinguished by their different colors, they were difficult to differentiate in the SEM image. In the SEM image of the cross section of the pipe (Figure 2), the thickness of the scale layers was about 75 µm. The top scale layer had higher concentrations of Ca and Al than did the bottom layer. The relative distributions of elements in the scale for the marked areas in Figure 2b are summarized in Table 1. Weight percentages of elements from the EDS analysis are only semi-quantitative. Area 1 with a high Pb percentage is unaltered lead pipe. Areas 2, 3, 4, 5 with higher Al, O and Ca concentrations are the scale layers. Area 6 is epoxy used to fill the pipe in preparing the cross section, and it is primarily carbon. Elemental mapping corresponding to the results found that Ca is most abundant in the top layer.

The XRD results for the scales from three layers are shown in Figure 3. Both the top and bottom layers of the scale on the pipe have XRD patterns that correspond to cerussite ($PbCO_3$) and hydrocerussite. Cerussite ($PbCO_3$) is more abundant in the bottom layer. A small amount of litharge (PbO) was found in the bottom layer. An amorphous phase could be present in the top scale layer as suggested by the broad of the diffraction peak around 2θ of 15° The elemental lead (Pb) in the patterns is from portions of the unaltered lead pipe that were also removed when the scale layers were scraped off the pipe. The key findings from the XRD patterns of both pipe segments are summarized in Table 3.

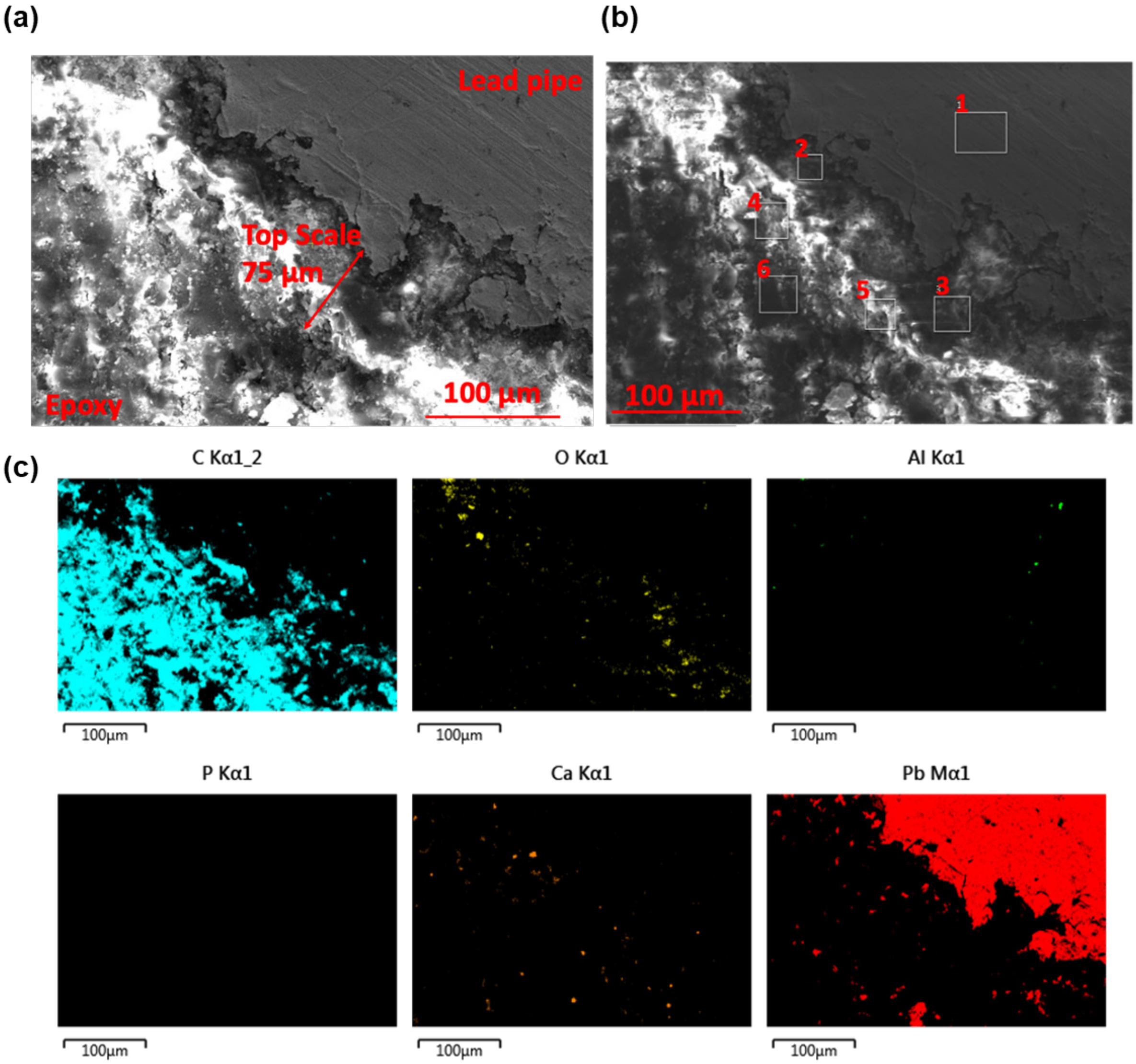

Figure 2. (a) SEM image of the cross-section of the pipe. (b) backscattered electron SEM image of the pipe with the highlighted regions on which EDS was conducted for elemental analysis, and (c) elemental mapping of different elements detected by EDS.

Table 1. Weight percentage (wt%) of different elements for different highlighted areas.

Element/wt %	Area 1	2	3	4	5	6
C K	10.5	63.1	66.9	70.5	69.2	78.5
O K	4.5	13.7	15.5	13.0	14.7	17.4
Pb M	84.7	19.2	15.3	15.1	15.0	3.8
P K	0.0	0.2	0.2	0.0	0.0	0.0
Al K	0.3	0.9	0.8	0.2	0.2	0.1
Ca K	0.0	2.9	1.4	1.2	0.9	0.1

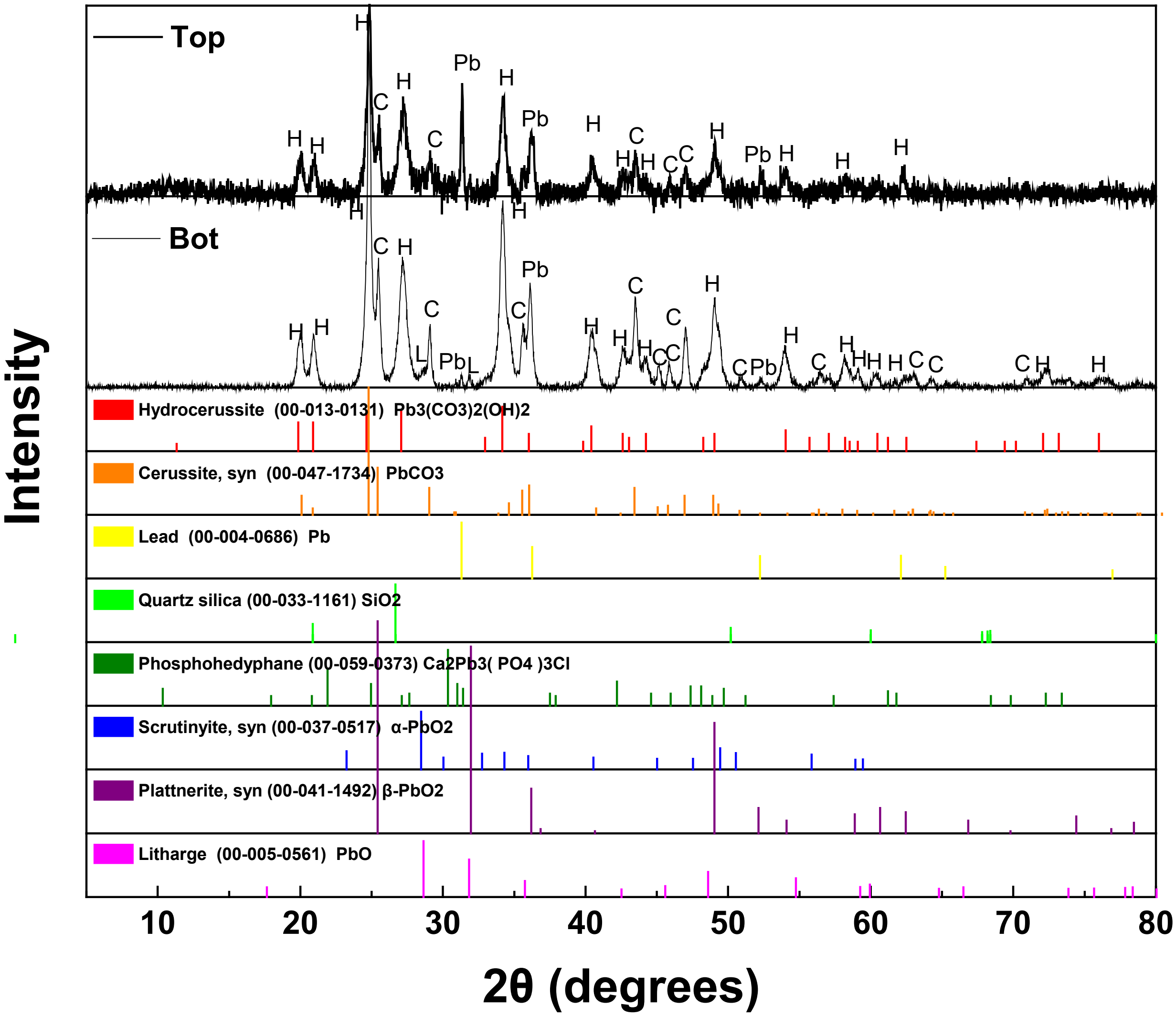

Figure 3. XRD patterns obtained from the surface of the pipe for the top layer (upper) and the bottom layer (bottom) for a range of 5° to 80° 2θ. The patterns at the bottom are the reference patterns for hydrocerussite ($Pb_3(CO_3)_2(OH)_2$), cerussite ($PbCO_3$), elemental lead (Pb), quartz (SiO_2), phosphohedyphane ($Ca_2Pb_3(PO_4)_3Cl$), scrutinyite (α-PbO_2), plattnerite (β-PbO_2) and litharge (PbO). Labels used throughout the patterns are peaks from corresponding solid phases abbreviated as H, C, Pb, Si, Ph, S, Pl and L in the same order as mentioned in the caption.

Summary of the Results

Table 3. Summary of XRD results for the powdered samples from the lead pipe surfaces. Elemental lead was observed in the materials, but it is not listed in this table because it is not part of the scale and is just a result of the process of scraping the scales from the pipe surfaces.

System ID	Hydrocerussite ($Pb_3(CO_3)_2(OH)_2$)	Cerussite ($PbCO_3$)	Litharge (PbO)
Top	+++	++	-
Bottom	+++	+++	+

*'+' indicates the abundance of a certain mineral.'-' Indicates not found.

Table 4. Mass concentration (mg/g) of elements in the scales determined by acid digestion of solids followed by analysis with ICP-MS.

System ID	Pb	Al	Mn	Fe	Ca
Top	288.1	28.1	7.1	44.7	49.5
Bottom	692.3	4.3	0.6	3.1	9.6

*Cu and Mg were also measured but both below the detection limit

As expected Pb was the major element for all layers. Also as expected was the higher concentration of lead in the bottom layer of the scale where the analysis could also have included portions of pure lead scraped from the unaltered lead pipe. Ca, Al and Fe were also founded in both layers and their concentrations decreased from the top to bottom. The scales also contained detectable Mn, and it is primarily in the top layer. The data are generally consistent with the findings in XRD and EDS, which suggest that there could be an amorphous phase in the top scale layer containing Al, Ca and Fe. The ground scale digested and analyzed by ICP-MS comes from a larger area of the inner pipe surface than the discrete slice for which a cross section is prepared. The remaining mass of the scale would be composed of elements that are not measured by ICP-MS, principally the oxygen and carbon that are present in lead oxides and lead carbonates.

Conclusions

- The pipe showed two different scale layers: a brownish and rough top layer, a white and compact bottom layer.
- The thickness is around 75 µm for the whole scale. However, it should be noted that these thicknesses are based on measurement of just one cross-section per pipe.
- Both the top and bottom layers have cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$. Cerussite ($PbCO_3$) is more abundant in the bottom layer, and litharge (PbO) was only found in a small amount in the bottom layer.
- The top layer could also have an amorphous phase containing Al, Ca and Fe.
- The acid digestion carried out on the scale deposits on the lead pipes indicate that they were predominantly Pb, and its concentration increased from the top to the bottom layer (from 288 to 692 mg/g). Ca, Fe and Al were found in both layers in a considerable amount with its concentration decreasing from the top to bottom (Ca: from 50 to 10 mg/g, Fe: from 44 to 3 mg/g, Al: from 28 to 4 mg/g). Detectable Mn was also found primarily in the top layer but with concentrations below 10 mg/g.

Appendix B Summary of Wausau Harvested Lead Service Line Scale Analysis 2022, 2024 and 2025

Memorandum

To: *Scott Boers, Wausau Water Works*

From: *Amrou Atassi and Javier Locsin, CDM Smith*

Date: *October 9, 2025*

Subject: *Summary of Wausau Harvested Lead Service Line Scale Analysis 2022, 2024 and 2025*

Introduction

On December 20, 2022, Wausau Waterworks transitioned to a new drinking water treatment facility that introduced new treatment processes, specifically anion exchange (AIX). Higher chloride residuals from the AIX process can increase galvanic corrosion of lead containing solder or fixtures connected to other pipe material like iron or copper. In October 11, 2024, a new granular activated carbon (GAC) treatment system for removing per- and polyfluoroalkyl substances (PFAS) went online. The water treatment plant experienced challenges maintaining pH after the PFAS treatment went online. Fluctuating pH can influence the formation and stability of pipe deposits, which may affect both water quality and distribution system performance.

Pipe scale analysis was conducted to evaluate how water quality changes from the new treatment process, including variable pH after PFAS treatment, may affect lead pipes in the service area. The pipe harvested in 2022 reflects conditions under the old water quality. The pipes collected in 2024 represent conditions under the treatment processes prior to PFAS treatment. In contrast, the pipe harvested in 2025 was exposed to approximately nine (9) months of water quality following the implementation of the PFAS treatment process.

Methods

Four pipes were harvested from Wausau's system for scale analysis—one in July 2022 (no address), two in May 2024 (1316 N 2nd Street and 3025 N 12th Street) and one in July 2025 (105 E Oak Street)—and sent to the Chemical and Environmental Analysis Facility at Washington University in St. Louis, MO.

Pipe scale analysis included visual inspection, cross-sectional imaging, elemental mapping using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), solids characterization using X-ray diffraction (XRD), and quantitative elemental composition using inductively-coupled plasma mass spectrometry (ICP-MS).

For visual inspection, each pipe was cut open, the top layer of scale photographed and removed, and the bottom layer examined. A cross section was prepared by filling one end with an epoxy-hardener mixture, then curing, cutting, and polishing the section. Five areas were analyzed using a Thermo Fisher Quattro S E-SEM with EDS to determine elemental composition.

For XRD analysis, the scraped top and bottom layers were visually distinguished by color and analyzed using a Bruker D8 Advance X-ray diffractometer with Cu Kα radiation, with samples mounted on MTI 1-inch low-background Si holders to identify crystalline mineral phases.

Other portions of the scraped-off scale were weighed and digested in a 3:1 (by volume) mixture of concentrated hydrochloric and nitric acids at 100 °C for two hours to dissolve the solids. The dissolved samples were then analyzed using a PerkinElmer NexION 2000 ICP-MS to determine the quantitative elemental composition.

Results

Pipe samples collected are shown in **Figure 1** and **Table 1** presents a summary of results.

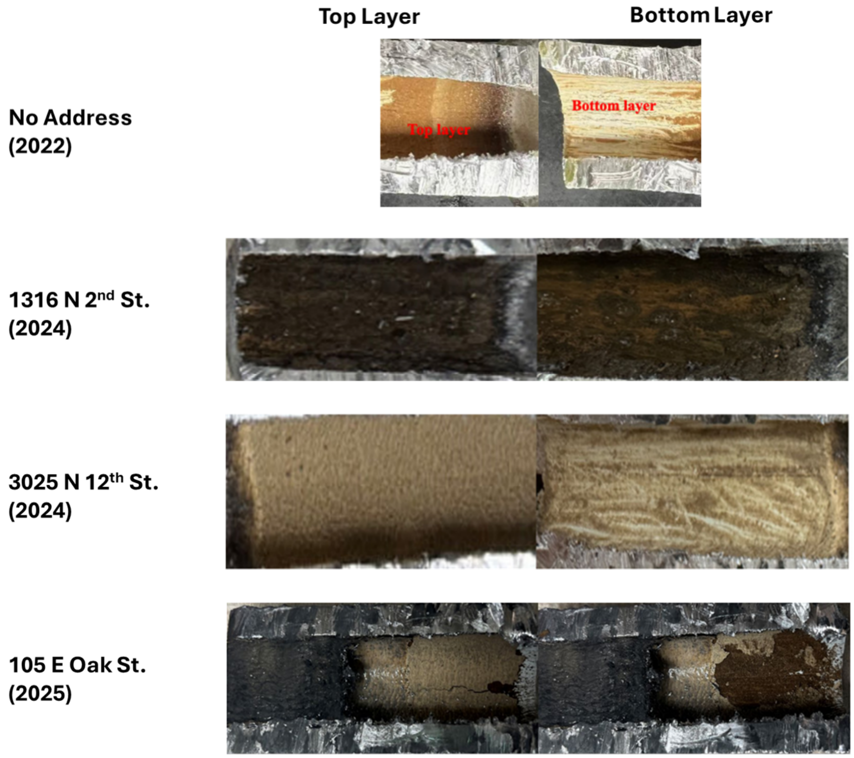

Figure 1 Harvested Lead Service Lines from Wausau, WI

The pipe harvested in 2022 showed two different layers - a brownish and rough top layer, a white and compact bottom layer (**Figure 1**). Both the top and bottom layers have cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$). Cerussite was more abundant in the bottom layer, and litharge (PbO) was only found in a small amount in the bottom layer (**Tabel 1**). XRD and ICP-MS suggested the presence of amorphous layers on the top of the pipe scale containing aluminum, calcium, and iron.

Both pipes harvested in 2024 exhibited two visually distinct scale layers. Pipe 1316 had a dark black top layer over a brown bottom layer, while Pipe 3025 displayed a fluffy brown top layer above a yellowish bottom layer (**Figure 1**). As identified by XRD and ICP-MS, the top scale layers of these 2024 pipes were largely amorphous, composed primarily of manganese, aluminum, silicon, and phosphorus. XRD identified lead (ii) carbonates – cerussite and/or hydrocerussite on the bottom layers of the two pipes

(**Table 1**). Some manganese dioxide, ramsdellite (MnO_2), was also present on the top layer from the pipe harvested at 1316 N 2nd St. Whereas, a calcium-substituted lead-phosphate ($Ca_8Pb_2(PO_4)_6(OH)_2$) was present on the bottom layer of the pipe harvested at 3025 N 12th St.

The pipe harvested from 105 E Oak St. in 2025 had two visually distinguishable layers - a fluffy light brown top layer and a dark brown bottom layer (**Figure 1**). The top layer contained amorphous materials, likely containing iron and silica, with some calcite ($CaCO_3$). The bottom layer contained a mixture of lead (ii) carbonate solids (cerussite and hydrocerussite) along with calcite and magnetite (Fe_3O_4) (**Table 1**). ICP-MS also identified that manganese was abundant in the scale, however, no manganese minerals were detected via XRD.

Summary

Lead minerals in scale were found to be consistent across locations and times, with the dominant phases identified as the lead (II) carbonates, cerussite and hydrocerussite, which aligns with Wausau's water quality. Some pipes also contained amorphous compounds with manganese, aluminum, silicon, and phosphorus. These amorphous phases are likely linked to Wausau's use of silicates in treatment, while manganese may originate from either raw water or the addition of permanganate. Differences in scale among pipes likely reflect variations in water quality, usage patterns, and water age in the areas where the pipes were harvested.

Overall, the change in water quality does not appear to have significantly impacted the mineralogy of lead pipes analyzed. However, the variability in pH following the installation of PFAS treatment has the potential to destabilize pipe scales, increasing corrosion and metals release. Because scale analysis cannot reliably estimate the extent of metals release, tap monitoring is recommended to better assess potential impacts on water quality.

Memorandum

Table 1 Summary of Pipe Scale Analysis Results

Address	Layer	Visual Characteristics	Dominant Crystalline Minerals via XRD	Other Crystalline Minerals via XRD	Dominant Elements via ICP-MS (≥50% by wt)[1]	Other Elements via ICP-MS (<50% by wt)	Key Elements Identified via SEM-EDS
No Address	Top	Brown, rough	▪ Hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) ▪ Cerussite ($PbCO_3$)	▪ None identified	▪ Lead	▪ Calcium ▪ Iron ▪ Aluminum ▪ Manganese	▪ Calcium ▪ Aluminum
	Bottom	White, compact	▪ Cerussite ▪ Hydrocerussite	▪ None identified	▪ Lead	▪ Iron ▪ Aluminum ▪ Manganese	▪ No analysis performed
1316 N 2nd St.	Top	Dark Black	▪ Amorphous	▪ Ramsdellite (MnO_2)	▪ Manganese	▪ Lead ▪ Aluminum ▪ Phosphorous	▪ Silicon ▪ Aluminum[2] ▪ Manganaese[2] ▪ Zinc[2]
	Bottom	Brown	▪ Cerussite	▪ None identified	▪ Lead	▪ Manganese ▪ Aluminum ▪ Phosphorous	▪ No analysis performed
3025 N 12th St.	Top	Brown, fluffy	▪ Amorphous	▪ None identified	▪ Lead	▪ Manganese ▪ Aluminum ▪ Phosphorous	▪ Silicon[2] ▪ Aluminum[2] ▪ Manganaese[2] ▪ Zinc[2]
	Bottom	Yellow	▪ Cerussite ▪ Hydrocerussite	▪ Calcium-substituted lead-phosphate ($Ca_8Pb_2(PO_4)_6(OH)_2$)	▪ Lead	▪ Copper ▪ Zinc ▪ Manganese ▪ Aluminum ▪ Phosphorous	▪ No analysis performed

Address	Layer	Visual Characteristics	Dominant Crystalline Minerals via XRD	Other Crystalline Minerals via XRD	Dominant Elements via ICP-MS (≥50% by wt)[1]	Other Elements via ICP-MS (<50% by wt)	Key Elements Identified via SEM-EDS
105 E Oak St.	Top	Light brown, fluffy	▪ Calcite ($CaCO_3$)	▪ None identified	▪ Lead	▪ Calcium ▪ Iron ▪ Manganese ▪ Zinc	▪ Aluminum[2] ▪ Iron[2] ▪ Silicon[2]
	Bottom	Dark brown	▪ None identified	▪ Calcite ▪ Cerussite ▪ Hydrocerussite ▪ Magnetite (Fe_3O_4)	▪ Lead	▪ Iron ▪ Manganese ▪ Zinc	▪ No analysis performed

Note:

1-The dominant elements listed for the top and bottom layers exclude carbon and oxygen, which were always highly abundant. Silicon was not measured via ICP-MS

2-Trace concentrations detected

Appendix C Pipe Loop Sampling Plan

Test Schedule/Plan for Water Quality Parameters for Each Pipe Rig (Schedule Replicated for Each of the 3 Pipe Rigs)

Collection Frequency	Project Phase	Water Quality Parameter																									
		Alkalinity	Chloride	Sulfate	Orthophosphate	Calcium	Hardness	Conductivity	Dissolved Aluminum	Dissolved Lead	Dissolved Iron	Dissolved Copper	Dissolved Manganese	Total Manganese	Total Aluminum	Total Lead	Total Iron	Total Copper	Silica	**Free Chlorine^2**	**Orthophosphate^3**	**pH**	**Temperature**	**Total Chlorine**	Ammonia	**Turbidity**	Fluoride
	Sample Volume (mL):	Unless specified, all other samples will grouped into one 500 mL bottle and two 250 mL bottles as specified by the testing lab for a total of 1 L.																		10	10	40	40	10		15	
Conditioning I: Continuous Flow																											
Monthly	Influent Water	x	x	x	x	x	x	x						x	x	x	x	x	x	x		x	x	x	x	x	x
	Loop 1 – Pb																			x		x	x	x	x	x	
	Loop 2 – Pb																					x	x			x	
	Loop 3 – Pb																					x	x			x	
	Loop 4 – Cu																			x		x	x			x	
	Loop 5 – Cu																					x	x			x	
	Loop 6 – Cu																					x	x			x	
Conditioning II: 8-hrs stagnation / 16-hrs flow																											
Weekly	Influent Water															x				x		x	x	x	x		
	Loop 1 – Pb															x				x		x	x	x	x		
	Loop 2 – Pb															x				x		x	x	x	x		
	Loop 3 – Pb															x				x		x	x	x	x		
	Loop 4 – Cu															x		x		x		x	x				
	Loop 5 – Cu															x		x		x		x	x				
	Loop 6 – Cu															x		x		x		x	x				

Collection Frequency	Project Phase	Water Quality Parameter																									
		Alkalinity	Chloride	Sulfate	Orthophosphate	Calcium	Hardness	Conductivity	Dissolved Aluminum	Dissolved Lead	Dissolved Iron	Dissolved Copper	Dissolved Manganese	Total Manganese	Total Aluminum	Total Lead	Total Iron	Total Copper	Silica	**Free Chlorine[2]**	**Orthophosphate[3]**	**pH**	**Temperature**	**Total Chlorine**	Ammonia	**Turbidity**	Fluoride
	Sample Volume (mL):	Unless specified, all other samples will grouped into one 500 mL bottle and two 250 mL bottles as specified by the testing lab for a total of 1 L.																		10	10	40	40	10		15	
Monthly	Influent Water	x	x	x	x	x	x	x						x	x		x	x	x							x	x
	Loop 1 – Pb	x				x	x												x							x	
	Loop 2 – Pb																									x	
	Loop 3 – Pb																									x	
	Loop 4 – Cu		x	x																						x	
	Loop 5 – Cu																									x	
	Loop 6 – Cu																									x	
Conditioning III: 0.5-hrs stagnation / 7.5-hrs flow 3x per day																											
Weekly	Influent Water															x		x		x		x	x	x	x	x	
	Loop 1 – Pb															x				x		x	x	x	x	x	
	Loop 2 – Pb															x				x		x	x	x	x	x	

Key: mL – milliliters, Pb – lead, L – liter, hr - hour

[2] Parameters bolded and underlined are anticipated to be measured in-house, by WWW.

[3] Orthophosphate is listed twice because it should be measured using a device, such as a Hach Orthophosphate Pocket Colorimeter II, that gives immediate results in addition to the usual, more accurate ICP-MS or Inductively coupled plasma atomic emission spectrometry (ICP-AES) methods. The immediate result should be used to determine that the flow and orthophosphate feeds are at the expected levels.

Collection Frequency	Project Phase	Water Quality Parameter																									
		Alkalinity	Chloride	Sulfate	Orthophosphate	Calcium	Hardness	Conductivity	Dissolved Aluminum	Dissolved Lead	Dissolved Iron	Dissolved Copper	Dissolved Manganese	Total Manganese	Total Aluminum	Total Lead	Total Iron	Total Copper	Silica	**Free Chlorine^2**	**Orthophosphate^3**	**pH**	**Temperature**	**Total Chlorine**	Ammonia	**Turbidity**	Fluoride
	Sample Volume (mL):	Unless specified, all other samples will grouped into one 500 mL bottle and two 250 mL bottles as specified by the testing lab for a total of 1 L.																		10	10	40	40	10		15	
	Loop 3 – Pb															x				x		x	x	x	x	x	
	Loop 4 – Cu															x		x		x		x	x			x	
	Loop 5 – Cu															x		x		x		x	x			x	
	Loop 6 – Cu															x		x		x		x	x			x	
Monthly	Influent Water	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x								x
	Loop 1 – Pb	x	x	x		x	x			x	x		x		x		x		x								
	Loop 2 – Pb									x	x		x		x		x										
	Loop 3 – Pb									x	x		x		x		x										
	Loop 4 – Cu									x		x	x		x		x										
	Loop 5 – Cu									x		x	x		x		x										
	Loop 6 – Cu									x		x	x		x		x										
Testing																											
Weekly	Influent Water				x											x		x	x	x	x	x	x	x	x	x	
	Loop 1 – Pb				x											x				x	x	x	x	x	x	x	
	Loop 2 – Pb				x											x				x	x	x	x	x	x	x	
	Loop 3 – Pb				x											x				x	x	x	x	x	x	x	
	Loop 4 – Cu				x											x		x		x	x	x	x			x	
	Loop 5 – Cu				x											x		x		x	x	x	x			x	
	Loop 6 – Cu				x											x		x		x	x	x	x			x	
Mo	Influent Water	x	x	x		x	x	x	x	x	x	x	x	x	x		x										x

Collection Frequency	Project Phase	Water Quality Parameter																									
		Alkalinity	Chloride	Sulfate	Orthophosphate	Calcium	Hardness	Conductivity	Dissolved Aluminum	Dissolved Lead	Dissolved Iron	Dissolved Copper	Dissolved Manganese	Total Manganese	Total Aluminum	Total Lead	Total Iron	Total Copper	Silica	**Free Chlorine^2**	**Orthophosphate^3**	**pH**	**Temperature**	**Total Chlorine**	Ammonia	**Turbidity**	Fluoride
	Sample Volume (mL):	Unless specified, all other samples will grouped into one 500 mL bottle and two 250 mL bottles as specified by the testing lab for a total of 1 L.																		10	10	40	40	10		15	
	Loop 1 – Pb					x	x	x	x	x	x		x	x	x		x										
	Loop 2 – Pb							x	x	x	x		x	x	x		x										
	Loop 3 – Pb							x	x	x	x		x	x	x		x										
	Loop 4 – Cu							x	x	x	x	x	x	x	x		x										
	Loop 5 – Cu							x	x	x	x	x	x	x	x		x										
	Loop 6 – Cu							x	x	x	x	x	x	x	x		x										

Appendix D Stabilization of Lead and Copper Release in the Acclimation Phase

D.1 Lead from Lead Pipes

No metals samples were collected during Conditioning Phase 1. It is expected that any loose scale particles dislodged during harvesting were flushed out during this phase. For all pipe loops, no extreme lead release events were observed during Conditioning Phase 2 (**Figure D-1**). Increasing lead concentrations in Conditioning Phase 3 may have been associated with increasing alkalinity in the full-scale finished water.

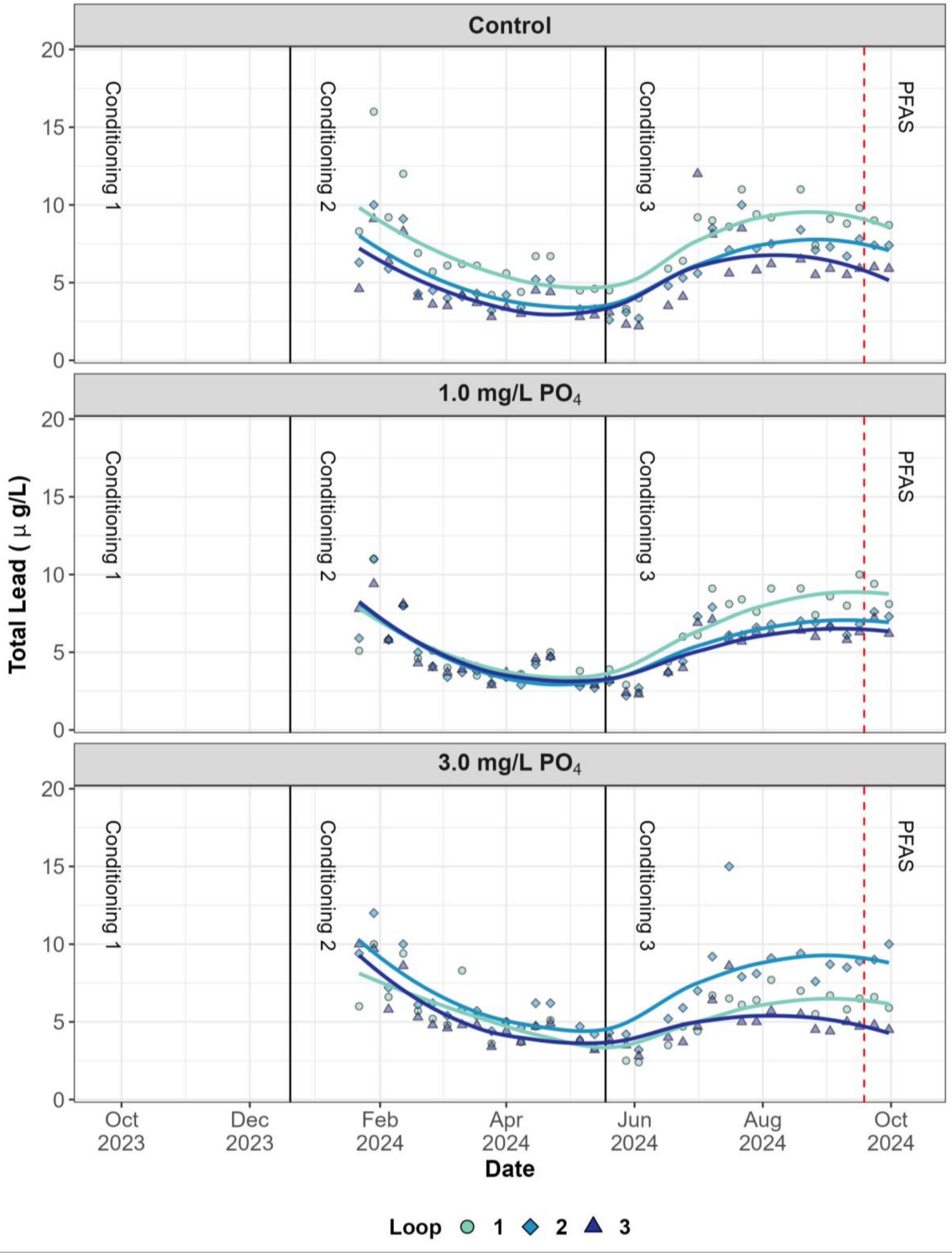

Figure D-1 Lead Release from Lead Pipes in the Acclimation Phase
Note: Points represent raw data, and lines indicate trends predicted using non-parametric LOESS models.

Median lead concentrations for all loops, except Loop 1 of the control skid and Loop 2 of the skid receiving 1.0 mg/L as PO_4, were relatively consistent, ranging from 3.0 to 3.8 µg/L (**Table D-1**). These two loops exhibited slightly higher median lead concentrations of 4.6 and 4.7 µg/L, respectively. No correlation was observed between water temperature and lead release during the acclimation phase. The standard deviation of the final seven consecutive sampling events for each loop in Conditioning 3 was less than 25%; therefore, it was determined that conditions were sufficiently stable to proceed to the Testing phase.

Table D-1 Summary of Stable Total Lead Release in the Lead Pipe Loops in Conditioning Phase 3

Experimental Condtion	Loop	Influent pH [Median (10th – 90th percentile)]	Median Total Lead Release (µg/L)	Standard Deviation of Total Lead Release (µg/L)
Control	1	8.8 (8.7 to 8.9)	9.0	1.1
Control	2		7.4	0.54
Control	3		5.9	0.34
1.0 mg/L PO_4	1	8.8 (8.7 to 8.9)	8.6	0.90
1.0 mg/L PO_4	2		6.9	0.48
1.0 mg/L PO_4	3		6.3	0.46
3.0 mg/L PO_4	1	8.8 (8.5 to 8.9)	6.5	0.55
3.0 mg/L PO_4	2		8.9	0.75
3.0 mg/L PO_4	3		4.7	0.38

D.2 Lead from Copper Pipes with Lead Solder

Elevated lead concentrations were observed during the acclimation phase, with periodic spikes in lead release (**Figure D-2**). Median lead concentrations were similar across most copper pipes with lead solder; however, Loops 4 and 5 in the skid receiving 3.0 mg/L as PO_4 and Loop 4 in the control skid exhibited higher lead release compared to the other copper pipes with lead solder (**Table D-2**). Similar to the full lead pipes, no correlation between lead release and temperature was observed. The standard deviation of the final seven consecutive sampling events for each loop in Conditioning 3 was less than 25%; therefore, it was determined that conditions were sufficiently stable to proceed to the Testing phase.

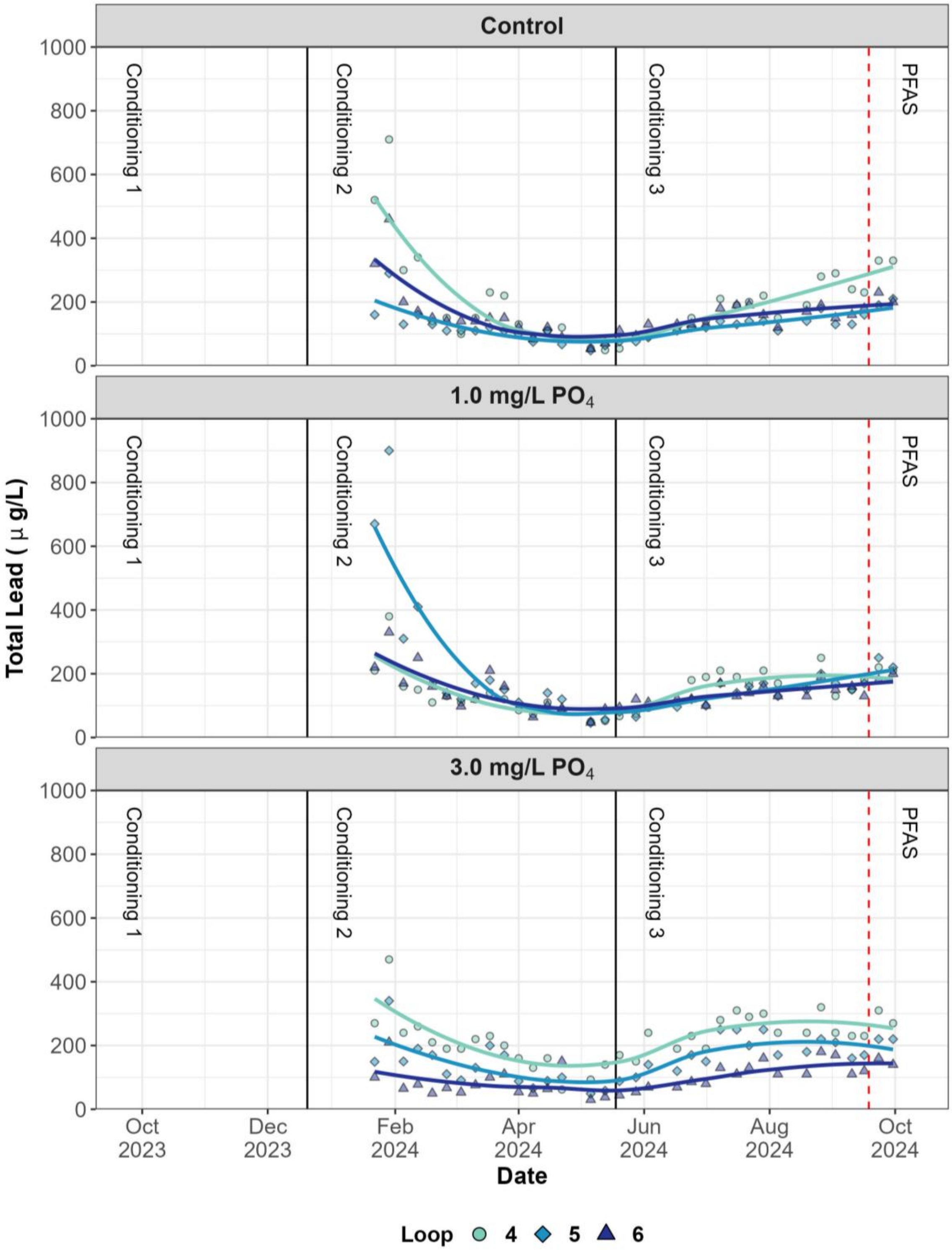

Figure D-2 Lead Release from Copper Pipes with Lead Solder in the Acclimation Phase

Note: Points represent raw data, and lines indicate trends predicted using non-parametric LOESS models.

Table D-2 Summary of Stable Total Lead and Copper Release in the Copper with Lead Solder Pipe Loops in Conditioning Phase 3

Experimental Condtion	Loop	Influent pH [Median (10th – 90th percentile)]	Median Total Lead Release (µg/L)	Standard Deviation of Total Lead Release (µg/L)	Median Total Copper Release (µg/L)	Standard Deviation of Total Copper Release (µg/L)
Control	4	8.7 (8.7 to 8.9)	280	53	12	1.6
Control	5		160	31	13	1.8
Control	6		180	27	14	1.8
1.0 mg/L PO_4	4	8.6 (8.5 to 8.9)	180	43	13	1.5
1.0 mg/L PO_4	5		170	38	14	2.0
1.0 mg/L PO_4	6		160	28	15	2.1
3.0 mg/L PO_4	4	8.8 (8.7 to 8.9)	240	38	17	2.2
3.0 mg/L PO_4	5		210	26	16	1.9
3.0 mg/L PO_4	6		140	29	19	1.9

D.3 Copper from Copper Pipes with Lead Solder

Copper concentrations steadily decreased from Conditioning Phase 2 to Phase 3 (**Figure D-3**). During Phase 3, copper concentrations were typically below 20 µg/L, with no concentration spikes observed. Median copper release was similar across all pipes, ranging from 12 to 19 µg/L (**Table D-2**). The standard deviation of the final seven consecutive sampling events for each loop in Conditioning 3 was less than 25%; therefore, it was determined that conditions were sufficiently stable to proceed to the Testing phase.

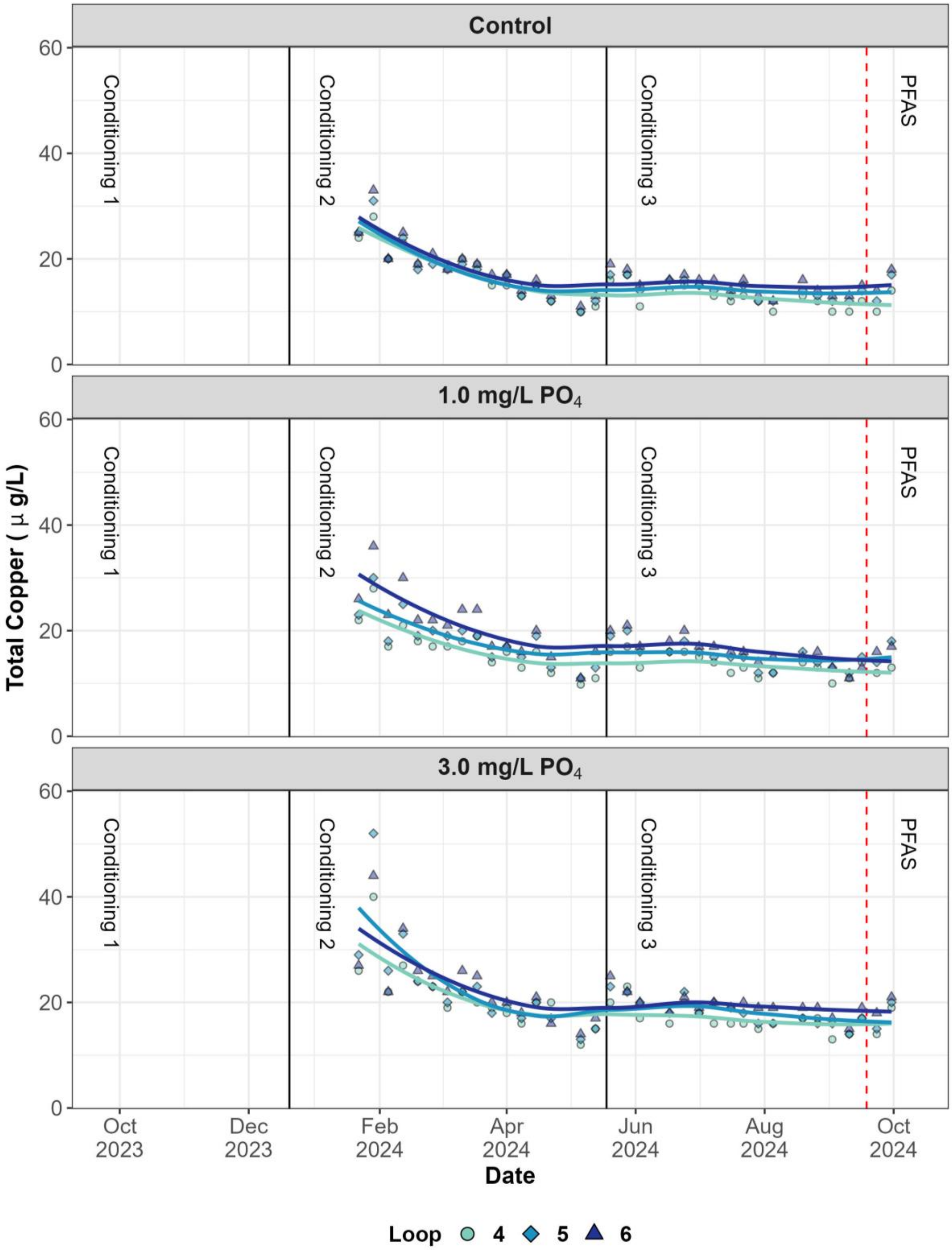

Figure D-3 Copper Release from Copper Pipes with Lead Solder in the Acclimation Phase

Note: Points represent raw data, and lines indicate trends predicted using non-parametric LOESS models.

Appendix E Supplementary Figures and Tables

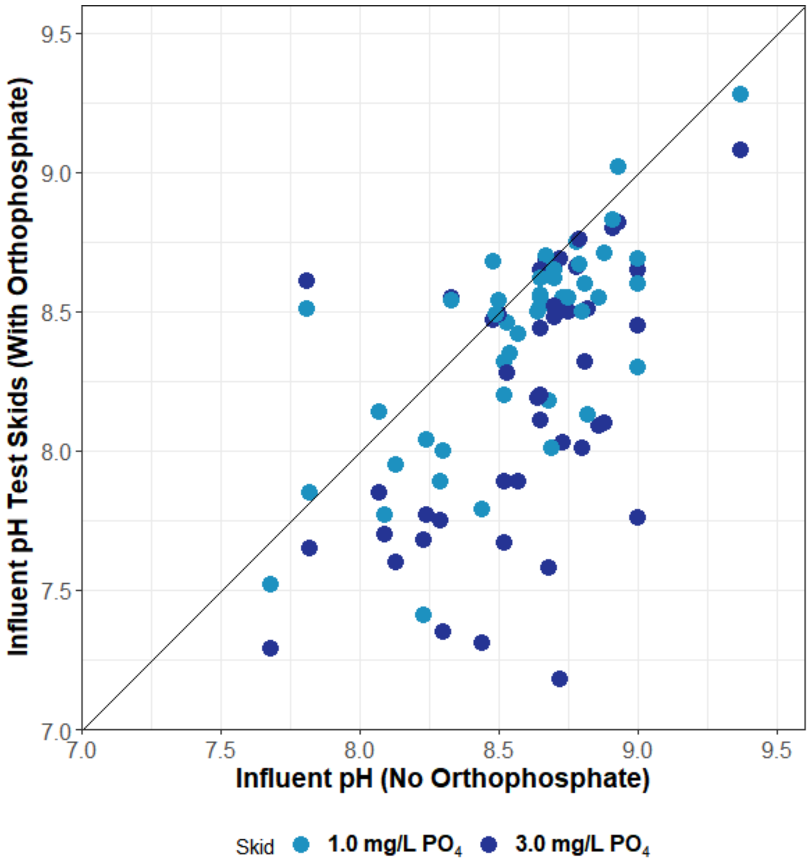

Figure E-1. Comparison of Influent pH Between Phosphoric Acid–Treated Skids and the Control Skid

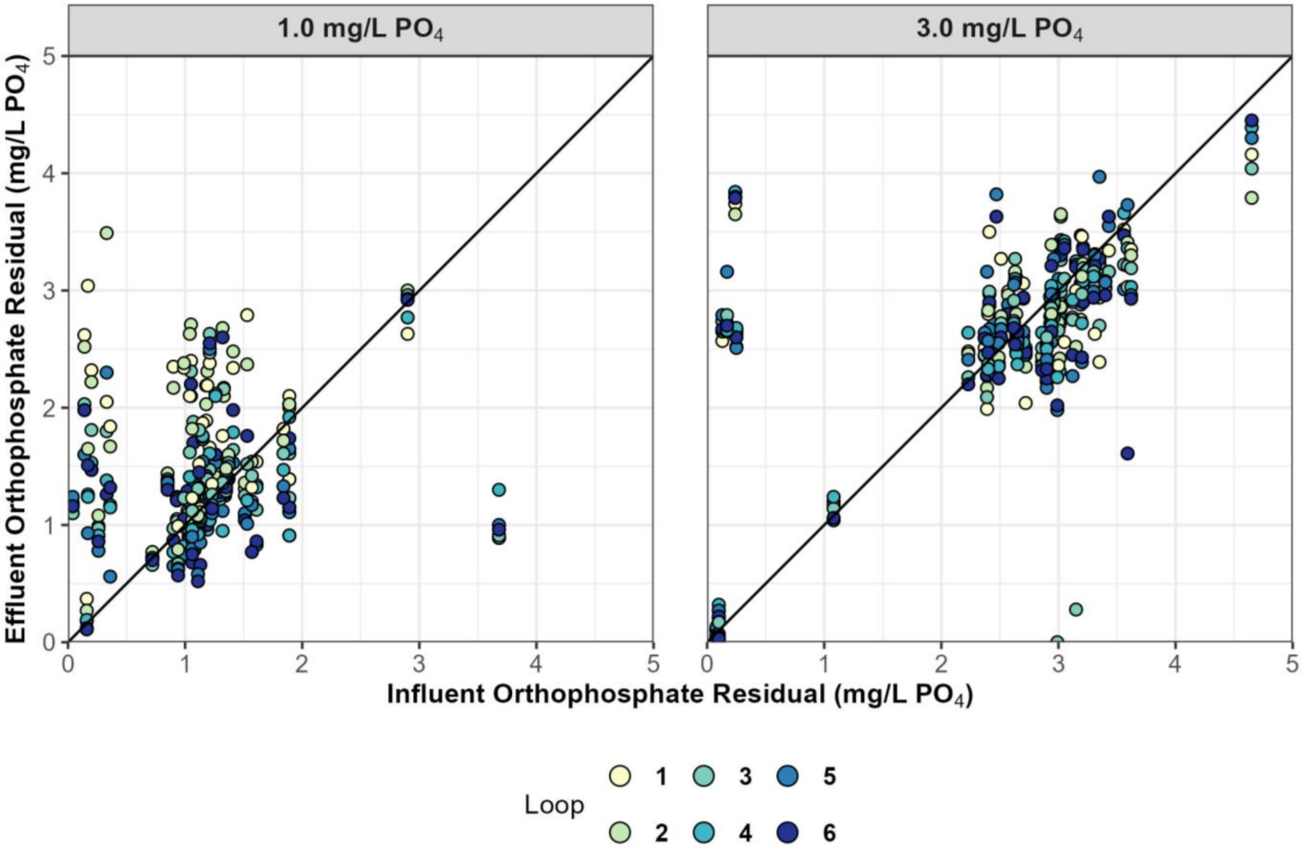

Figure E-2. Comparison of Influent and Effluent Orthophosphate Residuals

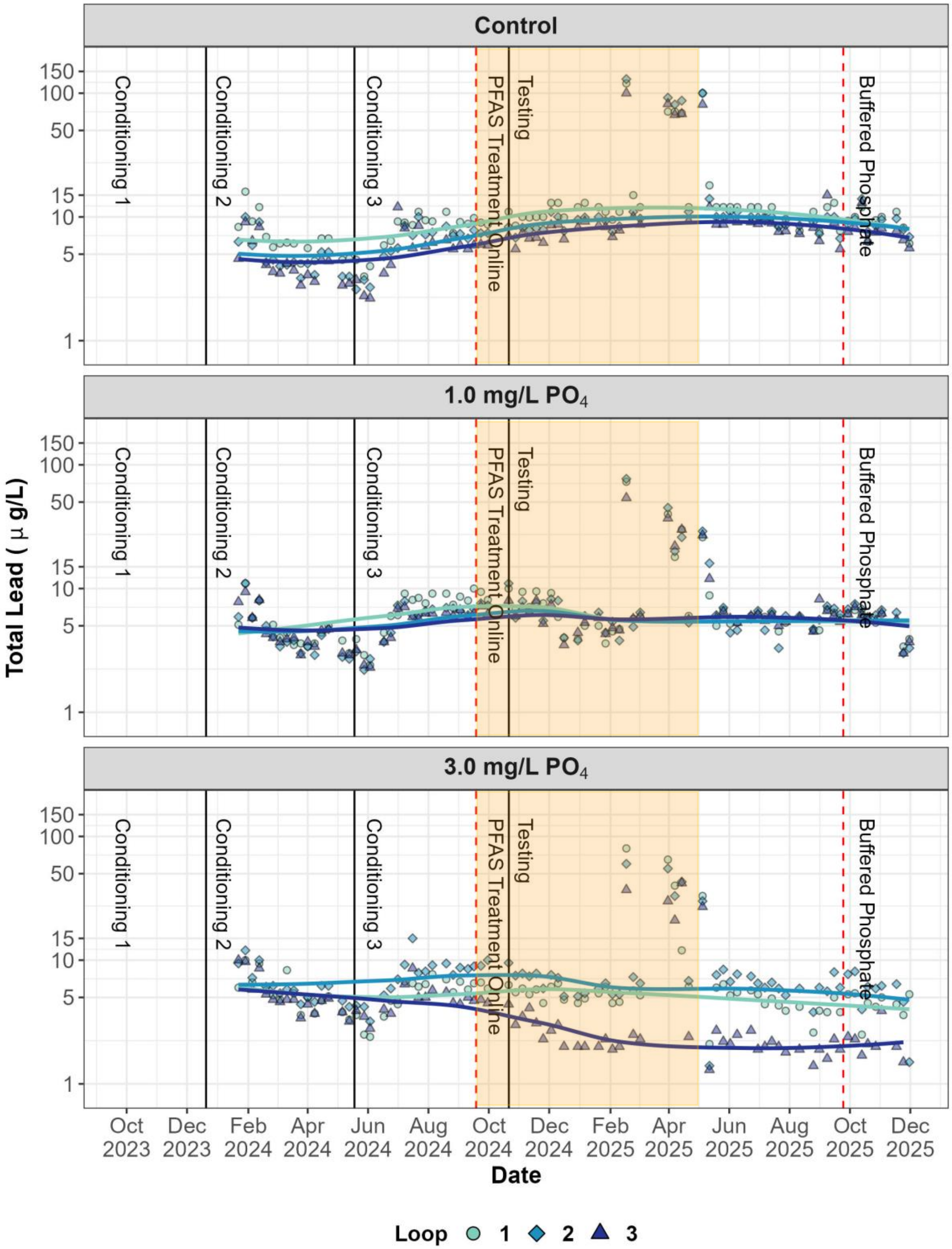

Figure E-3. Lead Release from Harvested Lead Pipes in Log Scale

Note: Points represent raw data, and lines indicate trends estimated using non-parametric LOESS models. The orange box shows the period where pH variability was high due to the pumping issue.

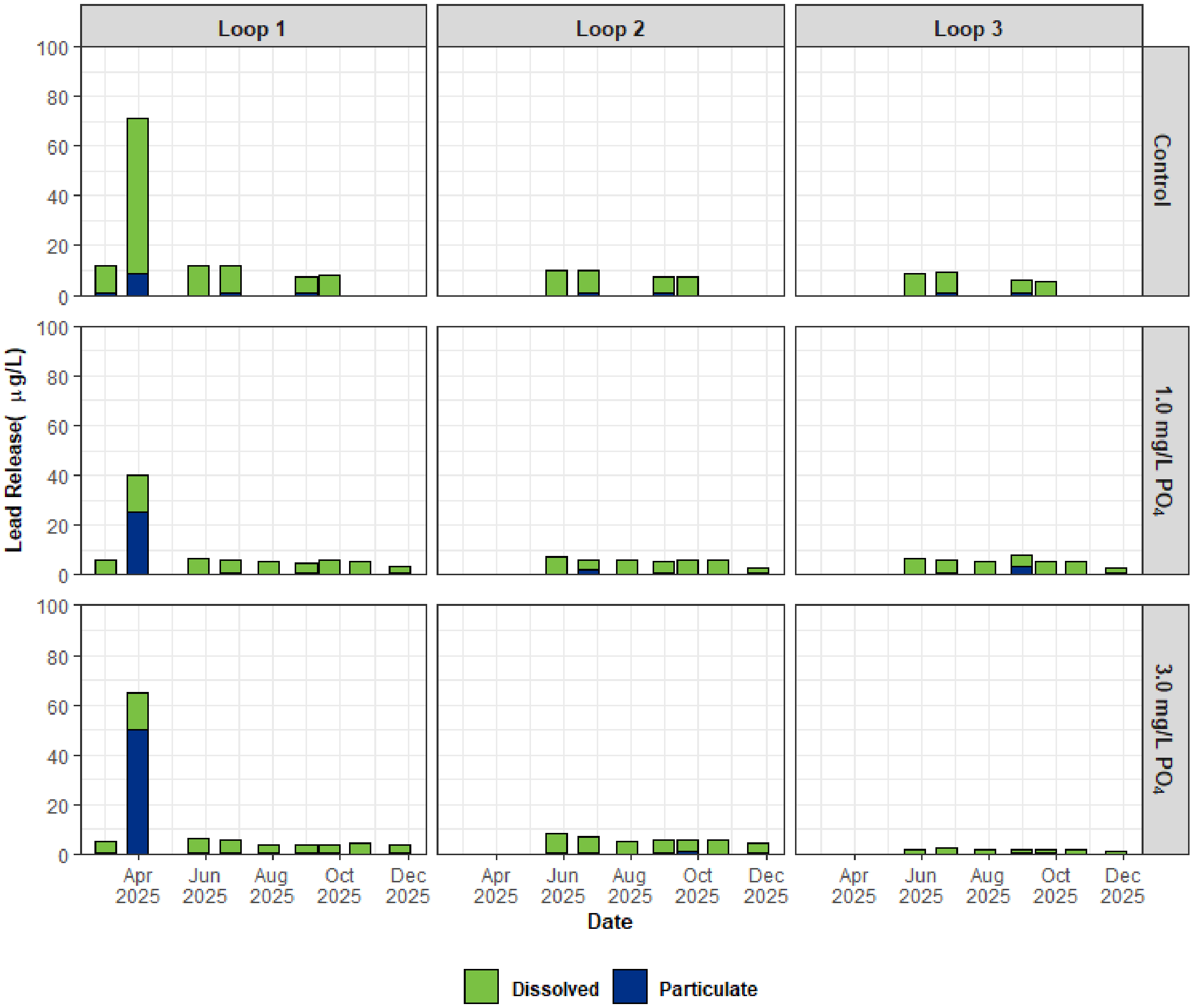

Figure E-4. Dissolved and Particulate Lead from Lead Pipes Under Orthophosphate and Control Conditions

Table E-1. Influent Water Quality during Testing for all Conditions

Parameter	Control	1.0 mg/L as PO_4	3.0 mg/L as PO_4
Alkalinity (mg/L as $CaCO_3$)	73 (65 – 80)	72 (64 – 82)	72 (62 – 82)
Conductivity (µS/cm)	250 (230 – 260)	240 (240 – 260)	250 (240 – 260)
Chloride (mg/L as Cl)	31 (26 – 32)	31 (26 – 32)	31 (26 – 32)
Sulfate (mg/L as SO_4)	3.0 (2.3 – 4.0)	3.0 (2.3 – 4.0)	3.0 (2.3 – 4.0)
Phosphorus (mg/L as P)	0.011 (0.0062 – 0.018)	0.32 (0.25 – 0.41)	0.99 (0.84 – 1.3)
Silicate (mg/L as SiO_2)	31 (29 – 34)	30 (29 – 34)	31 (29 – 35)
Turbidity (NTU)	0.19 (0.13 – 0.29)	0.19 (0.14 – 0.32)	0.20 (0.13 – 0.33)
Calcium (mg/L as Ca)	17 (16 – 18)	16 (16 – 19)	17 (16 – 18)
Copper (mg/L as Cu)	4.9 (1.6 – 12)	3.5 (2.9 – 4.3)	1.7 (1.5 – 2.6)
Magnesium (mg/L as Mg)	5.7 (5.3 – 6.0)	5.9 (5.3 – 6.0)	5.8 (5.3 – 6.1)
Manganese (mg/L as Mn)	0.36 (n.d. – 0.91)	n.d.	n.d.
Hardness (mg/L as $CaCO_3$)	67.0 (62 – 69)	66 (62 – 70)	67 (62 – 70)
pH (S.U.)	After PFAS Treatment[1]: 8.5 (8.1 – 8.9) Pump Issues Addressed[2]: 8.7 (8.5 – 9.0) After Buffered Phosphate[3]: 8.6 (8.4 – 8.8)	After PFAS Treatment[1]: 8.4 (7.8 – 8.7) Pump Issues Addressed[2]: 8.6 (8.3 – 8.7) After Buffered Phosphate[3]: 8.6 (8.4 – 8.7)	After PFAS Treatment[1]: 8.0 (7.3 – 8.7) Pump Issues Addressed[2]: 8.5 (8.1 – 8.7) After Buffered Phosphate[3]: 8.5 (8.3 – 8.7)
Temperature (°F)	56 (56 – 60)	56 (56 – 62)	56 (56 – 62)
Free Chlorine (mg/L as Cl_2)	2.0 (n.d.[4] – 2.3)	2.0 (n.d[4]. – 2.3)	2.0 (n.d. [4]– 2.3)
Total Chlorine (mg/L as Cl_2)	2.4 (2.1 – 2.6)	2.3 (2.2 – 2.5)	2.4 (2.2 – 2.5)
Free Ammonia (mg/L as NH_3-N)	0.0058 (0.0016 – 0.17)	0.05 (0.0045 – 0.13)	0.054 (n.d. – 0.14)
Total Ammonia (mg/L as NH_3-N)	0.51 (0.44 – 0.58)	0.51 (0.45 – 0.58)	0.51 (0.44 – 0.58)

Note:
1 – October 11, 2024
2 – June 22, 2025
3 – October 17, 2025
4 – Below detection limits
5 – Data presented as median (10th-90th percentiles)
Key: µS/cm – microsiemens per centimeter, P – phosphorus, Mn – manganese

Table E-2. Effluent Water Quality in Lead Pipes of the Control Skid

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	62 (56 - 63)	69 (67 - 71)	76 (70 - 83)
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	Not monitored	Not monitored	36 (35 – 36)
Sulfate (mg/L as SO_4)	Not monitored	Not monitored	3.4 (3.2 – 3.6)
Orthophosphate (mg/L as PO_4)	No orthophosphate in this experimental condition		
Silicate (mg/L as SiO_2)	33 (31 - 33)	32 (31 - 33)	30 (28 - 32)
Turbidity (NTU)	0.34 (0.23 - 0.44)	0.17 (0.15 - 0.29)	0.17 (0.13 - 0.25)
Calcium (mg/L as Ca)	17 (16 – 18)	15 (15 – 16)	16 (16 - 19)
Magnesium (mg/L as Mg)	5.8 (5.3 – 6.0)	5.6 (5.4 - 6.1)	5.6 (5.3 - 6.2)
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	65 (62 - 68)	61 (61 - 67)	64 (59 - 72)
pH (S.U.)	8.6 (8.4 - 8.7)	Before PFAS = 8.8 (8.6 - 8.8) After PFAS = 8.8	After PFAS Treatment: 8.6 (8.1 – 8.8) Pump Issues Addressed: 8.6 (8.3 – 8.8) After Buffered Phosphate: 8.5 (8.2 – 8.7)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.01)	0.08 (n.d. - 0.15)	0.10 (n.d. - 0.58)
Total Chlorine (mg/L as Cl_2)	2.3 (2.0 - 2.5)	2.2 (2.0 - 2.5)	2.2 (1.8 - 2.4)
Free Ammonia (mg/L as NH_3-N)	0.08 (0.016 - 0.14)	0.15 (0.036 - 0.20)	0.08 (0.017 - 0.15)
Total Ammonia (mg/L as NH_3-N)	0.52 (0.45 - 0.57)	0.59 (0.50 - 0.61)	0.51 (0.44 - 0.55)

Note:

1 – Below detection limit

2 – Data presented as median (10th-90th percentiles)

Table E-3. Effluent Water Quality in Copper Pipes with Lead Solder of the Control Skid

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	Not monitored		
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	31 (29 – 34)	27 (26 – 29)	30 (26 – 33)
Sulfate (mg/L as SO_4)	4.2 (2.3 - 4.9)	3.9 (3.0 - 4.6)	4.3 (2.7 - 5.3)
Orthophosphate (mg/L as PO_4)	No phosphate in this experimental condition		
Silicate (mg/L as SiO_2)	Not monitored		
Turbidity (NTU)	0.32 (0.26 - 0.38)	0.21 (0.18 - 0.28)	0.25 (0.17 - 0.36)
Calcium (mg/L as Ca)	Not monitored		
Magnesium (mg/L as Mg)	Not monitored		
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	Not monitored		
pH (S.U.)	8.7 (8.5 - 8.8)	Before PFAS = 8.8 (8.7 - 8.9) After PFAS = 8.8	After PFAS Treatment: 8.6 (8.2 – 8.9) Pump Issues Addressed: 8.6 (8.5 – 8.9) After Buffered Phosphate: 8.5 (8.3 – 8.7)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.07)	0.07 (n.d. - 0.14)	0.07 (n.d. - 0.40)
Total Chlorine (mg/L as Cl_2)	0.9 (0.6 - 1.1)	1.1 (0.98 - 1.3)	1.2 (1.0 - 1.6)
Free Ammonia (mg/L as NH_3-N)	0.35 (0.31 - 0.39)	0.35 (0.30 - 0.39)	0.27 (0.18 - 0.36)
Total Ammonia (mg/L as NH_3-N)	0.52 (0.46 - 0.55)	0.58 (0.50 - 0.61)	0.50 (0.24 - 0.56)

Note:

1 – Below detection limit

2 – Data presented as median (10th-90th percentiles)

Table E-4. Effluent Water Quality in Lead Pipes of the Skid Receiving 1.0 mg/L as PO_4

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	62 (55 - 65)	69 (68 - 70)	74 (69 - 84)
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	Not monitored	Not monitored	36
Sulfate (mg/L as SO_4)	Not monitored	Not monitored	3.4 (3.0 – 3.7)
Orthophosphate (mg/L as PO_4)	No phosphate in this phase	No phosphate in this phase	1.48 (1.01 - 2.25)
Silicate (mg/L as SiO_2)	33 (32 - 34)	33	32 (29 – 33)
Turbidity (NTU)	0.38 (0.26 - 0.51)	0.17 (0.14 - 0.22)	0.18 (0.13 - 0.27)
Calcium (mg/L as Ca)	16 (16 - 17)	16 (15 - 17)	16 (16 - 19)
Magnesium (mg/L as Mg)	5.6 (5.3 - 5.9)	5.5 (5.5 – 6.0)	5.7 (5.4 – 6.0)
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	63 (61 - 65)	62 (60 - 68)	64 (61 - 71)
pH (S.U.)	8.6 (8.3 - 8.7)	Before PFAS = 8.7 (8.6 - 8.8) After PFAS = 8.7 (8.6 - 8.7)	After PFAS Treatment: 8.2 (7.7 – 8.6) Pump Issues Addressed: 8.4 (8.2 – 8.6) After Buffered Phosphate: 8.4 (8.1 – 8.6)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. – 0.046)	0.06 (n.d. - 0.19)	0.10 (n.d. - 0.42)
Total Chlorine (mg/L as Cl_2)	2.2 (2.0 - 2.4)	2.3 (2.0 - 2.5)	2.2 (1.7 - 2.4)
Free Ammonia (mg/L as NH_3-N)	0.07 (0.028 - 0.15)	0.15 (0.058 - 0.19)	0.07 (0.0062 - 0.14)
Total Ammonia (mg/L as NH_3-N)	0.52 (0.46 - 0.55)	0.60 (0.51 - 0.61)	0.50 (0.43 - 0.56)

Note:

1 – Below detection limit

2 – Data presented as median (10th-90th percentiles)

Table E-5. Effluent Water Quality in Copper Pipes with Lead Solder of the Skid Receiving 1.0 mg/L as PO_4

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	Not monitored		
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	31 (29 – 34)	27 (26 – 29)	30 (27 – 33)
Sulfate (mg/L as SO_4)	4.2 (2.3 - 4.9)	3.9 (3.0 - 4.6)	4.6 (2.6 - 5.4)
Orthophosphate (mg/L as PO_4)	No phosphate in this phase	No phosphate in this phase	1.23 (0.80 - 1.75)
Silicate (mg/L as SiO_2)	Not monitored		
Turbidity (NTU)	0.29 (0.25 - 0.33)	0.18 (0.14 - 0.27)	0.36 (0.25 - 0.72)
Calcium (mg/L as Ca)	Not monitored		
Magnesium (mg/L as Mg)	Not monitored		
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	Not monitored		
pH (S.U.)	8.7 (8.5 - 8.8)	Before PFAS = 8.8 (8.7 - 8.9) After PFAS = 8.7 (8.7 - 8.8)	After PFAS Treatment: 8.4 (7.9 – 8.7) Pump Issues Addressed: 8.5 (8.4 – 8.7) After Buffered Phosphate: 8.4 (8.1 – 8.6)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.054)	0.04 (n.d. - 0.19)	0.06 (n.d. - 0.33)
Total Chlorine (mg/L as Cl_2)	0.80 (0.70 - 0.94)	1.2 (0.7 - 1.4)	1.3 (0.82 - 1.8)
Free Ammonia (mg/L as NH_3-N)	0.35 (0.32 - 0.40)	0.39 (0.30 - 0.42)	0.25 (0.054 - 0.34)
Total Ammonia (mg/L as NH_3-N)	0.50 (0.47 - 0.55)	0.58 (0.50 - 0.62)	0.49 (0.23 - 0.55)

Note:
1 – Below detection limit
2 – Data presented as median (10th-90th percentiles)

Table E-6. Effluent Water Quality in Lead Pipes of the Skid Receiving 3.0 mg/L as PO_4

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	65 (56 - 67)	69 (66 - 71)	75 (70 - 82)
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	Not monitored	Not monitored	37 (36 – 37)
Sulfate (mg/L as SO_4)	Not monitored	Not monitored	3.5 (3.1 – 3.8)
Orthophosphate (mg/L as PO_4)	No phosphate in this phase	No phosphate in this phase	2.8 (2.1 - 3.2)
Silicate (mg/L as SiO_2)	33 (32 - 34)	33 (32 - 34)	31 (30 - 32)
Turbidity (NTU)	0.33 (0.22 - 0.44)	0.15 (0.11 - 0.21)	0.17 (0.12 - 0.31)
Calcium (mg/L as Ca)	16 (15 - 18)	16 (15 - 17)	16 (16 - 19)
Magnesium (mg/L as Mg)	5.4 (5.3 - 5.7)	5.5 (5.4 – 6.0)	5.6 (5.3 – 6.0)
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	62 (61 - 67)	61 (60 - 66)	63 (61 – 71)
pH (S.U.)	8.5 (8.2 - 8.7)	Before PFAS = 8.60 (8.5 - 8.8) After PFAS = 8.5 (8.4 - 8.5)	After PFAS Treatment: 7.8 (7.3 – 8.3) Pump Issues Addressed: 8.2 (7.7 – 8.5) After Buffered Phosphate: 8.2 (7.8 – 8.4)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.12)	n.d. (n.d. - 0.12)	0.095 (n.d. – 0.97)
Total Chlorine (mg/L as Cl_2)	2.3 (1.8 – 2.5)	2.3 (1.8 – 2.5)	2.2 (1.8 – 2.4)
Free Ammonia (mg/L as NH_3-N)	0.09 (0.034 - 0.17)	0.16 (0.074 - 0.20)	0.077 (0.011 - 0.14)
Total Ammonia (mg/L as NH_3-N)	0.53 (0.45 - 0.57)	0.59 (0.53 - 0.62)	0.50 (0.39 - 0.55)

Note:
1 – Below detection limit
2 – Data presented as median (10th-90th percentiles)

Table E-7. Effluent Water Quality in Copper Pipes with Lead Solder of the Skid Receiving 3.0 mg/L as PO_4

Parameter	Conditioning 1 and 2	Conditioning 3	Testing
Alkalinity (mg/L as $CaCO_3$)	Not monitored		
Conductivity (µS/cm)	Not monitored		
Chloride (mg/L as Cl)	31 (30 – 35)	28 (26 – 29)	30 (27 – 33)
Sulfate (mg/L as SO_4)	4.3 (2.3 – 5.0)	3.9 (3.0 - 4.6)	4.6 (2.7 - 5.4)
Orthophosphate (mg/L as PO_4)	No phosphate in this phase	No phosphate in this phase	2.8 (2.2 - 3.4)
Silicate (mg/L as SiO_2)	Not monitored		
Turbidity (NTU)	0.34 (0.22 - 0.45)	0.19 (0.15 - 0.30)	0.62 (0.34 - 1.1)
Calcium (mg/L as Ca)	Not monitored		
Magnesium (mg/L as Mg)	Not monitored		
Manganese (mg/L as Mn)	Not monitored		
Hardness (mg/L as $CaCO_3$)	Not monitored		
pH (S.U.)	8.6 (8.4 - 8.8)	Before PFAS = 8.71 (8.56 - 8.81) After PFAS = 8.61 (8.51 - 8.71)	After PFAS Treatment: 7.99 (7.53 – 8.44) Pump Issues Addressed: 8.30 (8.00 – 8.56) After Buffered Phosphate: 8.31 (8.03 – 8.48)
Free Chlorine (mg/L as Cl_2)	n.d. (n.d. - 0.054)	0.025 (n.d. - 0.14)	0.08 (n.d. - 0.36)
Total Chlorine (mg/L as Cl_2)	0.90 (0.76 - 1.1)	1.1 (0.78 - 1.2)	1.1 (0.9 - 1.5)
Free Ammonia (mg/L as NH_3-N)	0.31 (0.28 - 0.40)	0.37 (0.30 - 0.40)	0.26 (0.074 - 0.37)
Total Ammonia (mg/L as NH_3-N)	0.49 (0.46 - 0.56)	0.56 (0.50 - 0.61)	0.47 (0.19 - 0.54)

Note:
1 – Below detection limit
2 – Data presented as median (10th-90th percentiles)

Table E-8. 90th Percentile Total Lead Release in Lead Pipe Loops and Copper Pipe Loops with Lead Solder during Testing

Experimental Condtion	Loop	Testing Phase- 90th Percentile Total Lead Release from Lead Service Lines (µg/L)	Testing Phase- 90th Percentile Total Lead Release from Copper with Lead Solder Service Lines (µg/L)
Control	1	11.4	314
Control	2	11.4	146
Control	3	10.1	208
1.0 mg/L PO_4	1	6.2	87
1.0 mg/L PO_4	2	6.7	160
1.0 mg/L PO_4	3	6.2	107
3.0 mg/L PO_4	1	5.1	156
3.0 mg/L PO_4	2	6.3	137
3.0 mg/L PO_4	3	6.3	132

Appendix F Pipe Loop Scale Analysis Report

Characterization of Scales of Lead Pipe Segments from Wausau, WI

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Washington University in St. Louis
March 2, 2026 (completion of partial report sent February 24)

Introduction:

This report summarizes the characterization of four lead pipe segments (2-1A, 2-3A, 3-1A, and 3-3A) received in January 2026 from Wausau, WI.

The pipes were cut open, photographed, and prepared for analysis of the corrosion scales. Analysis of the corrosion scales used scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS), X-ray powder diffraction (XRD), and inductively coupled plasma mass spectrometry (ICP-MS). The quantitative and qualitative information obtained from the scale analysis of the pipes is compiled and presented below.

Method for pipe scale analysis:

The scale analysis involved the examination of a cross section and transverse section of each pipe segment. To prepare a cross section, one end of each pipe was filled with a mixture of hardener and epoxy resin (18 wt.%). Once the epoxy had cured, this section was cut from the rest of the segment and polished using sandpapers of increasingly fine grit (up to 1200 grit). The polishing was done with mineral oil on the sandpaper to minimize the generation of airborne particles. The cross sections were analyzed using a Thermo Fisher Quattro S E-SEM for imaging. Energy dispersive X-ray spectroscopy (EDS) with SEM was used to semi-quantitatively determine the elemental composition and distribution of the pipe scales. For X-ray diffraction (XRD) characterization and inductively coupled plasma mass spectrometry (ICP-MS) analysis, scales were collected by scraping them off the inner surface of a transverse section with a stainless-steel spatula. Two different layers of scale were scraped off the inner pipe surface for 2-1 A and 2-3A. Scale materials on segments 3-1 A and 3-3 A were collected as single units due to their compact thickness. The different layers were visually distinguished by their colors. Portions of both layers were characterized by XRD on a Bruker d8 Advance X-ray diffractometer with Cu Ka radiation. MTI 1-inch low background Si was used as a sample holder. Other portions of the scales were weighed and then microwave-digested in concentrated nitric acid at 220 °C for thirty minutes using a CEM Mars 6 in preparation for quantitative analysis of their elemental composition using a PerkinElmer NexION 2000 ICP-MS.

Lead Pipe 2-1 A Results:

Visual Inspection. The pipe segment had two visually distinguishable layers (**Figure 1**): a light brown top layer and a dark brown bottom layer.

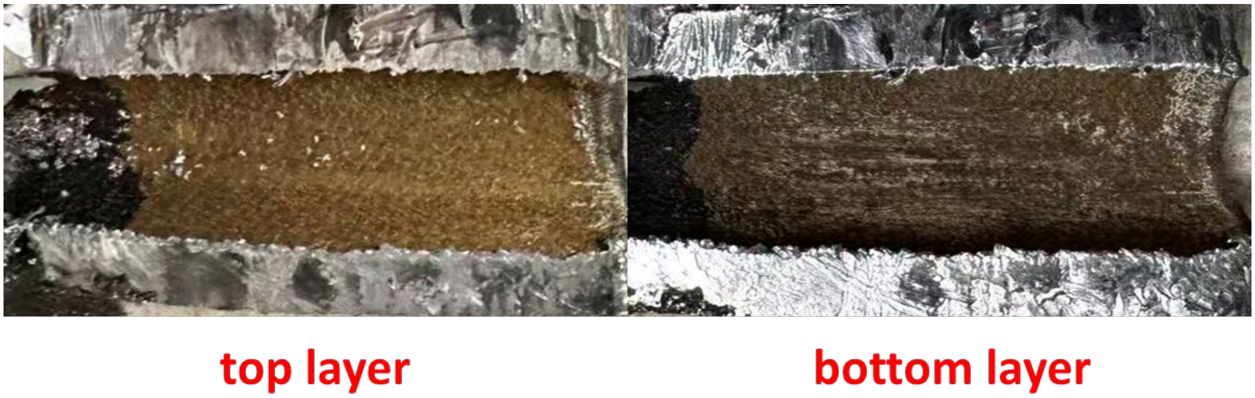


Figure 1. Photographs of the transverse sections of the pipe segment with a light brown top layer and a dark brown bottom layer.

Cross-sectional Imaging and Elemental Mapping Using SEM-EDS. SEM was utilized to obtain images of cross-sectional interfaces between unaltered pipe, pipe scale and epoxy. As shown in **Figure 2a**, the thickness of the scale was about 70 µm.

EDS analysis provided semi-quantitative information on weight percentages of selected elements (C, O, Pb, Mn, Al, Si and P). Overall elemental mapping was conducted on the cross-sectional image obtained by SEM **(Figure 2c)**. In addition to the overall elemental mapping, five marked areas were chosen for elemental composition analysis (**Figure 2b**). The distributions of selected elements for the marked areas are summarized in **Table 1**. Area 1 was the unaltered lead pipe. Area 2 was epoxy used to fill the pipe in preparing the cross section. Areas 3, 4, and 5 were the scale. C was most abundant in the epoxy and the scale. There were also a substantial amount of Mn and some Al, Si and P in the scale layer. Pb was the most abundant element in the unaltered pipe and in the scale.

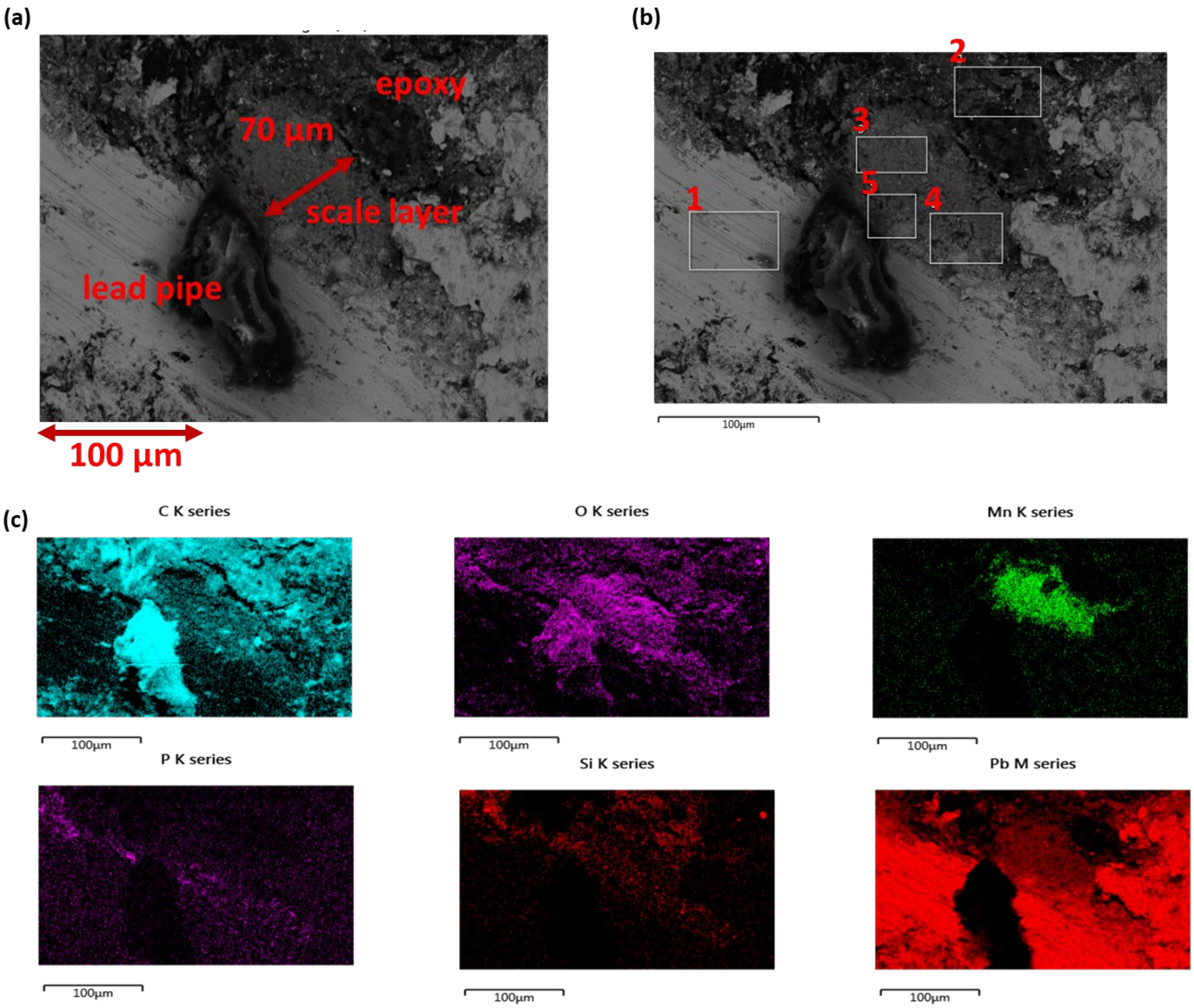


Figure 2. **(a)** SEM image of the cross-section of the pipe **(b)** backscattered electron SEM image of the pipe with the highlighted regions on which EDS was conducted for elemental analysis, and **(c)** overall elemental mapping of different elements detected by EDS.

Table 1. Weight percentage (wt%) of selected elements for different highlighted areas as determined using EDS. Numbers in red represent detected values of low confidence on the exact numerical value reported while numbers in black are readings that have a high level of confidence on the numerical value reported.

Element (wt %)	**Overall**	**1**	**2**	**3**	**4**	**5**
Pb	68.2	92.1	35.0	46.5	61.5	56.6
O	4.5	1.2	8.6	10.6	8.0	8.1
C	23.4	6.1	45.5	14.3	20.2	27.2
Al	0.4	0.2	1.1	0.5	0.5	0.4
Mn	1.9	0.0	2.5	24.6	6.1	4.6
Si	0.9	0.2	3.6	2.1	1.8	1.3
P	0.1	0.0	0.1	0.1	0.5	0.4

Solid Characterization Using XRD. XRD was used to identify crystalline phases in both the top and bottom layers. Results for the two layers are shown in **Figure 3.** Both layers did not have highly crystalline materials. Instead, there were a few broad peaks indicating poorly crystalline or amorphous materials. The specific solids in both layers cannot be definitively identified, but these peaks are consistent with those of the hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and magnetite (Fe_3O_4). The key findings from the XRD patterns of both pipe scale layers are summarized in **Table 5**.

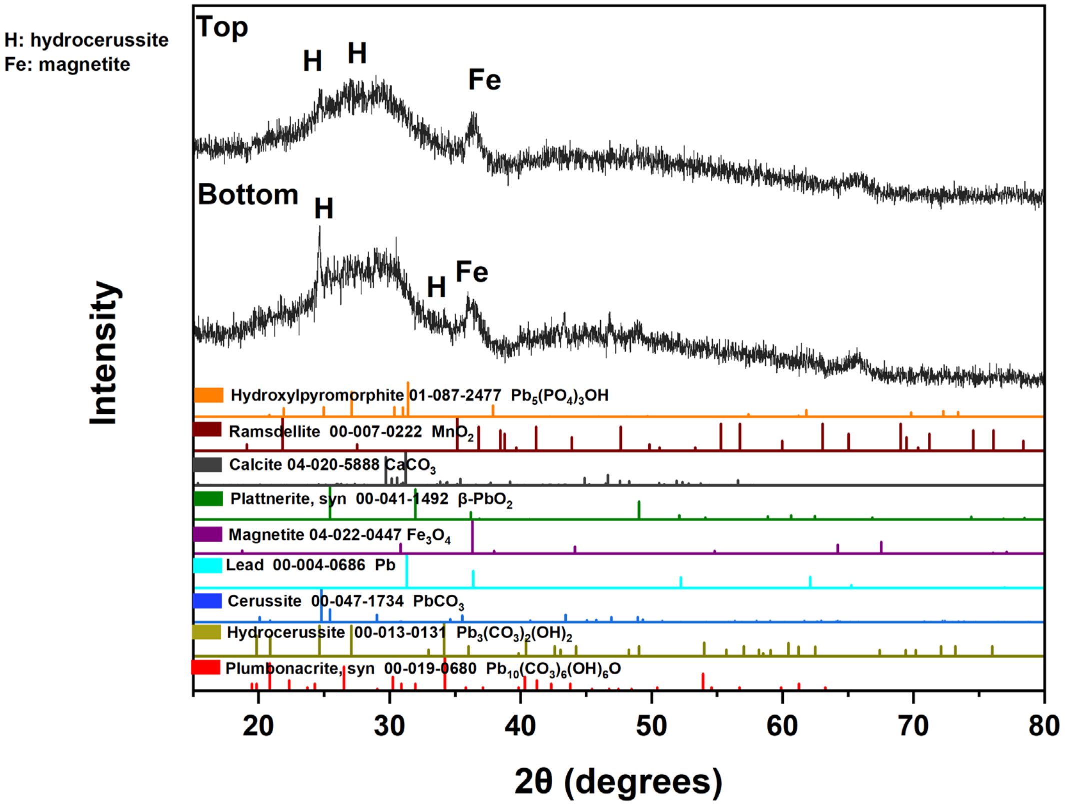
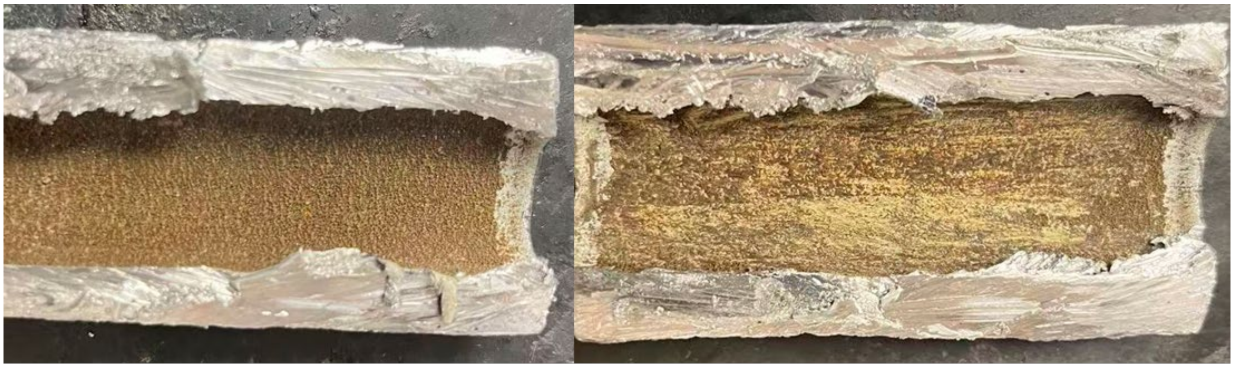


Figure 3. XRD patterns obtained from the surface of the pipe segment 2-1A for the top layer and the bottom layer for a range of 15° to 80° 2θ.

Quantitative Elemental Composition Using ICP-MS. ICP-MS was utilized to quantitatively determine elemental compositions of both the top and bottom layers. Results are summarized in **Table 6**. The top layer had a lead mass concentration of 155 mg/g while the bottom layer had a lead mass concentration of 131 mg/g. Both layers had a substantial amount of Mn and some Al, with the bottom layer having less of these two elements. This is consistent with EDS results. Some P was also detected in both layers. The relatively high content of Mn suggests the presence of amorphous solids containing manganese in the top layer of the scale. These amorphous materials probably contain Al and P as indicated by both EDS and ICP-MS. Carbon and oxygen were expected to be present in both layers.

Lead Pipe 2-3 A Results:

Visual Inspection. The pipe segment had two visually distinguishable layers (**Figure 4**): a dark brown top layer and a light yellow bottom layer.



Top layer

Bottom layer

Figure 4. Photographs of the transverse sections of the pipe segment with a dark brown top layer and a light yellow bottom layer.

Cross-sectional Imaging and Elemental Mapping Using SEM-EDS. SEM was utilized to obtain images of cross-sectional interfaces between unaltered pipe, pipe scale and epoxy. As shown in **Figure 5a**, the thickness of the scale was about 250 µm.

EDS analysis provided semi-quantitative information on weight percentages of selected elements (C, O, Pb, Mn, Al, Si, and Ca). Overall elemental mapping was conducted on the cross-sectional image obtained by SEM **(Figure 5c)**. In addition to the overall elemental mapping, five marked areas were chosen for elemental composition analysis (**Figure 5b**). The distributions of selected elements for the marked areas are summarized in **Table 2**. Area 1 was the unaltered lead pipe. Area 2 was epoxy used to fill the pipe in preparing the cross section. Areas 3, 4, and 5 were the scale. C was the most abundant element in the epoxy. Pb was the dominant element in the unaltered pipe. In the scale layer, C and Pb were present at comparable levels, along with a substantial amount of O. Minor amounts of Si, Al, and Ca were also detected in the scale layer.

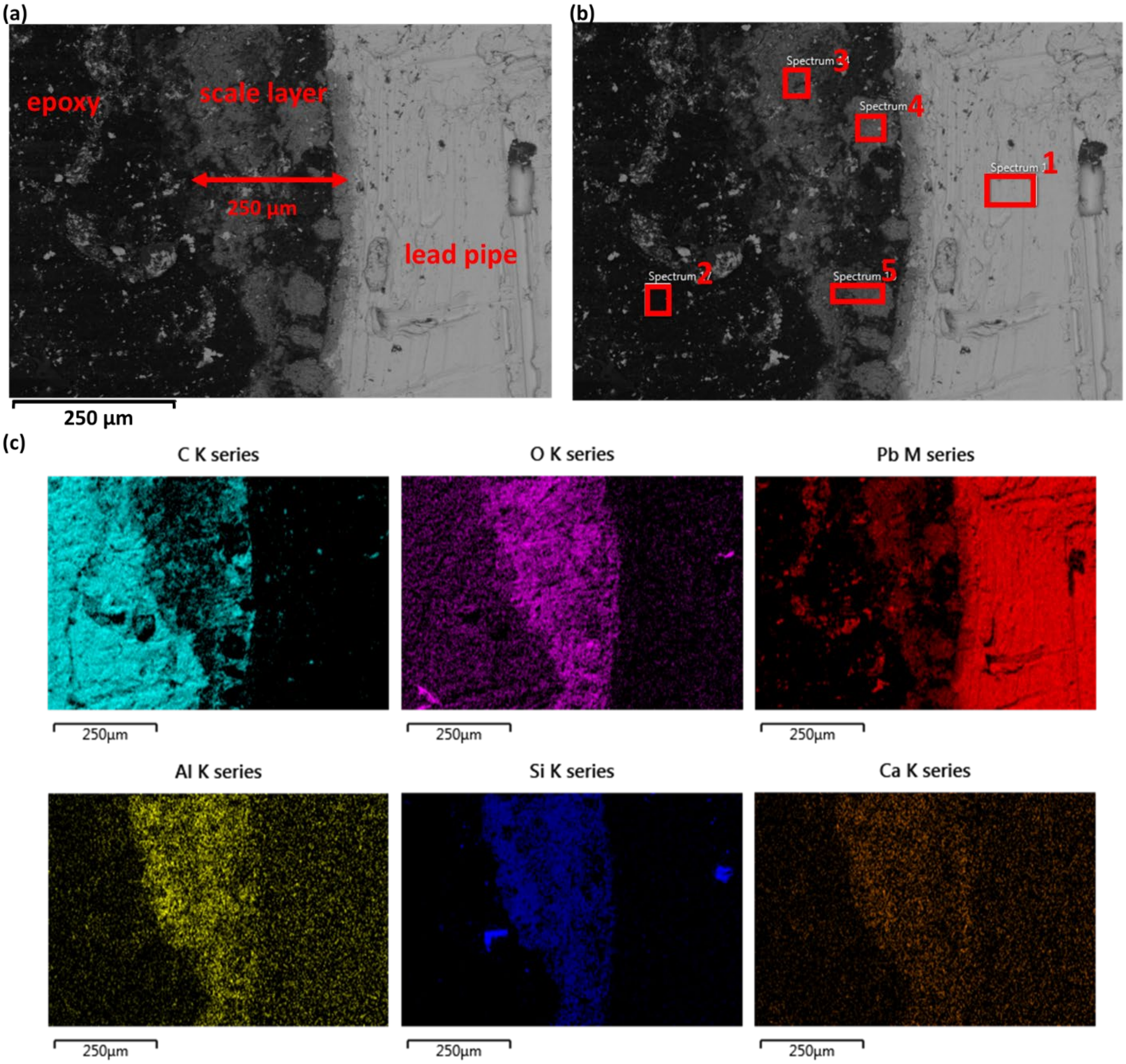


Figure 5. (a) SEM image of the cross-section of the pipe **(b)** backscattered electron SEM image of the pipe with the highlighted regions on which EDS was conducted for elemental analysis, and **(c)** overall elemental mapping of different elements detected by EDS.

Table 2. Weight percentage (wt%) of selected elements for different highlighted areas as determined using EDS. Numbers in red represent detected values of low confidence on the exact numerical value reported while numbers in black are readings that have a high level of confidence on the numerical value reported.

Element (wt %)	**Overall**	**1**	**2**	**3**	**4**	**5**
Pb	38.5	81.8	3.8	32.6	42.1	31.7
O	10.3	3.9	15.4	22.5	25.4	25.2
C	49.1	13.8	80.6	39.0	27.4	35.3
Al	0.4	0.2	0.1	1.1	1.0	1.5
Fe	0.2	0.0	0.0	0.7	0.4	0.6
Si	1.3	0.3	0.1	3.4	3.2	4.8
Ca	0.2	0.0	0.0	0.6	0.5	0.8

Solid Characterization Using XRD. XRD was used to identify crystalline phases in both the top and bottom scale layer. Results are shown in **Figure 6**. The top scale layer contained amorphous materials indicated by the broad patterns of XRD peaks. Patterns of cerussite (PbCO3), hydrocerussite (Pb3(CO3)2(OH)2), and hydroxylpyromorphite (Pb5(PO4)3OH) were detected in the bottom layer. Elemental lead (Pb) was also detected in both layers. This is likely due to incidental incorporation of underlying unaltered lead pipe when the scale layer was scraped from the pipe. The key findings from the XRD patterns are summarized in **Table 5**.

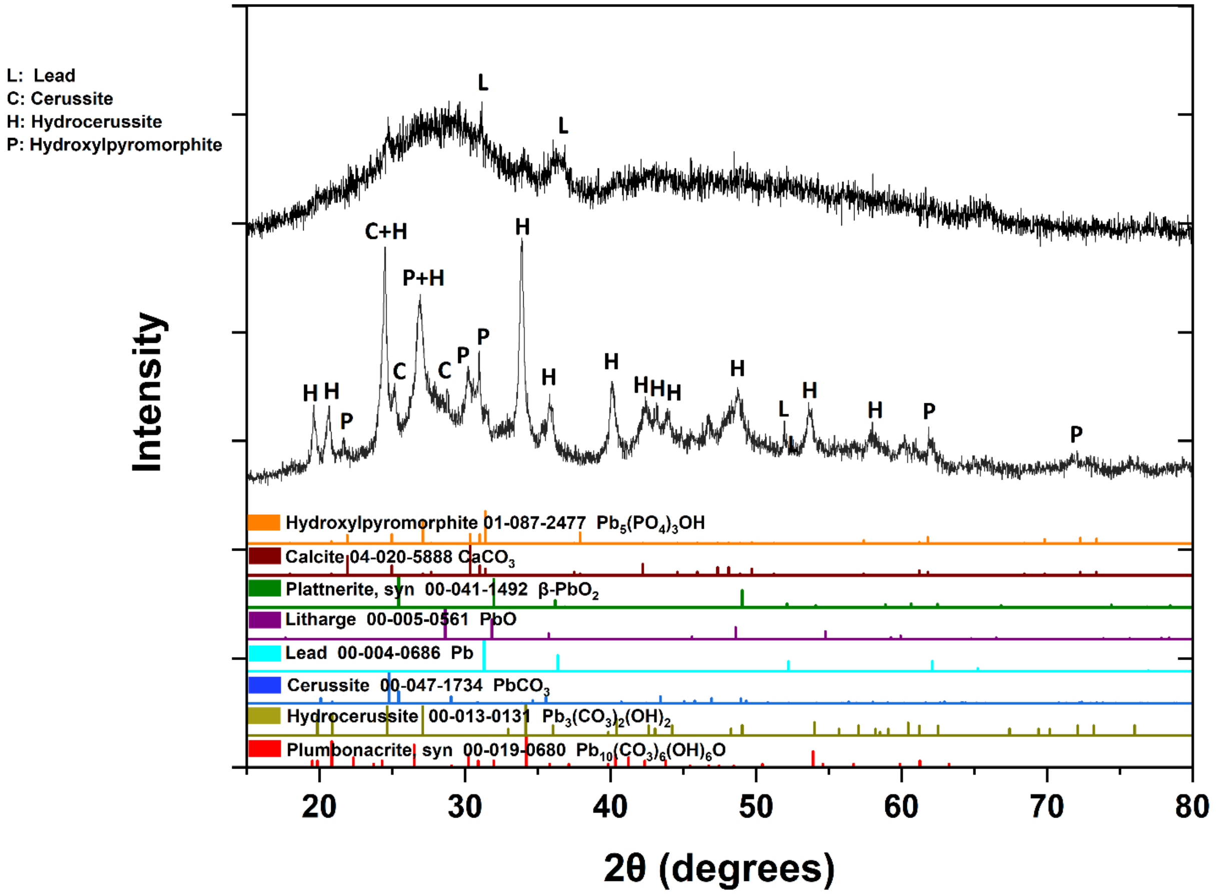


Figure 6. XRD patterns obtained from the surface of the pipe segment 2-3A for the top layer and the bottom layer for a range of 15° to 80° 2θ.

Quantitative Elemental Composition Using ICP-MS. ICP-MS was used to quantitatively determine the elemental compositions of both the top and bottom layers, and the results are summarized in **Table 6**. The top layer exhibited a lead concentration of 60 mg/g, while the bottom layer contained 56 mg/g. Both layers contained notable amounts of Al, Fe, and Ca, with slightly lower concentrations of these elements in the bottom layer. These findings are consistent with the EDS results. Phosphorus was also detected in both layers, with a higher concentration in the bottom layer. This agrees with the XRD results, which identified hydroxylpyromorphite in the bottom layer. Manganese was detected in both layers and was consistently observed across all four pipe segments. The relatively high Mn content suggests the presence of manganese-containing amorphous solids, particularly in the top layer of the scale. These amorphous materials likely incorporate other elements, including Al, Ca, Fe, and P, as indicated by both EDS and ICP-MS analyses. Carbon and oxygen were also expected to be present in both layers.

Lead Pipe 3-1 A Results:

Visual Inspection. The pipe segment had two visually distinguishable layers (**Figure 7**): a fluffy dark brown top layer and a compact light brown bottom layer. However, the due to the insufficient amount of scale materials in the bottom layer, two layers were collected as a single unit for XRD and ICP-MS analysis.

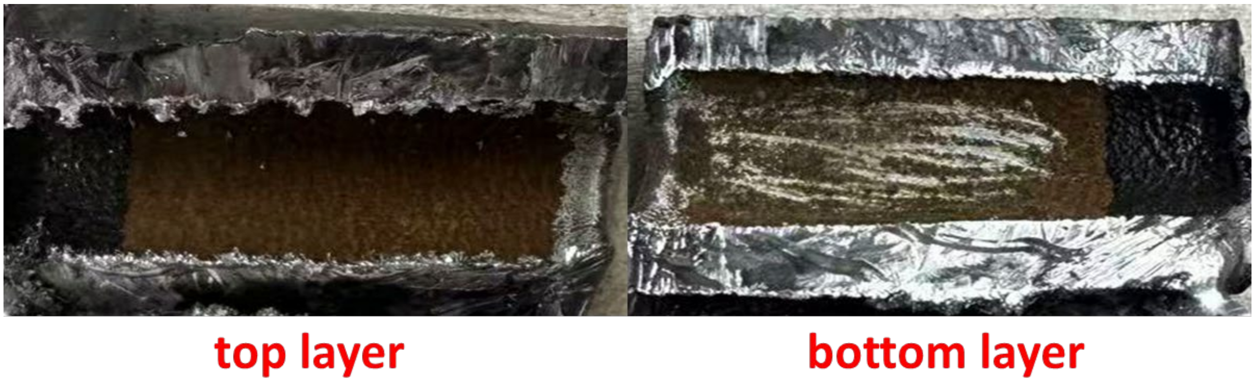


Figure 7. Photographs of the transverse sections of the pipe segment with a fluffy dark brown top layer and a light brown bottom layer.

Cross-sectional Imaging and Elemental Mapping Using SEM-EDS. SEM was utilized to obtain images of cross-sectional interfaces between unaltered pipe, pipe scale and epoxy. As shown in **Figure 8a**, the thickness of the scale was about 50 μm.

EDS analysis provided semi-quantitative information on weight percentages of selected elements (C, O, Pb, Mn, Al, Si and P). Overall elemental mapping was conducted on the cross-sectional image obtained by SEM **(Figure 8c)**. In addition to the overall elemental mapping, five marked areas were chosen for elemental composition analysis (**Figure 8b**). The distributions of selected elements for the marked areas are summarized in **Table 3**. Area 1 was the unaltered lead pipe. Area 2 was epoxy used to fill the pipe in preparing the cross section. Areas 3, 4, and 5 were the scale. C was detected to be most abundant in the epoxy and some in the scale. A substantial amount of Mn and some Al, Si and P were detected in the scales. Pb was the most abundant in the unaltered pipe and in the scale.

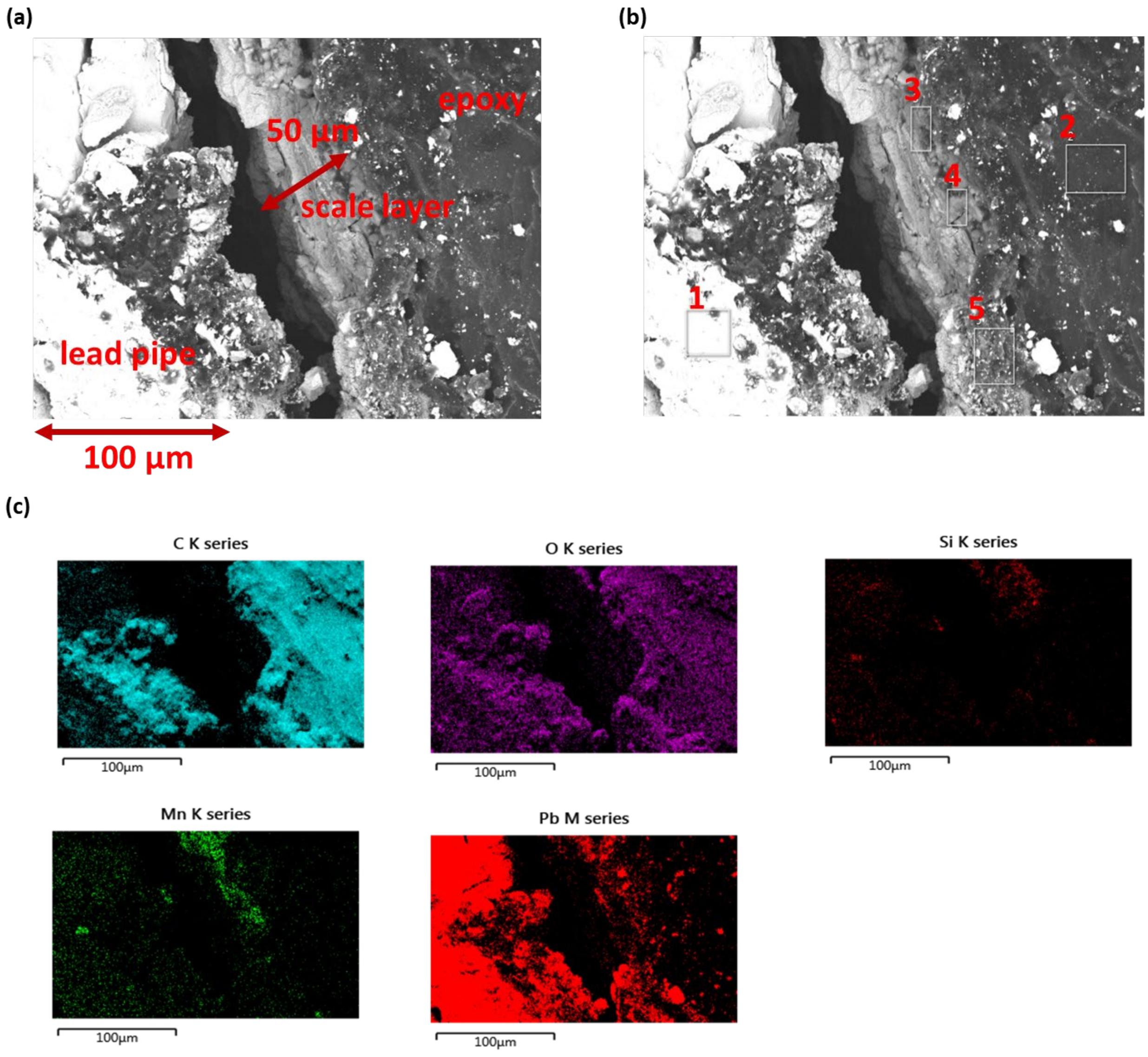


Figure 8. (a) SEM image of the cross-section of the pipe **(b)** backscattered electron SEM image of the pipe with the highlighted regions on which EDS was conducted for elemental analysis, and **(c)** overall elemental mapping of different elements detected by EDS.

Table 3. Weight percentage (wt%) of selected elements for different highlighted areas as determined using EDS. Numbers in red represent detected values of low confidence on the exact numerical value reported while numbers in black are readings that have a high level of confidence on the numerical value reported.

Element (wt %)	**Overall**	**1**	**2**	**3**	**4**	**5**
Pb	68.2	85.9	1.5	43.0	36.7	23.6
O	4.5	1.7	9.7	4.3	3.3	8.2
C	23.4	11.8	88.1	21.2	20.9	65.2
Al	0.4	0.2	0.1	0.7	0.1	0.2
Mn	1.9	0.0	0.1	17.7	32.6	0.2
Si	0.9	0.2	0.0	3.7	0.5	0.5
P	0.1	0.0	0.0	0.2	0.7	0.7

Solid Characterization Using XRD. XRD was used to identify crystalline phases in both the top and bottom layers. Results for the two layers are shown in **Figure 9.** Both layers only had amorphous phases with no distinct peaks. Patterns of hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and magnetite (Fe_3O_4) were detected. The key findings from the XRD patterns of both pipe scale layers are summarized in **Table 5.**

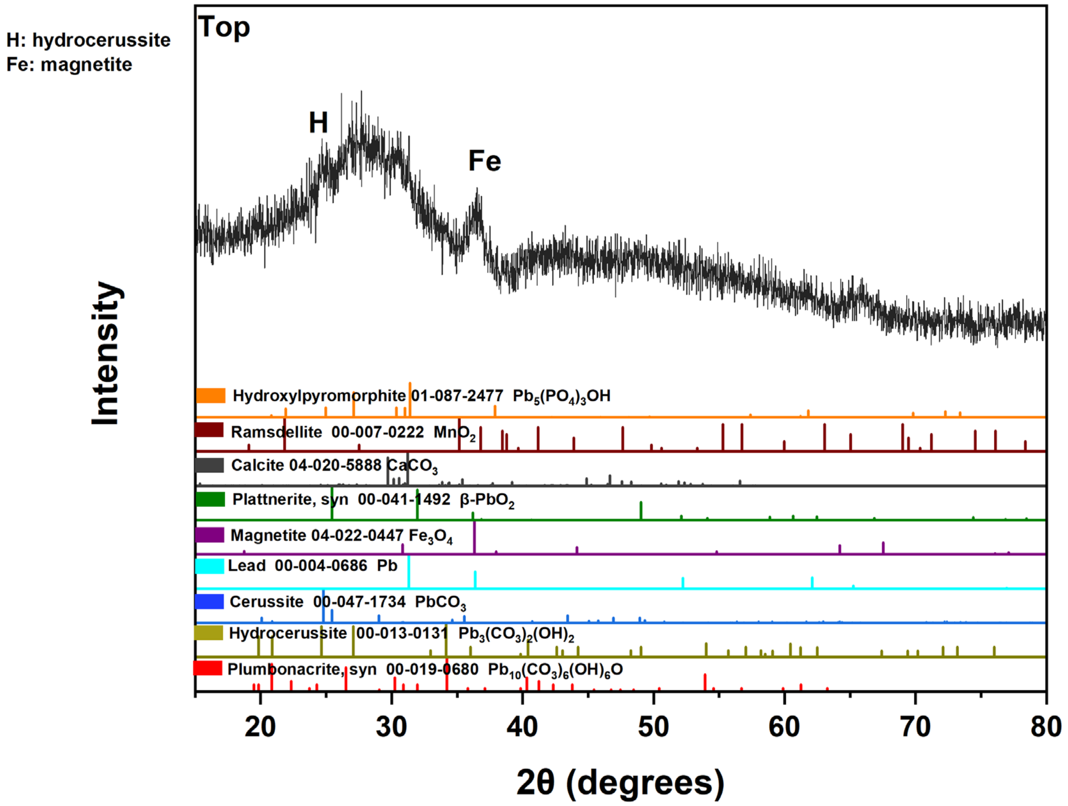


Figure 9. XRD patterns obtained from the surface of the pipe segment 3-1A for the top layer and the bottom layer for a range of 15° to 80° 2θ.

Quantitative Elemental Composition Using ICP-MS. ICP-MS was utilized to quantitatively determine elemental compositions of the scale layer. Results are summarized in **Table 6**. The scale layer had a lead mass concentration of 63 mg/g. The layer also had appreciable Mn and some Al detected. A minor amount of P was also detected. The relatively high content of Mn along with the detection of some Al and P in the layer without a crystalline phase indicated by XRD suggest that amorphous solids containing these elements are present in that layer. Carbon and oxygen were expected to be present in both layers.

Lead Pipe 3-3 A Results:

***Visual Inspection*.** The pipe segment had two visually distinguishable layers (**Figure 10**): a dark brown top layer and a light brown bottom layer. However, due to the insufficient amount of scale materials in the bottom layer, two layers were collected as a single unit for XRD and ICP-MS analysis.

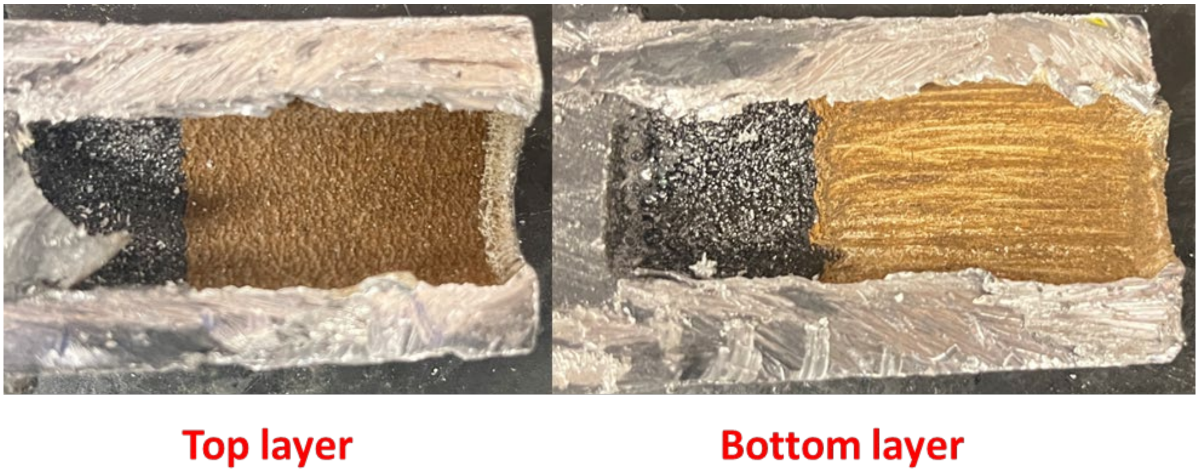


Figure 10. Photographs of the transverse sections of the pipe segment with a dark brown top layer and a light brown bottom layer.

Cross-sectional Imaging and Elemental Mapping Using SEM-EDS. SEM was utilized to obtain images of cross-sectional interfaces between unaltered pipe, pipe scale and epoxy. As shown in **Figure 11a**, the thickness of the scale was about 130 μm.

EDS analysis provided semi-quantitative information on weight percentages of selected elements (C, O, Pb, Al, and Si). Overall elemental mapping was conducted on the cross-sectional image obtained by SEM **(Figure 11c)**. In addition to the overall elemental mapping, five marked areas were chosen for elemental composition analysis (**Figure 11b**). The distributions of selected elements for the marked areas are summarized in **Table 4**. Area 1 was the unaltered lead pipe. Area 2 was epoxy used to fill the pipe in preparing the cross section. Areas 3, 4, and 5 were the scale. C was the most abundant element in the epoxy. Pb was the dominant element in the unaltered pipe. In the scale layer, C and Pb were present at comparable levels, along with a substantial amount of O. Minor amounts of Si, Al, and Ca were also detected in the scale layer.

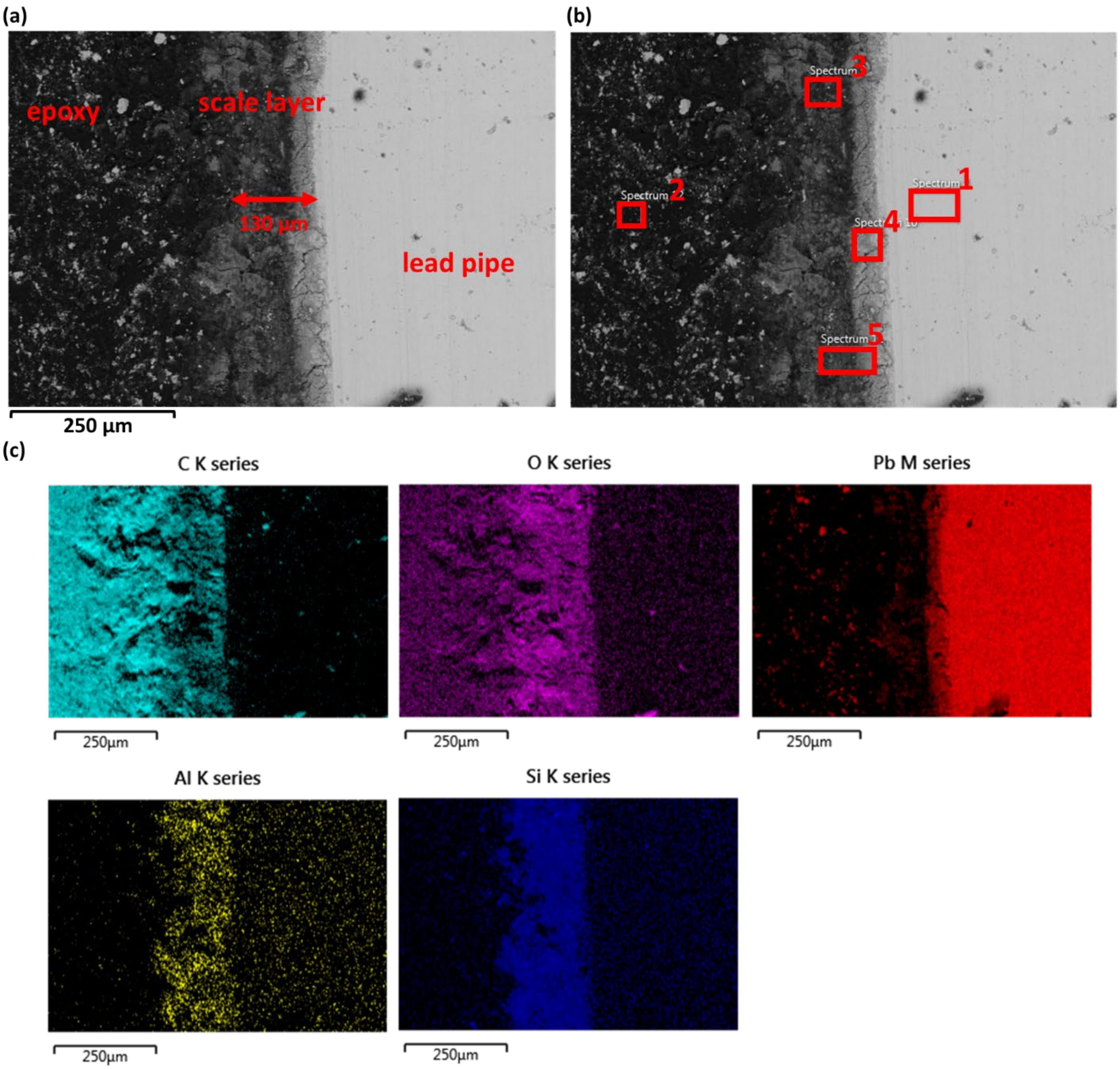


Figure 11. (a) SEM image of the cross-section of the pipe **(b)** backscattered electron SEM image of the pipe with the highlighted regions on which EDS was conducted for elemental analysis, and **(c)** overall elemental mapping of different elements detected by EDS.

Table 4. Weight percentage (wt%) of selected elements for different highlighted areas as determined using EDS. Numbers in red represent detected values of low confidence on the exact numerical value reported while numbers in black are readings that have a high level of confidence on the numerical value reported.

Element (wt %)	**Overall**	**1**	**2**	**3**	**4**	**5**
Pb	51.5	87.5	5.7	16.1	63.4	35.4
O	10.3	2.7	14.8	20.7	13.6	19.4
C	34.5	9.3	79.2	55.9	19.0	36.8
Al	0.7	0.2	0.1	1.3	0.7	1.5
Fe	0.4	0.0	0.0	0.8	0.1	0.6
Si	2.0	0.2	0.1	4.3	1.9	4.9
Ca	0.6	0.0	0.0	0.8	1.2	1.4

Solid Characterization Using XRD. XRD was used to identify crystalline phases in the scale layers. Results are shown in **Figure 12.** The scale layer contained amorphous materials indicated by the broad patterns of XRD peaks. Elemental lead (Pb) was also detected, likely due to incidental incorporation of underlying unaltered lead pipe when the scale layer was scraped from the pipe. The key findings from the XRD patterns of both pipe scale layers are summarized in **Table 5.**

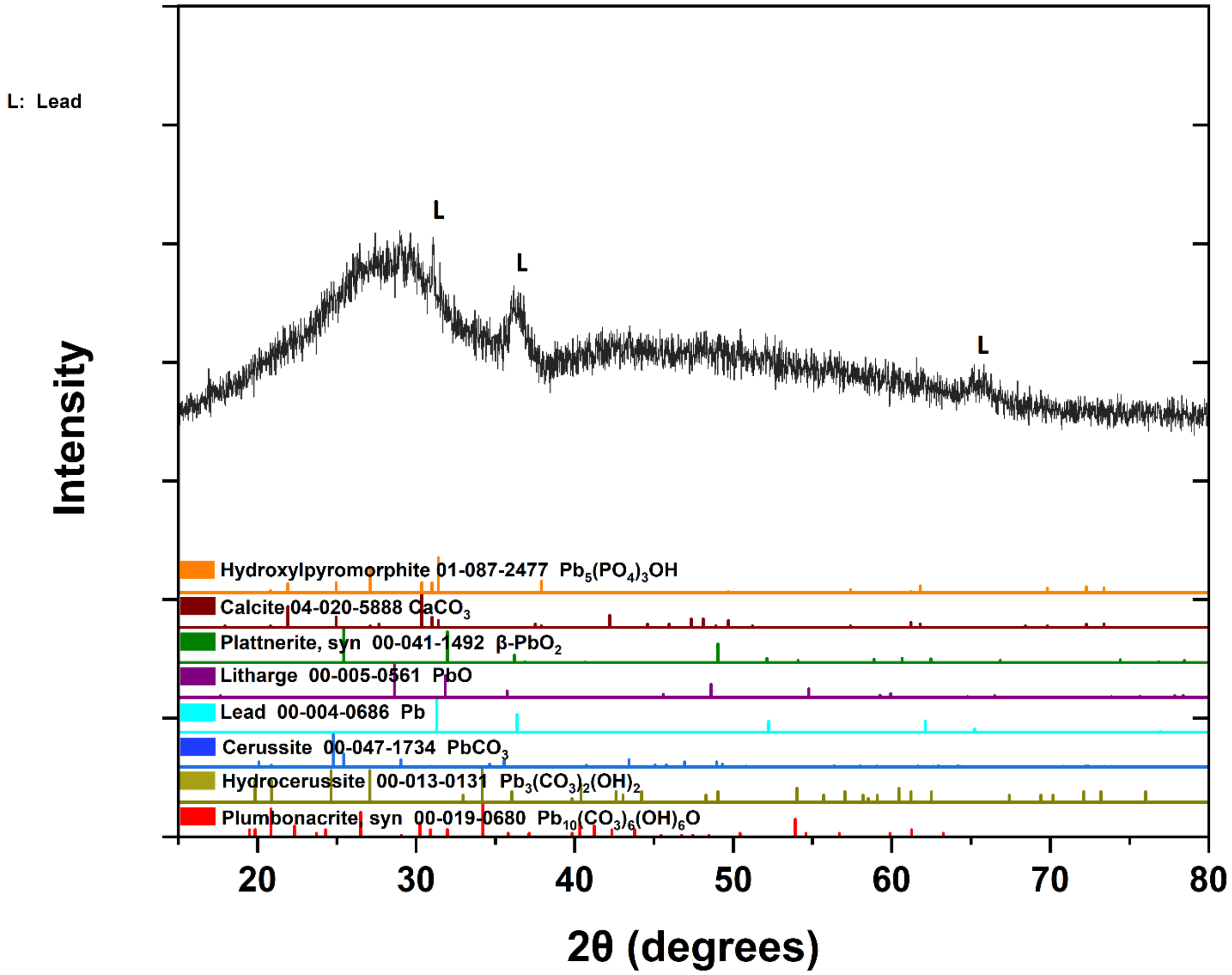


Figure 12. XRD patterns obtained from the surface of the pipe segment 3-3A for a range of 15° to 80° 2θ.

Quantitative Elemental Composition Using ICP-MS. ICP-MS was utilized to quantitatively determine elemental compositions of the scale layer. Results are summarized in Table 6. The scale layer had a lead mass concentration of 56 mg/g. The layer also had appreciable amounts of Al, Fe, Ca, and Mn. A minor amount of P was also detected. The relatively high Mn content suggests the presence of manganese-containing amorphous solids, particularly in the top layer of the scale. These amorphous materials likely incorporate other elements, including Al, Ca, Fe, and P, as indicated by both EDS and ICP-MS analyses. Carbon and oxygen were expected to be present in both layers.

Table 5. Summary of XRD results for the powdered samples from the lead pipe surfaces.
*'++' indicates that a certain mineral was abundant. '+' indicates that a certain mineral was detected but not abundant. '-' indicates that a certain mineral was not found.

Segment ID	Hydrocerussite ($Pb_3(CO_3)_2(OH)_2$)	Cerussite ($PbCO_3$)	Hydroxlypyromorphite ($Pb_5(PO_4)_3OH$)	Magnetite (Fe_3O_4)
2-1 A Top	+			+
2-1 A Bottom	+			+
2-3 A Top				
2-3 A Bottom	+	+	+	
3-1 A	+			+
3-3 A				

Table 6. Mass concentration (mg/g) of elements in the scales determined by acid digestion of solids followed by analysis with ICP-MS.

Layer	**Pb**	**Fe**	**Ca**	**Al**	**Mn**	**P**
2-1 A Top	154.5 ± 11.9	N.D.	N.D.	38.6 ± 3.0	170.9 ± 13.2	11.0 ± 0.8
2-1 A Bottom	130.5 ± 10.1	N.D.	N.D.	32.7 ± 2.5	125.2 ± 9.7	5.1 ± 0.4
2-3 A Top	60.1 ± 5.1	47.1 ± 4.0	56.4 ± 4.8	55.9 ± 4.8	33.7 ± 2.9	5.1 ± 0.4
2-3 A Bottom	55.9 ± 4.6	35.1 ± 3.0	32.3 ± 2.7	36.9 ± 3.1	12.8 ± 1.8	11.5 ± 1.0
3-1 A	62.7 ± 4.8	N.D.	N.D.	27.5 ± 2.1	127.7 ± 9.9	5.6 ± 0.4
3-3 A	55.5 ± 4.5	46.2 ± 3.9	25.8 ± 2.2	51.7 ± 4.4	20.6 ± 1.8	3.3 ± 0.3
Detection limit	6	25	6	5	5	6

Uncertainties indicated are from the propagation of uncertainty in the specific measurements made in determining the mass concentrations.

Conclusions

- All four pipe segments showed two visually different scale layers: a darker brown top layer and a lighter brown or yellowish bottom layer for Pipe segment 2-3 A, 3-1 A, and 3-3 A; a light brown top layer and a dark brown bottom layer for Pipe segment 2-1 A.
- While the thickness of the Segment 2-3 A scales was around 250 µm as determined by SEM, Scales on segments 2-1 A, 3-1 A and 3-3 A were much thinner (50-130 µm). Measurement from EDS showed that the scale layer was mostly composed of Pb, C and O. Some Al and Si were detected in all pipes, while substantial amounts of Mn were detected in Segments 2-1A and 3-1A. This observation is consistent with our previous scale analysis, in which Mn was extensively detected in both the top and bottom layers of the lead pipe segment collected from 105 E-Oak Street, Wausau, Wisconsin, in August 2025. Although Mn was not identified by EDS in Segments 2-3 A and 3-3 A, potentially due to its heterogeneous distribution, ICP-MS results indicate its presence in all four pipe segments.
- According to XRD, the top layers of all four segments were largely amorphous. Peaks associated with hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and magnetite (Fe_3O_4) were detected in the top layer of Segments 2-1A and 3-1 A.
- For Segment 2-1A, the bottom layer exhibited XRD patterns similar to those of the top scale layer, consisting primarily of amorphous phases with peaks corresponding to hydrocerussite ($Pb_3(CO_3)_2(OH)_2$) and magnetite (Fe_3O_4). In contrast, the bottom layer of Segment 2-3A showed distinct peaks associated with cerussite ($PbCO_3$), hydrocerussite ($Pb_3(CO_3)_2(OH)_2$), and hydroxylpyromorphite ($Pb_5(PO_4)_3OH$), aligning with the scale formation expected under orthophosphate-amended conditions.
- ICP-MS results indicated substantial amounts of Mn and Al in all four segments. This indicates the compositions of amorphous materials identified by XRD. In addition, Fe and Ca were also present at appreciable amounts in Segments 2-3A and 3-3A.
- Phosphorus was detected in the scale from all four segments (3.3-11.5 mg/g), consistent with the application of orthophosphate. Notably, the highest phosphorus concentration was observed in the bottom layer of Segment 2-3A. This aligns with the XRD results, which suggest that orthophosphate treatment facilitated the formation of lead-phosphate mineral phases.

Wausau Water Works
Ben Brooks, Wastewater Superintendent

DATE: April 8, 2026
TO: Wausau Water Works Commission
SUBJECT: Discussion and Update on Influent, Effluent and Biosolids PFAS Testing.

PURPOSE

Discussion and Update on Influent, Effluent and Biosolids PFAS Testing.

BACKGROUND

Dear Commissioners,

This memo provides an update on ongoing testing and monitoring efforts related to per- and polyfluoroalkyl substances (PFAS) in both treated effluent and biosolids at the Wausau Wastewater Treatment Facility. Please reference the PFAS testing spreadsheet for recent results. Please keep in mind that Effluent PFAS concentrations are measured in units of part per trillion (ppt) or nanograms per liter (ng/l). Biosolids are measured in units of parts per billion (ppb) or nano grams per liter (ng/g).

As a WDNR requirement listed in the draft WPDES permit received, the wastewater utility is required to test effluent PFAS concentrations bi-monthly for two years and biosolids PFAS concentrations one time annually for the length of the five-year permit term. Even though the final WPDES Permit has not been issued, the requirements listed in the draft permit must be adhered to.

Effluent PFAS Testing:

The Utility will continue to conduct bi-monthly sampling of treated effluent to evaluate the presence and concentration of PFAS compounds. Recent sampling results indicate that PFAS levels remain consistent with previously observed trends, which include a couple of statistical outliers. Concentrations detected are within the WDNR guidance level of eight parts per trillion.

Sampling protocols follow current state guidance, and all laboratory analyses are conducted using approved EPA methodologies. Results are being reported to the appropriate regulatory agencies, and staff continue to monitor for any changes in regulatory standards or recommended limits.

Biosolids PFAS Testing:

Biosolids generated at the facility have also been sampled and analyzed for PFAS compounds. Test results confirm the presence of PFAS at levels below the WDNR guidance, meaning no action or treatment is required by the Utility. WDNR guidance requires action be taken by a utility with levels reported above a combined PFOA/PFOS concentration of twenty ppb or (ng/g).

At this time, there are no enforceable federal or state regulatory limits specific to PFAS concentrations in biosolids. However, the Utility is proactively tracking developments in regulatory policy and guidance, particularly regarding land application practices.

Ongoing Actions:
The Wausau Wastewater Utility is taking the following steps to address PFAS concerns:

- Continuing routine monitoring of both effluent and biosolids
- Maintaining compliance with all current sampling and reporting requirements
- Staying informed on evolving state and federal PFAS regulations
- Evaluating potential source reduction strategies in collaboration with industrial and commercial contributors

Conclusion:
PFAS remains an emerging area of concern for wastewater utilities nationwide. While current results do not indicate any immediate compliance issues, the Utility remains committed to proactive monitoring, regulatory compliance, and transparent communication with the Commission.

We will continue to provide updates as new information, guidance, or regulatory requirements become available.

Please feel free to contact us with any questions or if additional information is desired.

Best regards,

Ben Brooks
Wausau Waterworks – Wastewater, Superintendent

RECOMMENDATION

WAUSAU WASTEWATER: INFLUENT, EFFLUENT & BIOSOLIDS PFAS TESTING

				< 20 ng/L *(ppt)* = WDNR proposed limit	**< 8 ng/L *(ppt)* = WDNR proposed limit**			**< 20 ng/g *(ppb)* = no further action required by WDNR**	2/15/24 DNR Guidance
Wk. Day	**Sample Date:**	**Influent PFOA: ng/L *(ppt)***	**Influent PFOS: ng/L *(ppt)***	**Effluent PFOA: ng/L *(ppt)***	**Effluent PFOS: ng/L *(ppt)***	**Biosolids: PFOA ng/g *(ppb)***	**Biosolids: PFOS ng/g *(ppb)***	**Biosolids: Combined PFOA & PFOS: ng/g *(ppb)***	
DNR Tested	1/5/2021			14.8	8.48	N/A	N/A	N/A	
Tues.	10/24/2023	4.68	6.3	5.86	7.81	0.744	7.06	7.8	
Thurs.	11/30/2023	4.8	8.91	7.73	34 (sampling contamination?)	0.561	7.78	8.3	
Wed.	12/20/2023	4.67	6.36	6.68	6.74	1.00	10.3	11.3	
Mon.	1/22/2024	6.11	22.6	5.73	4.91	0.755	7.72	8.5	
Tues.	2/27/2024	5.84	6.03	7.39	5.41	0.352	5.94	6.3	
Mon.	3/25/2024	10.1	8.98	8.83	4.48	1.04	5.87	6.91	
Wed.	9/10/2025	N/A	N/A	9.33	7.18	0.529	6.63	7.159	
Tues.	2/10/2026	N/A	N/A	7.47	3.6	0.466	5.6	6.066	

Results should be inconclusive. Quality Control error on Lab COC form.