CALIFORNIA
Water Boards

Gavin Newsom
Governor

Yana Garcia
Secretary for
Environmental Protection

State Water Resources Control Board
Division of Drinking Water

Sent via email to: jbarrett@cvwd.org

May 17, 2024

James Barrett
General Manager
Coachella Valley Water District
P.O. Box 1058
Coachella, CA 92236

Dear Mr. Barrett:

COACHELLA VALLEY WATER DISTRICT – IMPROVEMENT DISTRICT NO. 8, SYSTEM NO. CA3310048 – APPROVAL OF PIPE LOOP STUDY AND CUSTOMER MONITORING PROTOCOL

The State Water Resources Control Board, Division of Drinking Water (Division) has reviewed the CVWD ID-8 Stannous Chloride Addition Implementation Plan Amendment (Amendment), submitted by Coachella Valley Water District (CVWD) on March 29, 2024. A copy of the Amendment is enclosed for reference. The Amendment was developed in response to the Division's request for a pipe loop study to evaluate the extent of chromium and tin accumulation on different pipe materials representative of typical distribution system and premise plumbing. A component of the study includes a customer tap sampling program and complaint tracking system.

The Division finds the Amendment to be comprehensive and well thought out. The proposed monitoring protocol adequately addresses the Division's request for increased monitoring in the distribution system and premise plumbing to assess long-term effects from accumulation and/or deposition of chromium and tin in distribution system and premise plumbing pipes and fixtures.

As discussed during the April 17, 2024, meeting with CVWD and CVWD consultants on the project, the Division offers the following recommendations for consideration:

1. Include a qualitative check of customer fixtures, such as kitchen faucet aerators, showerheads, home treatment devices, etc. before and after the study, to document any stannous accumulation that may impact flowrates.

2. Conduct extensive community outreach prior to stannous addition to ensure that customers are properly educated about the study and process to encourage greater understanding and participation, and ultimately, more useful data. The outreach effort should consider the target community and include implementation of a multi-lingual public education program as needed to ensure that information is properly and effectively communicated to customers.

The Division hereby approves the Amendment. CVWD may proceed with the pipe loop study and full-scale implementation of stannous chloride addition as outlined in the January 19, 2023, Stannous Chloride Addition Implementation Plan (Implementation Plan) and enclosed Amendment.

If you have any questions regarding this letter, please contact Manuel Delgado at (619) 525-4408 or manuel.delgado@waterboards.ca.gov, or me at (619) 525-4159 or chun.huang@waterboards.ca.gov .

Sincerely,

Chun Y. Huang Digitally signed by Chun Y. Huang
Date: 2024.05.17 00:08:20 -07'00'
Water Boards

Chun Y. Huang, P.E.
District Engineer

Enclosure: CVWD ID-8 Stannous Chloride Addition Implementation Plan Amendment

cc: Joanne Le, Director of Environmental Services, CVWD (via email w/ encl)
Randy Mayes, WQ Supervisor, CVWD (via email w/ encl)
County of Riverside, Department of Environmental Health (via email w/o encl)

ENCLOSURE

CVWD ID-8 Stannous Chloride Addition Implementation Plan Amendment

CHAPTER 1. INTRODUCTION

On January 19, 2023, Coachella Valley Water District (CVWD) submitted to the State Water Resources Control Board, Division of Drinking Water (Division) a *Stannous Chloride Addition Implementation Plan* (hereafter referred to as the 2023 Implementation Plan) for reductive treatment of hexavalent chromium at wells serving its Improvement District No. 8 (ID-8) water system. On September 27, 2023, the Division conditionally approved full-scale demonstration of stannous chloride ($SnCl_2$) addition without filtration (stannous treatment) as an extension of the previous demonstration testing performed in ID-8 for purposes of gathering the necessary data to evaluate the efficacy and long-term impacts of this treatment method.

Specifically, the Division noted potential risks of stannous treatment related to accumulation, release, and re-oxidation within distribution and premise plumbing systems. Additional testing and data collection were deemed necessary to demonstrate that stannous treatment can be operated to meet treatment objectives consistently and reliably at all locations in the distribution system without adverse long-term impacts.

This document builds upon and serves as an amendment to the 2023 Implementation Plan for the purposes of addressing the Division's comments and conditions (per its letter to CVWD dated September 27, 2023) including the following updates:

- Additional distribution system sampling to better evaluate the effects of stannous chloride treatment (Chapter 3.1)
- The addition of customer premise plumbing tap sampling (Chapter 3.2)
- The addition of a customer complaint tracking tool (Chapter 3.3)
- Development of a pipe rig study protocol to evaluate the extent of chromium and tin accumulation on different pipe materials representative of the distribution system and premise plumbing (Chapter 5)

In addition to the elements requested, this document also provides a summary of how the preliminary technical performance criteria and metrics will be used assess the effectiveness, risks, and viability of stannous treatment (Chapter 4).

It should be noted that this document was developed as part of a broader demonstration plan framework for stannous treatment that included a literature review, a comprehensive risk and uncertainties analysis applicable to both the ID-8 and Cove Community systems, an evaluation of various testing "tools" (inclusive of bench-, pilot-, and full-scale methods) to address the identified risks and uncertainties, and more extensive testing recommendations. Each of these elements were developed with input from a

Technical Advisory Committee (TAC)[1] comprised of drinking water industry technical experts in chromium treatment, chemistry, and distribution system effects.

CVWD has planned for a sequenced approach to testing that involves implementing the pipe rig protocol first, prior to a full-scale demonstration in ID-8. This approach will help identify potential technical performance concerns early in the evaluation process and without risk to customers. If such concerns or issues are identified during the pilot, CVWD may elect to discontinue further testing of stannous treatment and/or re-direct pilot testing efforts towards other treatment approaches (including possible stannous application with filtration). If stannous treatment appears viable after completion of pilot testing, this sequenced approach will allow the full-scale test approach to be refined based on findings from the pilot.

The key elements of this document are:

- **Chapter 2 - Evaluation Framework and Schedule** provides a summary of the amended testing elements from the 2023 Implementation Plan
- **Chapter 3 - Monitoring Plan** describes the updates to the 2023 Implementation Plan related to monitoring for the ID-8 full-scale demonstration including distribution system and customer premise tap sampling, and customer experience tracking
- **Chapter 4 - Performance Evaluation Criteria** summarizes how the preliminary technical performance criteria and metrics will be used assess the effectiveness, risks, and viability of stannous treatment
- **Chapter 5 - Pipe Rig study Protocol** provides a protocol for a pipe rig study to evaluate the extent of chromium and tin accumulation on different pipe materials representative of the distribution system and premise plumbing

During the course of the full-scale demonstration, CVWD will review data as it's produced and may elect to discontinue the demonstration prematurely if results indicate the process is ineffective, does not meet the objectives, or presents unacceptable and/or unmitigable risks. As appropriate, the Implementation Plan may be further amended in the future to capture key findings from the pilot tests, in which case CVWD would submit a revised amendment to the Division.

[1] Members of the TAC include Paul Westerhoff, Arizona State University; Haizhou Liu, UC Riverside; Phil Brandhuber, Brandhuber Water Quality and Treatment; and Darren Lytle, USEPA. Appendix A includes a short bio for each of the TAC members.

CHAPTER 2. EVALUATION FRAMEWORK AND SCHEDULE

CVWD has identified the risks and uncertainties with stannous treatment that are best addressed through full-scale demonstration (vs. pilot testing) and proposed a framework of activities tailored to evaluate these in the Implementation Plan. This document presents the additional testing elements requested by the Division in response to the 2023 Implementation Plan submission. The additional monitoring is summarized in Table 1 and additional details on each of the test plan elements are provided in the following chapters.

Table 1. Framework of Updated ID-8 Full-Scale Demonstration Test Activities

Test Element	Added Elements	Uncertainties Addressed
Updated Distribution System Water Quality Monitoring	• Additional phases • New sampling locations • Event-Based Monitoring	• Confirm water quality objectives are achieved • Releases (of Sn, Cr, etc.) under various representative system operations, including during higher-risk events • Changes in water quality from system entry-point through the distribution system (inc. storage and dead-ends) • Water quality impacts of varying Sn levels (based on differences in well-specific treatment needs)
Premise Water Quality Monitoring	• Stagnation Testing • High-Flow Testing	• Water quality (including potential Cr re-oxidation) at customer taps under various hydraulic conditions • Releases (of Sn, Cr, etc.) and hydraulic release potential within premise plumbing systems • Impacts on corrosion control and Pb/Cu levels at the tap • Water quality from (and impacts to) point-of-use (POU) devices, hot water systems, etc. (and comparison to cold taps without POU devices)
Customer Complaint and Experience Tracking	• Information Collection and Categorization • Utility Response	• Aesthetic impacts to customers • Changes in customer confidence and perceptions of water quality • Performance and fouling impacts to POU devices, hot water systems, etc. • Effectiveness of utility response measures

The schedule provided in the 2023 Implementation Plan has been modified to reflect the finite nature of the demonstration test extension (driven by regulatory compliance timeframe limitations) and to best support fulfilling the objectives of the proposed activities. This including adding a baseline phase along with testing the removal of stannous feed after the period of steady operation. Table 2 provides the new schedule, which consists of five phases of unique purposes and operational conditions.

Table 2. Revised ID-8 Full-Scale Demonstration Schedule and Associated Activities						
		Phase				
		1	2	3	4	5
	Phasing from 2023 Implementation Plan, if applicable	NA (new phase)	Phase 1	Phases 2 and 3	NA (new phase)	NA (new phase)
Operations	Purpose	Establish Baseline	System Re-Acclimation	Steady Operation	System Re-Acclimation	New Baseline
Operations	Estimated Duration	At least 4 weeks	Data-dependent	At least 16 weeks (1)	Data-dependent	At least 4 weeks
Operations	$SnCl_2$ Feed Operation	Off	Turn On	On	Turn Off	Off
Activities	Distribution System Monitoring	✓	✓	✓	✓	✓
Activities	Premise Water Quality Monitoring	✓		✓	✓ (at start)	✓
Activities	Customer Complaint Tracking	✓	✓	✓	✓	✓

(1) Duration may need to be extended based on findings from pilot testing, but also must consider regulatory compliance deadlines.

NA – Not applicable

CHAPTER 3. MONITORING PLAN

The objective of this chapter is to describe the updated monitoring for the ID-8 full-scale demonstration, which includes:

- Updated distribution system water quality monitoring
- Premise water quality monitoring
- Customer complaint and experience tracking

3.1 Updated Distribution System Water Quality Monitoring

A two-tiered approach consisting of "sentinel" and "event-based" water quality monitoring is proposed to obtain a more comprehensive understanding of water quality conditions and spatial/temporal changes throughout the ID-8 distribution system. This is similar to the monitoring approach presented in Table 7 of the 2023 Implementation Plan with the following updates: the event-based sampling is separated out, there are two new monitoring locations, and there a two new phases to the monitoring as discussed in Chapter 2.

Sentinel Monitoring

Sentinel monitoring involves paired-in-time sampling throughout the system (from sources to extremities) on a regular, pre-determined schedule. This approach is best suited for informing spatial changes in water quality and identifying re-acclimation equilibrium in Phases 2 and 4. Figure 1 illustrates the proposed locations of sentinel monitoring sites throughout the ID-8 system. The sentinel sample locations within ID-8 were previously listed in Table 5 of the 2023 Implementation Plan and include each of the four well entry-points (POEs), four sample stations (SSs) used for routine bacteriological sampling (located at Palm Drive, Rask Rd, Holeman Rd, and BPS 4701), and two storage tanks (T3501-1, T4711-1).

In addition to the locations identified in the 2023 Implementation Plan, CVWD will identify and include two additional sentinel locations as follows:

- A dead-end site in the eastern-most pressure zone (Indio Hills). CVWD will identify a suitable sample location that is along a dead-end segment but is also upstream of one or more customers so as to reflect water that could be consumed (see "Indio Hills Dead-End Site" in Figure 1).
- A site in the Bubbling Wells pressure zone, which is a "dead-end" neighborhood near the wells with significant asbestos cement (AC) pipe on the western side of the system (see "Bubbling Wells Site" in Figure 1).

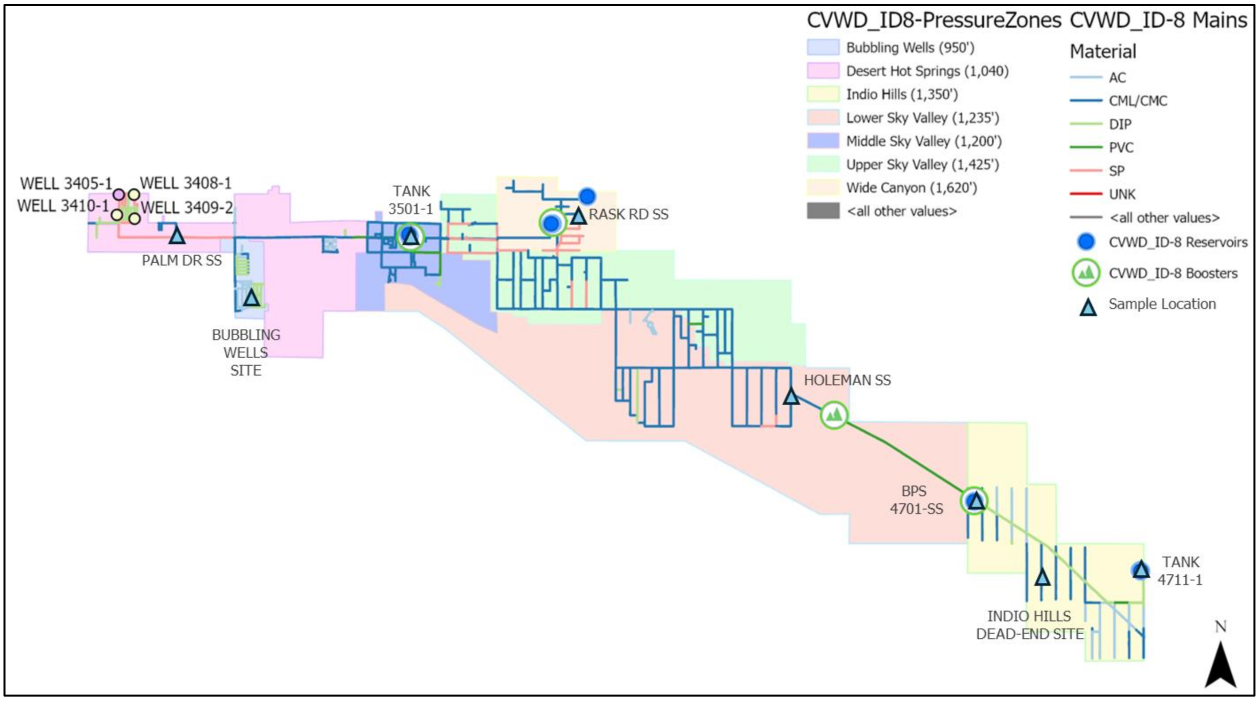

Figure 1. ID-8 Distribution System Sentinel Monitoring Locations Including Two New Sampling Locations

Event-Based Monitoring

Event-based monitoring involves localized, higher frequency sampling performed during and after system events that pose a higher risk of mobilizing pipe deposits, including Sn and Cr that may have accumulated. This approach is best suited to help identify the conditions, frequencies, and extent to which releases may occur. Events could include both anticipated operations (e.g., turning one or more wells on or off, turning a booster pump on/off, turning $SnCl_2$ feed off, replacing a main, valve exercising, flushing activities, etc.) as well as responding to customer complaints or system upsets (e.g., main break). Event-based sampling locations are selected to be local to the source of event and can include sentinel monitoring sites and nearby fire hydrants.

Water Quality Parameters

Table 3 lists water quality parameters proposed for sampling and analysis during full-scale demonstration testing. Notably, this list has been expanded relative to the 2023 Implementation Plan. Additional parameters may be included in the future pending findings from the pilot phase and additional POE monitoring conducted prior to full-scale demonstration testing to fill identified data gaps.

	Parameter	Units	Analytical Method	Detection Limit
Field	pH	pH units	SM[a] 4500-H+	n/a
	Temperature	degrees C	SM 2550	n/a
	Free Chlorine Residual	mg/L as Cl_2	HM[b] 8021	0.02
	Turbidity	NTU	EPA 180.1	n/a
	Oxidation-Red. Potential (ORP)	mV	SM 2580	n/a
	Hexavalent Chromium (Cr-6)	μg/L	Hach 8023	10
Laboratory	Hexavalent Chromium (Cr-6)	μg/L	EPA 218.6	0.25
	Total Chromium (Cr)	μg/L	SM 3113-B	2.0
	Total Tin (Sn)	mg/L	EPA 200.7	0.046
	Alkalinity	mg/L as $CaCO_3$	SM 2320-B	3.0

Table 3. Water Quality Parameters and Methods[1]

(1) Final method selection subject to consideration of existing CVWD lab capabilities

(2) Parameters in **bold** indicate a new parameter or method not previously included in the 2023 Implementation Plan

a Standard Method

b Hach Method

c Environmental Protection Agency Method

3.2 Premise Water Quality Monitoring

Sampling will be coordinated within the premises of customer participants to understand water quality associated with real-world premise systems and confirm whether water quality objectives are consistently met all the way to points of use/consumption.

CVWD will solicit the involvement of ideally 5 to 10 customers in the ID-8 system (reflecting a combination of homes, businesses, and CVWD facilities) to participate in premise sampling activities. Participants will be selected based on consideration of: past participation in LCR sampling (to provide a point of comparison with historical Pb/Cu results); service line and plumbing materials (to obtain a representative sampling of materials used throughout CVWD's systems); and customer willingness to participate at various levels and multiple times over the course of the study (to assess changes over time).

As shown in Table 4, multiple sampling methods will be pursued to evaluate different aspects of premise water quality and impacts of premise conditions. The parameters previously listed Table 3 will also be analyzed during premise sampling activities, although there may be limitations in monitoring field parameters when customers are relied upon to collect samples from within their homes. For each round of premise testing, sampling will be conducted in the distribution system near the premise connection to establish background water quality serving the premise.

Table 4. Anticipated Premise Sampling Methods		
Sampling Method	Purpose	Sample Tap(s)
First Draw after ≥ 6-hour Stagnation	First draw 125 – 250 mL Modified 1st (750 mL) through 5th (1000 mL) volumes – approximates LCR regulatory approach to assess corrosion control effectiveness (opportunity to compare with historical results and over the course of the study with/without $SnCl_2$ addition) Assess releases due to long stagnation	Kitchen tap w/o point-of-use (POU) device, cold
First Draw after 30-minute Stagnation	Reflects a typical exposure scenario Compare with POU device performance Compare hot vs cold	Kitchen tap w/o POU, cold Kitchen/fridge tap with POU, cold Kitchen tap, hot
Profile Sampling During High-Flow Condition (open all cold taps and hose bibs)	Assess accumulation Assess hydraulic release and concentration potential	Kitchen tap w/o POU, cold Sample point furthest along flow stream

3.3 Customer Complaint and Experience Tracking

Water quality-based customer complaints will be tracked throughout the full-scale demonstration test and used to obtain detailed information on customer experiences with respect to aesthetic water quality (e.g., turbidity, discoloration, taste, odor, etc.), fouling of home devices/systems, spotting, etc. CVWD will create a template to standardize information collection (see example below). Ultimately, the data will be compared: (i) to historical complaint trends, and (ii) between each of the five test phases, to characterize changes in customer experiences and differences over time. CVWD will follow its standard protocol for response activities, with the addition of follow-up sample collection when warranted (consistent with the event-based monitoring protocol).

In addition, customers who participate in premise sampling will be queried for their experience and observations with respect to aesthetic water quality conditions and changes with stannous treatment, impacts to POU devices, etc. A series of targeted questions will be developed to standardize the information collection process.

Example of Costumer Complaint Template

- Location / address / customer name and phone
- Date the complaint was placed or call received
- Date and time the issue most recently occurred
  - When did the issue first start (approx. date)?
  - How long and how many times has this been observed?
- Describe the nature of the complaint, and check if it falls within one of the following categories:
  - Discolored water (what is the color?)
  - Turbid or particle-laden water (do the particle settle or float if a glass of water sits?)
  - Taste problem (describe taste)
  - Odor problem (describe odor)
  - Fouling of a device, such as a home filter
  - Spotting of a fixture or surface
  - Staining of laundry
  - Other type of issue (describe)
  - Non-water quality concern (i.e. low pressure)
- What is the water usage pattern at the location/property prior to observation (i.e. how long since the tap was previously used, was the property vacant for some time)?
- Did the issue occur with hot water, cold water, or both?
  - If hot water is involved, when was the last prior time hot water was used?
  - Is the issue / observation resolved if cold water is used?
- Did the issue occur at a tap with an in-home treatment device (such as a filter, water softeners, or other)?
- What is the age of the property?
- What is the plumbing type (i.e., copper, galvanized, or plastic)?
- Did you notice anything that helped the problem (such as running cold or hot water for a period of time)?

CHAPTER 4. PERFORMANCE EVALUATION CRITERIA

CVWD will review data throughout the ID-8 demonstration study to assess the effectiveness, risks, and viability of stannous treatment. Various criteria will be used to guide on-going decision-making on any necessary adjustments or restorative measures as well as determine any "technical performance concerns" that may warrant cessation of the study as proposed. If the full-scale demonstration test is considered successful, CVWD may re-start the full-scale demonstration to capture long-term data that would improve the understanding of any potential long-term concerns with stannous addition.

Table 5 provides a preliminary summary of technical performance criteria and metrics to be applied to the data, subject to refinement based on findings from the pilot phase.

Table 5. Preliminary Performance Criteria and Metrics for Full-Scale Data Evaluation

Criteria	Example Technical Performance Concerns
1. Numerical water quality objectives previously defined in Table 3 of the 2023 Implementation Plan	Inability to consistently meet objectives throughout the distribution system and at premise taps
2. Accumulation rates and inventories of contaminants (especially Sn/Cr)	Pipe volume-normalized total inventories exceed water quality objectives by a certain ratio (TBD from pilot testing)
3. Hydraulic release potential of accumulated contaminants (especially Sn/Cr)	Pipe volume-normalized hydraulically mobile inventories exceed water quality objectives by a certain ratio (TBD from pilot testing)
4. Premise Pb/Cu levels based on stagnation tests	A meaningful increase in Pb/Cu levels attributed to stannous treatment and/or alternating between phases
5. Customer water quality-based complaints	A meaningful increase in complaints attributed to stannous treatment and/or alternating between phases
6. Aesthetic water quality observations by CVWD and customers	A trend of verifiably impaired aesthetic water quality attributed to stannous treatment
7. Performance of in-home devices and systems	A trend of verifiably impaired performance, shorter lifespan, fouling/spotting, etc. of POU devices, hot water heaters, or other home systems.

CHAPTER 5. PIPE RIG STUDY PROTOCOL

This chapter provides a pipe rig study protocol which was developed as part of a broader demonstration plan framework to address remaining uncertainties in the addition of stannous chloride without filtration. Some of the key unknowns and uncertainties for the distribution system and premise plumbing pipe/appurtenances include the following:

Fate (accumulation and/or release) of Cr and Sn with:

- different pipe materials
- variable temperature and bulk water chemistry
- changing hydraulic conditions
- blending of wells with different water quality

Accumulation of co-occuring metals with Cr and Sn deposits:

- arsenic (As), iron (Fe), manganese (Mn), etc.

Aesthetic impacts:

- clogging, scaling, and/or discoloration of premise plumbing appurtences
- color, taste, or odor issues at the tap

Impacts of $SnCl_2$ addition cessation:

- continued accumulation or release of Cr_T and Sn_T and other metals
- corrosion scale impacts from changing water quality

Impacts on distribution system biofilms:

- biofilm stability or disruption and release

Impact of $SnCl_2$ with free chlorine in distribution system:

- free chlorine decay with $SnCl_2$
- total trihalomethanes and haloacetic acid formation potential
- extent of re-oxidation of Cr-3 to Cr-6 with free chlorine

5.1 Evaluate Stannous Chloride without Filtration to Achieve Hexavalent Chromium Compliance

The primary focus of this study is to evaluate whether $SnCl_2$ addition without filtration can achieve compliance with the pending Cr-6 MCL while avoiding unintended consequences caused by the accumulation and/or release of Cr and Sn. Accordingly, Table 6 identifies how certain key results would indicate either measures of success or critical failures for the pilot-scale pipe rig study.

Table 6. Summary of the Qualitative and Quantitative Goals That Will Be Used to Measure Success of $SnCl_2$ Addition Without Filtration for the ID-8 Pipe Rig Study		
Parameter/Goal	**Measure of Success**	**Critical Failure**
Cr-6 Reduction	Reduction of Cr-6 to below 10 µg/L within expected reduction times and maintained within expected distribution system residence times in 95% of samples.	Cr-6 reduction to below 10 µg/L is not consistently met, or re-oxidation causes Cr-6 concentration above 10 µg/L within expected distribution system residence times.
Cr_T Stability	Cr_T concentrations are consistent with raw water concentrations.	Cr_T concentrations are not consistent with raw water concentrations, especially if they exceed the 50 µg/L Cr_T MCL in flow through or stagnation samples.
Sn_T Stability	Sn_T concentrations are consistent with dosed concentrations.	Sn_T concentrations will be evaluated against the NSF/ANSI limit of 0.63 mg/L Sn_T in flow through or stagnation samples as well as how Sn affects Cr accumulation and release
Turbidity	Turbidity measured in flow through samples does not increase by more than 100% with $SnCl_2$ addition.	$SnCl_2$ addition results in a turbidity increase greater than 5 NTU.
Appurtenances	Headloss and flow rate through appurtenances are equivalent to the control and no fouling (clogging and scaling) is observed.	Headloss compared to control appurtenance is 20% greater, flow rate decreases by half, or visual aesthetic issues are observed (discoloration, staining, particle settlement, etc.).

5.2 Fate of Chromium and Tin with Stannous Chloride Addition

The goal of this objective is to evaluate the fate of Cr_T and Sn_T, namely their accumulation and release, with $SnCl_2$ addition to the distribution system. This will allow for a better understanding of $SnCl_2$ acclimation periods, as well as the potential risk of associated Cr_T and Sn_T, release. The fate of Cr_T and Sn_T will be evaluated by comparing pre-sediment filter concentrations of a pipe rig with $SnCl_2$ addition and a control without $SnCl_2$ addition. The impacts of pipe material, hydraulic conditions, and $SnCl_2$ cessation on Cr_T and Sn_T accumulation and/or release will be evaluated throughout the study. Upon completion, supplementary testing such as swabbing, flow reversal, or pipe scale analyses, will be completed to further quantify the potential accumulation of Cr_T and Sn_T within the pipe rig system.

5.3 Accumulation of Co-Occurring Metals with Chromium and Tin Deposits

The goal of this objective is to evaluate the accumulation and subsequent release of co-occurring metals, such as As, Fe, and Mn, within Cr and Sn deposits. This will be evaluated by comparing flow through and stagnated metals results from a pipe rig with $SnCl_2$ addition and a control without $SnCl_2$ addition. Note that this testing is dependent on the selected source water having detectable metal concentrations (e.g. As, Fe, and Mn) and may not be fully addressed during the proposed duration and observed water quality in the ID-8 wells.

5.4 Aesthetic Impacts of Stannous Chloride Addition

Aesthetic issues such as high turbidity, discoloration, and cloudiness were observed following periods of stagnation in recent $SnCl_2$ without filtration studies. This objective aims to determine whether $SnCl_2$ negatively impacts finished water aesthetics such as color, and turbidity, that may result in customer complaints. This objective also intends to evaluate whether $SnCl_2$ addition prematurely clogs, stains, or scales customer appurtenances such as flow through sediment filters, pitcher filters, and kettles. This will be completed by comparing flow and pressure, turbidity, discoloration, and staining, from appurtenances such as 5 µm sediment filters, pitcher filters, kettles, and tiles that have interacted with $SnCl_2$ dosed water and control water.

5.5 Impacts of Stannous Chloride Addition Cessation

Disruptions in water chemistry could result in the release of accumulated Cr_T and Sn_T in distribution systems from pipes, appurtenances, and potentially corrosion scales. This objective aims to evaluate the impact of removing $SnCl_2$ addition from a system previously acclimated with $SnCl_2$. Following prolonged operation, the $SnCl_2$ dosed pipe rig will stop receiving $SnCl_2$. At a minimum, $Cr_{T,}$ $Sn_{T,}$ and As, will be sampled to evaluate if removing $SnCl_2$ disrupts the equilibria of the system and results in the release of Cr_T, $Sn_{T,}$ and other co-occurring metals.

5.6 Impacts of Stannous Chloride Addition on Distribution System Corrosion Scales

Water quality parameters used to calculate corrosion and scaling indices will be collected and compared between the pipe rig with $SnCl_2$ addition and a control without $SnCl_2$ addition to further evaluate the impact of stannous chloride on distribution system corrosion scales. Pipe scale analyses at the end of the testing period can be used to compare the corrosion scales of pipes with and without $SnCl_2$ addition.

5.7 Impacts of Stannous Chloride on Chlorine Residuals and Disinfection By-Product Formation

The goal of this objective is to evaluate the chlorine demand imparted by $SnCl_2$ and potential changes to disinfection by-product (DBP) formation in water where $SnCl_2$ was added. This will be completed by observing chlorine decay with and without $SnCl_2$ addition through bottle hold tests and conducting DBP formation testing if the chlorine decay results indicate that additional chlorine is required with $SnCl_2$ to maintain CVWD's free chlorine goals.

5.8 Test Plan

A phased pipe rig test plan has been developed to facilitate the acquisition of early results. As summarized in Table 7, Phase 1 will consist of operations with new pipe materials, while Phase 2 will consist of operations with harvested pipe materials. New pipe material requires a much shorter acclimation period compared to harvested materials and will allow the evaluation of the impact of $SnCl_2$ on new services and appurtenances. Following the acclimation period, additional operational conditions will be evaluated such as flow through conditions, stagnating conditions, the cessation of $SnCl_2$ addition, as well as flow reversals or swabbing at the end of the testing period. Phase 2 will follow a similar track, with a significantly longer acclimation period. Accordingly, Phase 2 will commence upon receipt of harvested material; however, Phase 2 will be terminated if any critical failures are observed from the Phase 1 results.

Table 7. Wellsite W3408-1 Raw Water Quality Summary				
	Phase 1: New Materials		**Phase 2: Harvested Materials**	
	Phase 1A	Phase 1B	Phase 2A	Phase 2B
	1-2 weeks	3-6 months	2-3 months	3-6 months
Purpose / Goal	Acclimation of new pipe materials & evaluate impact of $SnCl_2$ on new service lines and new appurtenances	Longer term evaluation of $SnCl_2$ without filtration on new pipe materials under various operational conditions	Acclimation of harvested pipe materials & evaluate impact of $SnCl_2$ on existing service lines	Longer term evaluation of $SnCl_2$ without filtration on harvested pipe materials under various operational conditions
Design	Pipe rig consisting of new pipe materials (cement lined pipe, copper, and polyvinyl chloride (PVC), with and without $SnCl_2$ addition.		Pipe rig consisting of harvested pipe materials (cement lined pipe and/or copper, galvanized, or PVC, with and without $SnCl_2$ addition.	
Operation	Continuous flow through conditions	Periods of flow through and stagnation. Additional testing will include the cessation of $SnCl_2$ addition and flow reversal or swabbing at the end of the testing period.	Continuous flow through conditions	Periods of flow through and stagnation. Additional testing will include the cessation of $SnCl_2$ addition and flow reversal or swabbing at the end of the testing period.
Additional Testing	In-home appurtenances will be tested such as 5 µm sediment filters, pitcher filters, and tile testing.	In-home appurtenances will be tested such as 5 µm sediment filters, pitcher filters, and tile testing. DBP formation will also be evaluated.	In-home appurtenances will be tested such as 5 µm sediment filters, pitcher filters, and tile testing.	In-home appurtenances will be tested such as 5 µm sediment filters, pitcher filters, and tile testing. Disinfection by-product formation will also be evaluated.

The following chapters describe the initial pipe rig design and includes source water selection, pipe materials, chemical dosing strategies, flow rates and controls, additional appurtenances, and additional testing. Note that similar to all pipe rig studies final selection of certain conditions needs to be flexible to accommodate field conditions or initial data.

Source Water

As stated, the ID-8 PWS consists of four wellsites, 3405-2 (3405), 3408-1 (3408), 3409-02 (3409), and 3410-1 (3410), each of which have historic Cr-6 concentrations greater than 10 µg/L and will require treatment to achieve the proposed Cr-6 MCL compliance. The pipe rig study will be completed at one wellsite, with these results being projected to the remaining wellsites through desktop analyses, as necessary. These wellsites have relatively similar water quality in terms of pH, but differ in Cr_T and Cr-6 concentrations, as shown in Figure . Well 3408 appears to have slightly higher alkalinity, along with conductivity, major anions, and major cations compared to the other wellsites.

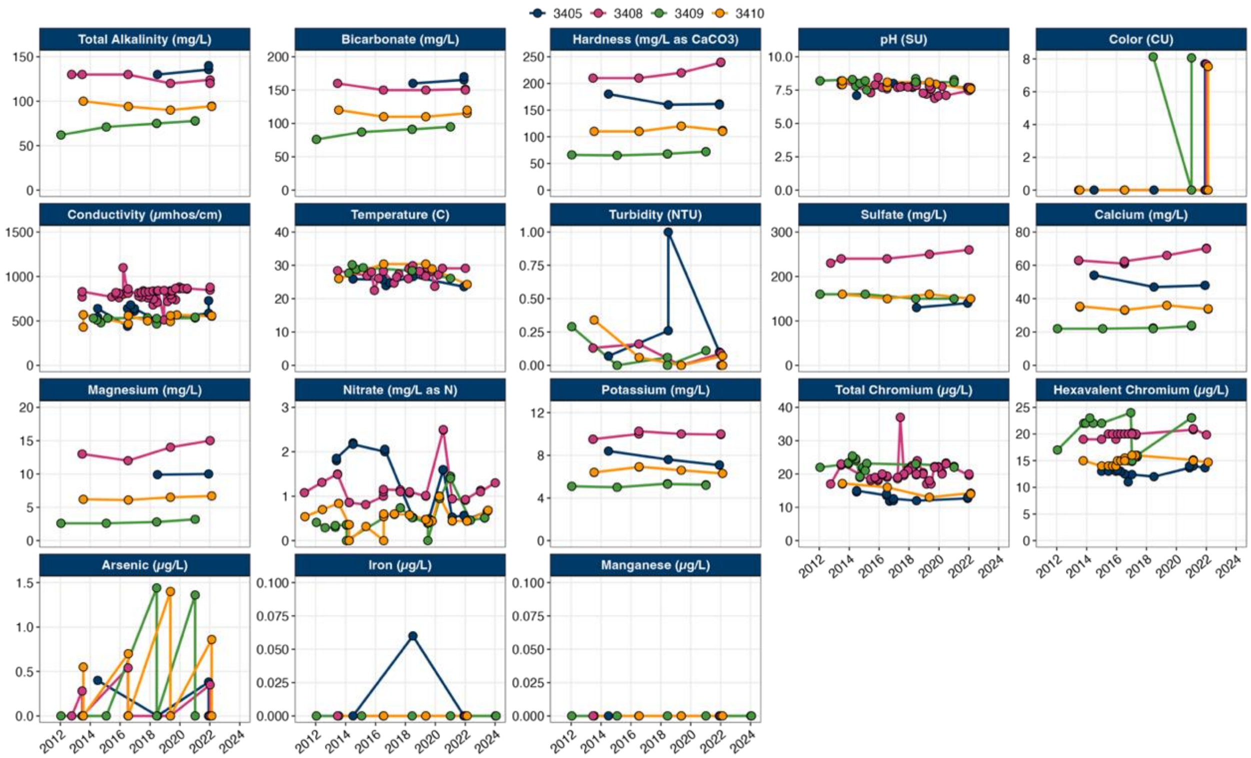

Figure 2. ID-8 PWS Source Water Raw Water Quality (2013-2022)

As previous studies have shown that Cr-6 reduction with $SnCl_2$ is relatively independent of groundwater quality, additional criteria such as site footprint, facilities, discharge capabilities, and overall safety were taken into consideration for source water selection. As such, wellsite 3408 was selected as it is the least remote location for safety, has an abandoned wellhouse for secure storage of chemicals and equipment, as well as a large shade structure to house pipe rig materials. A summary of wellsite 3408's raw water quality is presented in Table 8.

Table 8. Wellsite W3408-1 Raw Water Quality Summary from Data Over The Period 2011-2024

Analyte	Minimum	Median	Average	Maximum	Count
Alkalinity (mg/L as $CaCO_3$)	120	127	126	130	6
Hardness (mg/L as $CaCO_3$)	210	220	224	240	5
pH (SU)	6.9	7.7	7.7	8.5	28
Color (CU)	0	0	2	78	8
Conductivity (µmhos/cm)	511	823	810	1100	44
Temperature (deg C)	22.5	27.4	27.3	29.9	21
Total Dissolved Solids (mg/L)	528	550	556	670	34
Turbidity (NTU)	0.0	0.1	0.1	0.2	6
Bicarbonate (mg/L)	150	150	152	160	5
Chloride (mg/L)	26	27	28	31	5
Nitrate (mg/L as N)	0.8	1.1	1.2	2.5	34
Sulfate (mg/L)	230	240	244	260	5

Table 8. Wellsite W3408-1 Raw Water Quality Summary from Data Over The Period 2011-2024					
Analyte	**Minimum**	**Median**	**Average**	**Maximum**	**Count**
Calcium (mg/L)	61	63	64	70	9
Magnesium (mg/L)	12	14	14	15	4
Potassium (mg/L)	9.5	10	9.9	10	7
Sodium (mg/L)	2.4	88	77	89	9
Total Chromium (µg/L)	17	20	21	37	28
Hexavalent Chromium (µg/L)	19	20	20	21	16
Arsenic (µg/L)	0.0	0.3	0.3	0.5	9
Iron (µg/L)	0.0	0.0	0.0	0.0	6
Manganese (µg/L)	0.0	0.0	0.0	0.0	6

To help illustrate the initial pipe rig design, a simplified schematic of the proposed pipe rig is provided in Figure 3 below. Details of the proposed pipe rig study are further described in the Test Plan below

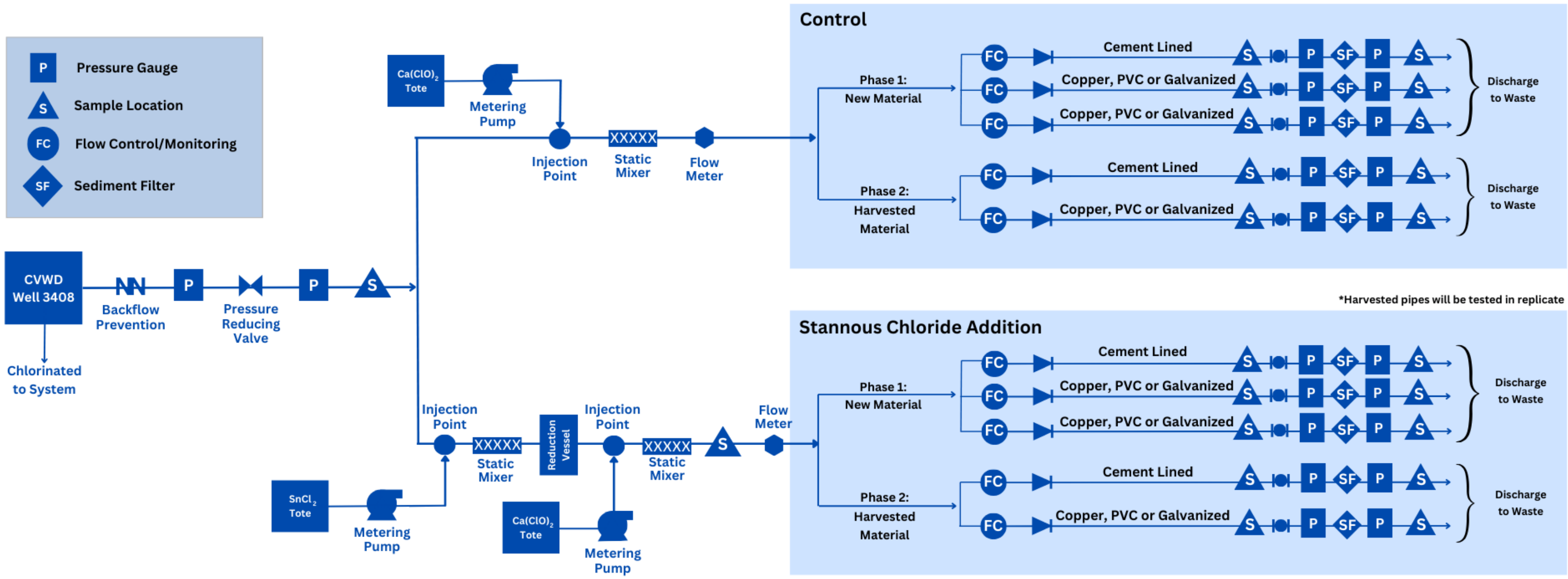

Figure 3. Simplified Pilot Schematic, Demonstrating Typical Chemical Operations, Pipe Materials, and Sampling Locations

Pipe Materials

The pipe rig study will be conducted using pipe materials that are representative of the materials found in ID-8 PWS's distribution system and service lines. Based on hydraulic model distribution system data from February 2024, the most prevalent material in the ID-8 distribution system is concrete mortar lined/concrete mortar coated steel pipe (CML/CMC), asbestos cement pipe (ACP), steel pipe (SP) and ductile iron pipe (DIP). According to the 2018 lead service line inventory completed for the publicly owned portion of the service, the most common service line material was copper, followed by PVC. A summary of the percent breakdown of each pipe material is provided in Table 9.

Table 9. ID-8 PWS Distribution System and Service Line Material Summary

Pipe Material	Length or Count	Percentage
Distribution System		
ACP	81,637 ft	13%
CML/CMC	393,970 ft	62%
DIP	61,037 ft	10%
SP	65,890 ft	10%
Other	29,132 ft	5%
Service Line		
Copper	1,089	70%
Galvanized Steel	16	1%
PVC	451	29%

If CML/CMC can be harvested at diameters feasible at pilot-scale (4-inch diameter or less), it will be included to represent the distribution system. Other pipe materials will include PVC and copper to represent service line material. New, 1-inch diameter pipe will be used during Phase 1 of the study and will be used to evaluate the impact of $SnCl_2$ on new services and appurtenances. Harvested pipe from the ID-8 PWS will be used during Phase 2 of the study, as it becomes available. Due to the protracted acclimation period required with harvested material, this phase may run concurrently with Phase 1 as soon the pipe is obtained.

Chemical Dosing Strategy

During typical pipe rig operation, the test pipe rigs will receive $SnCl_2$ fed from a diluted stock solution of Guard Products PAS 8105. The reaction time required to reduce Cr-6 will be achieved through a reduction vessel that will be installed following a static mixer. Both the control and test pipe rigs will then be fed free chlorine as calcium hypochlorite [$Ca(ClO)_2$]. While the full-scale demonstration utilized Guard Products PAS 8150 (50% $SnCl_2$), the pilot study may potentially require a 5% $SnCl_2$ solution, which may have to be further diluted based on the agreed upon pilot flowrates to maintain the dosing target at the lower flow rates at pilot-scale. $Ca(ClO)_2$ solution may be pulled from an ID-8 $Ca(ClO)_2$ reaction vessel or will be batched by dissolving $Ca(ClO)_2$ tablets into distilled water for dosing. In either case, the free chlorine strength will be measured, and the bulk solution will be diluted as needed for the pipe rig study.

Results from previous bench- and demonstration scale testing completed at the ID-8 PWS have indicated that a 0.50 mg/L as Sn is required to reduce Cr-6 and limit re-oxidation within the distribution system. As such, 0.50 mg/L as Sn will be the starting point from $SnCl_2$ addition for the pipe rig study and will be adjusted as needed. These studies also indicated 4.0 seconds of reaction time is required to reduce Cr-6 to below 10 µg/L and will be provided by a reduction vessel. $Ca(ClO)_2$ will be dosed at 2.0 mg/L as chlorine to match ID-8's EPDS free chlorine residual goal of 1.5 mg/L. Chemical feed system operation will be tied to well pump operation to ensure chemicals are not dosed when the well is not running. Table 10 summarizes the strength, intended doses, and flow rates of the chemicals being used during the pipe rig study.

Table 10. Pipe Rig Study Chemical Summary

Parameter	Value	Units	Notes
Stannous Chloride ($SnCl_2$)			
Stock percent	5.0	% as $SnCl_2$	Guard Products PAS 8105
Stock specific gravity	1.04		
Concentration	52,000	mg/L as $SnCl_2$	
	33,000	mg/L as Sn	
Diluted Concentration	26,000	mg/L as $SnCl_2$	1:1 dilution with distilled water
	16,500	mg/L as Sn	
Dose	0.79	mg/L as $SnCl_2$	
	0.50	mg/L as Sn	
Flow rate	2.0	mL/min	1-inch nominal pipe at 1 ft/sec
Calcium Hypochlorite ($Ca(ClO)_2$)			
Stock percent	TBD	% as $Ca(ClO)_2$	
Stock specific gravity	TBD		
Diluted concentration	TBD	mg/L as $Ca(ClO)_2$	
	TBD	mg/L as Cl_2	
Diluted concentration	TBD	mg/L as $Ca(ClO)_2$	
	TBD	mg/L as Cl_2	
Dose	TBD	mg/L as Cl_2	
Flow rate	TBD	mL/min	1-inch nominal pipe

Potential decreases in the performance of the stock $SnCl_2$ solution, caused by reactions with dissolved oxygen will be evaluated throughout the study. Observed changes to the solution such as color, turbidity or particle settlement will be documented, and stock solution strength will be evaluated by periodical laboratory analyses of stock dilutions of the stored 5% solution.

Flow Rates and Controls

Raw water from well 3408 will flow to pilot pipes through a nominal 3" schedule 80 PVC main feed pipe and associated saddle, complete with a backflow prevention device, isolation valves, and a pressure reducing valve, as needed. The goal is to have the well operating as near as continuously as possible to facilitate flow through conditions; however, the pipe rig will also be alternating between flowing and stagnating conditions. Flow will first be split between the control and $SnCl_2$ testing rigs, with half the flow being dosed with $Ca(OCl)_2$ for the control systems, while the other half will be dosed with $SnCl_2$ followed by $Ca(OCl)_2$. Flow through the individual pipes will be manually controlled through rotameter needle valves to achieve a velocity of 1 ft/sec during typical flow through operations, which is consistent with typical service lines and limits scouring[2].

Pipe lengths were selected to accommodate the space available within the shaded structure at well 3408, while ensuring the test sections provide a sufficient volume of water for the water quality analyses to be performed. At a velocity of 1 ft/sec with 1-in diameter, 8 ft length pipe sections, the hydraulic residence time (HRT) of each section is 8.0 seconds, with a sample volume of 1.1-L. Flow and volume calculations were also completed for 4-inch diameter cement lined pipe, as smaller diameters may not be available for harvesting. A summary of the pipe segment design and operational flow rates and volumes for new pipe materials are presented in Table 11.

Table 11. Pilot Pipe Segment Design and Operational Parameters

Parameter	CML/CMC		Copper, PVC, or Other	Notes
Diameter (in)	1.0	4.0	1.0	Nominal diameter
Velocity (ft/sec)	1.0	1.0	1.0	WRF #5081
Flow Rate (gpm)	2.1	35.8	2.1	Manually controlled by rotameter
Length (ft)	8.0	2.0 – 8.0[a]	8.0	Shorter section of CMC may need to be selected to limit the weight imposed on pipe rack
Volume (gal)	0.3	1.2 – 5.0[a]	0.3	
Volume (L)	1.1	4.7 – 18.8[a]	1.1	Sample volume available
HRT (sec)	8.0	2.0 – 8.0[a]	8.0	While flowing at 1 ft/sec

[a] Range provided for 2.0 to 8.0 ft length of pipe.

To accommodate the total flow required for 14 pipe segments (inclusive of replicates), of 1-inch diameter pipe at 1 ft/sec, a total flow rate of 30 gpm will be required to be diverted from well production and discharged to waste on-site. With the harvested 4-inch diameter CML/CMC, this flow rate increases to over 230 gpm. Final pipe selection will be based on available materials and other factors.

[2]WRF, 2023: https://www.waterrf.org/research/projects/guidance-using-pipe-rigs-inform-lead-and-copper-corrosion-control-treatment

Periods of stagnation will be selected that balances representing full-scale operations and respecting CVWD staff availability for sampling and monitoring. Ball valves will be installed to isolate each pipe segment to allow for stagnation. These can be manual ball valves that are controlled by operations staff, or they can be actuated ball valves that can be electrically controlled. In either case, an electrical signal will need to be utilized to operate the chemical feed pumps to ensure chemical dosing discontinues during periods of stagnation and when the source water well is offline.

Additional Appurtenances

Common appurtenances used by CVWD customers will be incorporated into the pipe rig study to evaluate whether $SnCl_2$ addition will prematurely clog and scale these items and lead to customer complaints. These will include 5 µm sediment filters installed at the end of each pipe segment, filter pitchers that will be filled with known water volumes and timed, hot water kettles to evaluate the impact of heating $SnCl_2$ dosed waters, and tile testing to observe the impact of evaporating $SnCl_2$. Larger point-of-entry devices such as whole home water softeners, granular activated carbon, or reverse osmosis may be incorporated in Phase 2 of the study if warranted.

Design Summary

The pipe rig study will consist of two phases to facilitate the acquirement of early results. Phase 1 will consist of operations with new pipe materials, while Phase 2 will consist of operations with harvested pipe materials. Both phases will include an acclimation period, followed by a variety of operational conditions such as flow through, stagnation, the cessation of $SnCl_2$ addition, as well as increased flow, flow reversals, or swabbing at the end of the testing period. Phase 2 will commence upon receipt of harvested material and review of data collected during Phase 1.

The pipe rig will consist of four pipe rigs, two controls without $SnCl_2$ addition, and two testing rigs with $SnCl_2$ addition, both with new and harvested materials. These pipes will be representative of the prevalent materials found in CVWD's distribution system and service connections, which include cement lined pipe, copper, and PVC. Harvested pipes will be operated in replicate. Wellsite 3408 will be used as the source water for the duration of the study. Flow will be controlled through rotameter needle valves to achieve a velocity of 1 ft/sec, which is consistent with typical service and limits scouring. A simplified schematic of the pipe rig design was presented in Figure 3.

A summary of the pipe materials and appurtenances to be included in the pipe rig study is presented in Table 12. The summary also includes the aspects to be evaluated from each feature.

Table 12. Summary of Primary Pipe Rig Features and Appurtenances		
Feature	**Nominal Size**	**Aspects to Evaluate**
Pipe segment		
Cement lined pipe	1.0 – 4.0 in	chromium and tin accumulation
Schedule 80 PVC pipe	1.0 in	chromium and tin accumulation
Type L copper (Cu) pipe	1.0 in	chromium and tin accumulation
Potential Fixtures and Appurtenances		
5 µm sediment filter	typical	flow, headloss, chromium and tin accumulation
Pitcher filter	typical	flow, chromium and tin accumulation
Kettle	typical	discoloration, scaling, chromium and tin accumulation
Whole house treatment	typical	discoloration, scaling, chromium and tin accumulation
Household water heater	typical	discoloration, scaling, chromium and tin accumulation
Kitchen/bathroom tiles	typical	discoloration, scaling, chromium and tin accumulation

Water Quality Sampling and Methods

A summary of the water quality parameters that will be measured during routine operations of the pipe rig are summarized in Table 13. Note that supplementary parameters may be added based on preliminary results to address study questions that may arise. Sampling will commence upon pilot start-up to capture the acclimation period of the pipe materials with $SnCl_2$ addition. Flow through samples will be collected following a minimum of 15 minutes of flow through operation, while stagnation samples will be collected immediately following a prescribed stagnation period, collecting the water volume stagnated within the pipe. Samples will be collected twice a week under both modes of operation. Field results will be recorded and stored, while laboratory samples will be transported for analysis at an analytical lab.

Table 13. Routine Operations Water Quality Sampling Summary[(1)]			
Parameter	**Method**	**Detection Limit**	**Volume (mL)**
Field Measurements			
Free chlorine (mg/L as Cl_2)	HM[a] 8021	0.020	10
Hexavalent chromium (µg/L)	HM 8023	0.010	10
ORP (mV)	TBD	TBD	50
pH[b] (SU)	SM[c] 4500-H^+	NA	50
Temperature (°C)	EPA[d] 170.1	NA	10
Turbidity (NTU)	EPA 180.1	0.020	10
Analytical Laboratory Analysis			
Total Alkalinity (mg/L as$CaCO_3$)	SM 2320B	3.0	500
Hexavalent Chromium (µg/L)	EPA 218.6	0.25	250
Total Chromium (µg/L)	SM 3113B	2.0	250

Table 13. Routine Operations Water Quality Sampling Summary(1)			
Parameter	**Method**	**Detection Limit**	**Volume (mL)**
Total Arsenic (µg/L)	SM 3113B	2.0	250
Total Manganese (µg/L)	EPA 200.7	4.5	250
Total Tin (mg/L)	SM 3113B	0.010	250

(1) Final method selection subject to consideration of existing CVWD lab capabilities

[a] Hach Method.

[b] Includes temperature (°C)

[c] Standard Method

[d] Environmental Protection Agency Method

Additional monitoring to be conducted with each sampling event will include recording pressure readings, measuring and adjusting flow through each pipe segment. Supplementary sampling of the appurtenances interacting with water with and without $SnCl_2$ addition will be completed and documented weekly. This will include recording the time required to filter a known volume through a pitcher filter, observing discoloration or particle settlement after boiling water in a kettle, and spraying water onto tile to observe particle accumulation or discoloration following evaporation. Particles accumulated within an appurtenance will be analyzed for Cr_T, Sn_T, As, Mn, Fe, Silica (Si), and Magnesium (Mg), at the end of the pilot study.

Non-routine testing and sampling will be completed less frequently or on an opportunistic basis as events occur. This will include simulated distribution system hold test to evaluate chlorine decay with and without $SnCl_2$, as well as DBP formation testing if chlorine decay results indicate that additional chlorine is required with $SnCl_2$ to maintain CVWD's distribution system free chlorine goals. Other sampling may include the collection of water quality parameters required to calculate corrosion and scaling indices, pipe scale analyses, and water quality and particle analyses following unidirectional flushing, flow reversals, or swabbing at the end of the study.

5.9 Schedule

A schedule outlining the expected duration of each phase of the study is presented in Table 14. Note the duration of each phase is contingent on the availability of material, such as harvested pipe, and the time required to achieve acclimation in each pipe material. The duration of each phase is dependent on pipe rig study results, where an observed critical failure (Table 6) may result in the cessation of the pipe rig study.

Table 14. Estimated Pipe Rig Study Schedule																						
Task or Phase	Week																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Supplies Procurement and Harvesting	■	■																				
Construction			■																			
Phase 1A Operation				■	■																	
Phase 1B Operation						■	■	■	■	■	■	■	■	■	■	■	■					
Phase 2A Operation			■	■	■	■	■	■	■	■												
Phase 2B Operation											■	■	■	■	■	■	■	■	■	■	■	■

Appendix A

Technical Advisory Committee

Technical Advisory Committee

The technical advisory committee (TAC) includes experienced research experts that specialize in the chemistry of inorganic contaminants, drinking water distribution system water quality, and water treatment processes. TAC members provided input on hexavalent chromium treatment with a focus on stannous-based treatment processes and potential effects in distribution systems and premise plumbing.

Phil Brandhuber, PhD

BRANDHUBER WATER QUALITY & TREATMENT

Dr. Philip Brandhuber has almost 30 years of experience specializing in the behavior of inorganic contaminants in drinking water, including the management of chromium, manganese, lead, copper, arsenic, and perchlorate. Phil was an HDR Fellow for work involving lead and their national expert in inorganic contaminant treatment. He has been the principal or co-principal investigator for ten drinking water related research projects, including two WRF chromium projects: Sources, Chemistry, Fate and Transport of Chromium in Drinking Water Treatment Plants and Distribution Systems and Low-Level Hexavalent Chromium Treatment Options. He also performed the initial studies using stannous chloride as an approach for treating hexavalent chromium in drinking water. Phil is interested in answering open questions regarding the long-term behavior of chromium and tin as well as other water quality parameters in the distribution system when using a stannous based treatment process.

Haizhou Liu, PhD, PE

UNIVERSITY OF CALIFORNIA, RIVERSIDE

Dr. Haizhou Liu is a Professor of Chemical and Environmental Engineering at the University of California, Riverside. Haizhou's research interests include water chemistry, disinfection-driven redox processes, drinking water distribution system water quality and corrosion process, and metal/metalloid redox chemistry. Haizhou's current research has been sponsored by the National Science Foundation, Department of Interior, Department of Agriculture, and California Department of Water Resources. Haizhou received a National Science Foundation CAREER Award in 2017, and a Young Professional Award from International UV Association in 2019, and an Honorable mention of the ACS James Morgan Award in 2021. Haizhou is an editor of the Journal of Hazardous Materials and holds a Professional Engineer License in California. His research expertise is directly aligned with this proposed project. He has previously worked with the proposal team and CVWD to investigate hexavalent chromium fate and transport in drinking water distribution systems.

Darren A. Lytle, PhD, PE

ENVIRONMENTAL PROTECTION AGENCY

Dr. Darren A. Lytle is an environmental engineer and acting branch chief for the US Environmental Protection Agency (EPA). Since beginning work at EPA in 1991, Darren's primary goal has been to research the quality of drinking water. He has investigated and published works on drinking water systems, focusing on distribution system corrosion control and water quality; biological water treatment approaches; filtration; EPA Contaminant Candidate List contaminant removal studies; and iron and arsenic removal. Darren is available to contribute on related technical discussions and activities, including study design, data review, reporting, and other technical matters. Darren's technical expertise is centered around the treatment and chemistry (e.g., solubility and redox chemistry) of inorganic contaminants (e.g., iron, manganese, lead, copper, arsenic, lithium, and others) found in water. He has additional expertise in particle (silts, clay, and bacteria) properties, particularly relating to the mobility of particles through the environment including, water treatment and distribution systems. Darren has a great deal of expertise addressing drinking water distribution system issues, including corrosion control (lead, copper, and iron); studying biofilms (including Legionella); building water quality; and addressing accumulation of inorganic contaminants in distribution systems.

Paul K. Westerhoff, PhD, PE, BCEE, NAE

ARIZONA STATE UNIVERSITY

Dr. Paul Westerhoff is a Regents Professor in and the founding director of the School of Sustainable Engineering and the Built Environment at Arizona State University and the Fulton Chair of Environmental Engineering. He has almost 30 years of experience in water treatment and is the Deputy Director the NSF-funded Nanosystems Engineering Research Center for Nanotechnology Enabled Water Treatment (newtcenter.org) and co-Deputy Director of the NSF Science and Technologies for Phosphorus Sustainability Center (steps-center.org). He has over 400 journal publications and multiple patents on his research related to fate of nanomaterials in water, developing novel technologies for water and reuse treatment, and understanding reactions related to the fate of pollutants during treatment. He was elected to the National Academy of Engineering in 2023.