Background & Understanding

The City is preparing to implement two major changes to its drinking water system, both of which have significant implications for distribution system (DS) water quality. First, in Y2019, the City plans to chlorinate its groundwater (GW) supplies, introducing chlorine residual into the system for the first time. Then, in Y2022, upon completion of the SRWA treatment plant, the City will introduce finished Tuolumne River surface water (SW) into the DS. While each of these changes will enhance water quality at system entry-points, they also present near-term risks and *potential* unintended consequences with respect to tap water quality if not proactively managed (see **Figure 1**). These risks arise due to the numerous chemical, microbial, and hydraulic reactions that occur between water and pipe surfaces. Since the City's pipes have been acclimated to unchlorinated, mineralized GW supply for decades, the corrosion scales and legacy deposits will undergo re-equilibration with each of the upcoming changes. Preventative management of the DS and strategic integration measures are essential to prevent the myriad of potential consequences of re-equilibration, which span public health risks, regulatory compliance challenges, and aesthetics/customer satisfaction issues (e.g., discoloration, taste and odor).

***Figure 1**. Risks and Potential Consequences of the City's System Changes*

Event		Risk	Consequences
Groundwater Chlorination	Increase in ORP	Destabilization of corrosion scales on unlined iron mains	• Discolored water • Loss of passivation layer; accelerated re-corrosion
Groundwater Chlorination	Increase in ORP	Mobilization of legacy pipe deposits and co-occurring trace inorganics (arsenic, chromium)	• Elevated concentration of regulated inorganic contaminants at the tap • Public health risk
Groundwater Chlorination	Increase in ORP	Disruption of passivation films on premise pipe and plumbing	• Elevated concentration of lead and/or copper at the tap • Public health risk and LCR issues
Groundwater Chlorination	Disinfection	Sloughing of biologically-active film (biofilm) from pipe surfaces	• Release of biofilm-based pathogens • Coliform occurrences • Degraded taste and odor
Groundwater Chlorination	Disinfection	Presence of free chlorine residual	• Chlorinous taste and odor • Impacts to various end uses (dialysis, aquariums, etc.)
Surface Water Integration	Change in Chemistry Profile	Destabilization of corrosion scale and legacy pipe deposits	• Discolored water • Public health risk due to co-release of co-occurring trace contaminants
Surface Water Integration	Change in Chemistry Profile	Disruption of passivation films on premise pipe and plumbing	• Elevated concentration of lead and/or copper at the tap • Public health risk and LCR issues
Surface Water Integration	Change in Chemistry Profile	Instability due to dynamic blending of dissimilar GW and SW	• Longer-term / on-going destabilization and release events
Surface Water Integration	Hydraulics	Hydraulic releases from changing flow directions and velocities	• Discolored water • Release of co-occurring contaminants

While it is natural to focus on risks of introducing surface water into the DS for the first time, **the first change, initial chlorination of the existing groundwater supplies, will likely pose a more adverse "shock" to the City's distribution system** for reasons described below. Thus, there are several critically-important measures that the City should implement prior to startup of wellhead chlorination systems. **Figure 2** outlines the best practices to implement before the upcoming changes, and the basis for our proposed approach and scope of work.

Groundwater Chlorination

Major chemistry shifts posed by initial chlorination are conversion to an oxidizing environment, reflected by increased Oxidation-Reduction Potential (ORP); and creation of a disinfecting environment, impacting stability of existing biofilm complexes. Both are discussed below.

***Figure 2**. Overview of Best Practices to Ensure Smooth Transitioning for the City*

Key Assessment Measures			Key Implementation Measures		
• Forensic analysis of native pipes to characterize pipe condition, deposit composition and mobility • Hydraulic and chemical modeling; identify hi-risk shifts	• Prioritize main cleaning and pipe replacement throughout the system • Identify treatment needs for optimal corrosion control and LCR compl.	• Conduct bench/pilot tests to identify: pipe response to GW chlorination and SW intro., chemistry adjust., GW:SW blends, and intro. needs	• Replace or rehabilitate/reline unlined iron mains based on condition and risk assessment • System-wide UDF to remove loose solids	• Conduct swabbing in target areas to remove cohesive deposits • Provide gradual increase in chlorine residual and surface water blend fraction	• Conduct sentinel water quality monitoring in the distribution system before and during each major change

Significance of ORP Shift as a Destabilizing Risk Factor

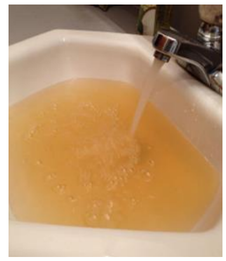
ORP affects metals speciation, solubility, and stability. Introduction of chlorine residual into the DS will dramatically in-crease the ORP and cause oxidation of corrosion scales and legacy deposits, triggering several reactions (see **Figure 3**). Discolored water (red, brown) is the most visible unintended consequence of initial chlorination. Less visible but potentially more significant to avoid is the phenomena of trace metals release.

Regulated inorganic contaminants like arsenic (As) and chromium (Cr) co-precipitate with Fe/Mn and accumulate on pipe walls over time. Eventual chemical shifts – most notably large changes in ORP and switching between GW and SW – causes these co-occurring metals to be released in an uncontrolled manner back into the bulk water, resulting in elevated concentrations at customer taps and potential public health risks. Confluence has developed the industry guidance on assessment, prevention, and control of trace metals accumulation and release phenomena. Based on our extensive work with source integration and chlorination introduction, we are keenly aware of the multitude of issues and risk factors that need to be considered. For example:

***Figure 3**. ORP affects metals stability and can cause discolored tap water (photo source: Hill & Friedman et al., 2010)*

Metal Reactions to ORP Increase

1. Precipitation of particles that cause <u>discolored</u> water, e.g., $Fe(OH)_3$, MnO_2
2. Co-release of <u>regulated toxic</u> metal contaminants, e.g., As, Cr-6, Pb
3. Conversion to <u>more soluble</u> corrosion passivation film, e.g., $Cu_2O \rightarrow Cu(OH)_2$



- **Without proper preparation, the City may have an elevated risk of arsenic and chromium-6 accumulation and release potential.** Trace metals concentration on pipe solids is typically related to their concentration in water (see **Figure 4**). Utilities that supply water with much lower As and Cr-6 concentrations than the City's wells – and thus likely had lower accumulation on their pipes – have experienced major upsets in conjunction with treatment / ORP / supply changes in which these contaminants were released from deposits back into the water to the point of exceeding MCLs at customer taps over large areas for several months. These events resulted in extreme public dissatisfaction, public relations challenges, and regulatory scrutiny.
- **Flushing is rarely sufficient for removal.** Major re-equilibration release events have occurred in systems that have aggressive, proactive unidirectional flushing (UDF) programs. Similarly, reactive UDF could not quickly mitigate chemistry/ORP-induced release events that were already underway.
- **A holistic approach is needed for chemistry adjustments.** Measures intended to stabilize one aspect of the changes can exacerbate another. For example, while orthophosphate use might be considered to minimize "red water" problems with unlined iron pipe, it will also elute As and Cr-6 from iron scales and can significantly increase concentration of these metals at customer taps (see **Figure 5**).

Finally, after reviewing the City's historical water quality data, it is anticipated an ORP increase will negatively affect copper (Cu) levels in homes with copper premise pipe. Under the current unchlorinated GW environment, copper passivation is likely based on low solubility Cu(I) films. Chlorine will oxidize and convert these films to a

***Figure 4**. Trace metals concentrate in pipe deposits in proportion to their concentration in water (source: Friedman & Hill et al., 2010)*

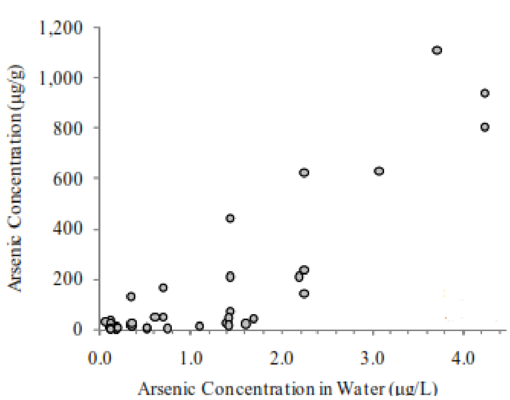
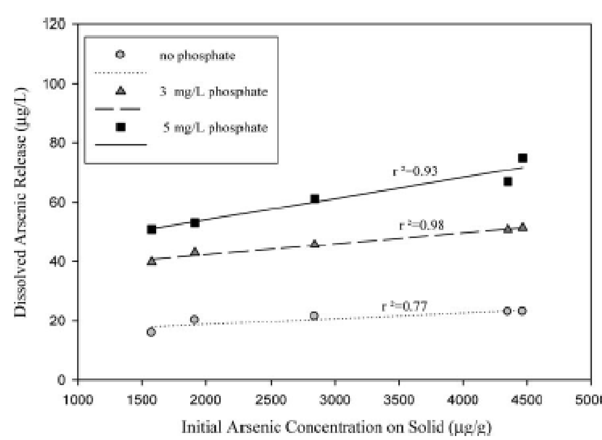
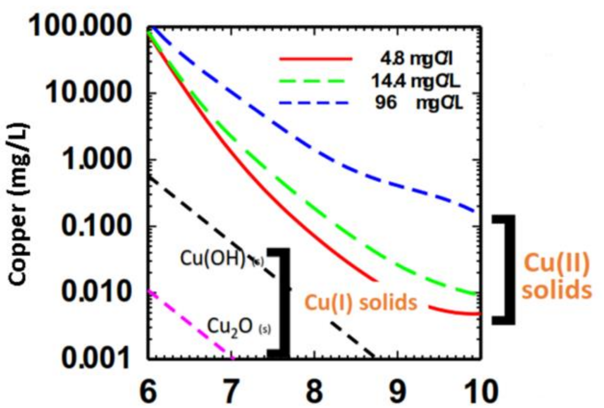


***Figure 5**. Orthophosphate addition will release arsenic and chromium-6 from pipe deposits (source: Copeland et al. 2007)*



much more soluble Cu(II) form, resulting in higher Cu levels and potential LCR issues (**Figure 6**). Smooth transitioning to a chlorinated system while maintaining compliance with the Lead and Copper Rule (LCR) will

Figure 6*. Oxidation, during the chlorination of groundwater, is expected to convert copper films in the City's DS and/or customers' premise plumbing to a more soluble Cu(II) form (source: Lytle, 2018)*



require proper management of source use/blending, chlorine residual, and pH.

Surface Water Integration

Major shifts posed by integration of treated Tuolumne River water into the City's historical GW system are (1) a change in water chemistry and dissolved mineral profile; and (2) change in system hydraulics as a result of introducing a large percentage of the flow from a single, new location. The latter has the potential to re-suspend loose deposits, contributing to discolored water and elevated levels of co-occurring metals.

Significance of Change in Chemistry and Mineral Profile

The Tuolumne River SW supply has a sharply different chemistry and mineral profile than the City's wells. Although its lower dissolved solids content should improve palatability of the water, the dramatic shift from a highly-mineralized GW to a softer SW could destabilize solids and soften corrosion scales, increasing their hydraulic mobility. Several parameters impact scale stability, i.e., pH, DIC, temperature, dissolved oxygen, chlorine residual, ORP, calcium, chloride, sulfate, phosphate, and organic carbon. Because of the number of variables and reactions, we propose to conduct bench-scale "fill-and-dump" studies with native pipe specimens to ascertain pipe response and optimize finished water quality to ensure DS stability as the changes are made (**see box below**).

Key Advantages of Our Proposed "Fill-and-Dump" Bench-Test Approach

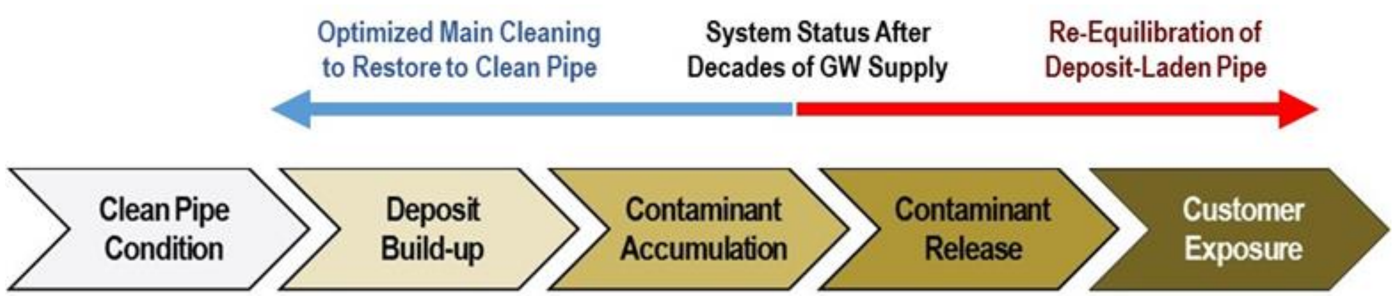
- Definitive confirmation how City's pipes will respond to chlorination and surface water. Avoids over-reliance on theory, models, or others' experiences.
- Rapid screening of different variables to identify how response can be improved with controlled changes to water quality, e.g., pH adjustment, orthoPO4, chlorine residual ramp-up, controlled SW:GW blends, etc.
- Establish optimal conditions for corrosion control.

Need for Optimized Main Cleaning

Cleaning the City's DS mains will be amongst the most important preventative measures. As shown in the progression below, the DS is at a critical juncture. Decades of supplying unfiltered, unchlorinated groundwater have contributed to a degree of legacy accumulation (i.e., deposits, scales, biofilm) that is vulnerable to destabilization and release. Main cleaning – when performed in an optimal manner – breaks the progression towards release and exposure and instead moves the DS back towards a cleaner, low-risk status. The benefits of cleaning pipes are significant:

- It prevents the possibility of uncontrolled releases and upsets (since there is little-to-nothing to be released);
- It provides significant leeway on chemistry shifts between the GW and Tuolumne River SW, alleviating chemical re-equilibration risks; and
- It maximizes operational flexibility of the City's sources and helps reduce blending constraints.

Complete removal of legacy deposits is rarely practical over an entire DS. Rather, our objective is to prioritize areas for cleaning, rehabilitation, or replacement based on degree of risk, as determined by our proposed pipe/deposit analytical activities, pipe inventory (type, age, condition), known problem areas, and other



considerations. Once portions of the DS have been prioritized, area-specific optimal main cleaning techniques will be selected and demonstrated to train crews.

Selecting the Optimal Main Cleaning Technique(s) is Critical to Success

- There is no "one-size-fits-all" approach – optimal is system-specific, based on matching technique capabilities to the type/condition of pipe, nature of legacy deposits, and local feasibility constraints.
- Consequences of using the wrong technique or wrong flush velocity include: ineffective cleaning, excessive cost, risk of pipe damage, and causing water quality upset.

Main Cleaning is More Than Flushing

Utilities often mistakenly regard unidirectional flushing (UDF) as a "catch-all" cleaning process. Optimized high-velocity UDF (or zero-discharge NO-DES) will certainly play an important role in the overall strategy with respect to preventing hydraulic releases and reducing overall chlorine demand (thus allowing lower Cl2 doses and improving residual stability throughout the DS, which will be important for T&O control).

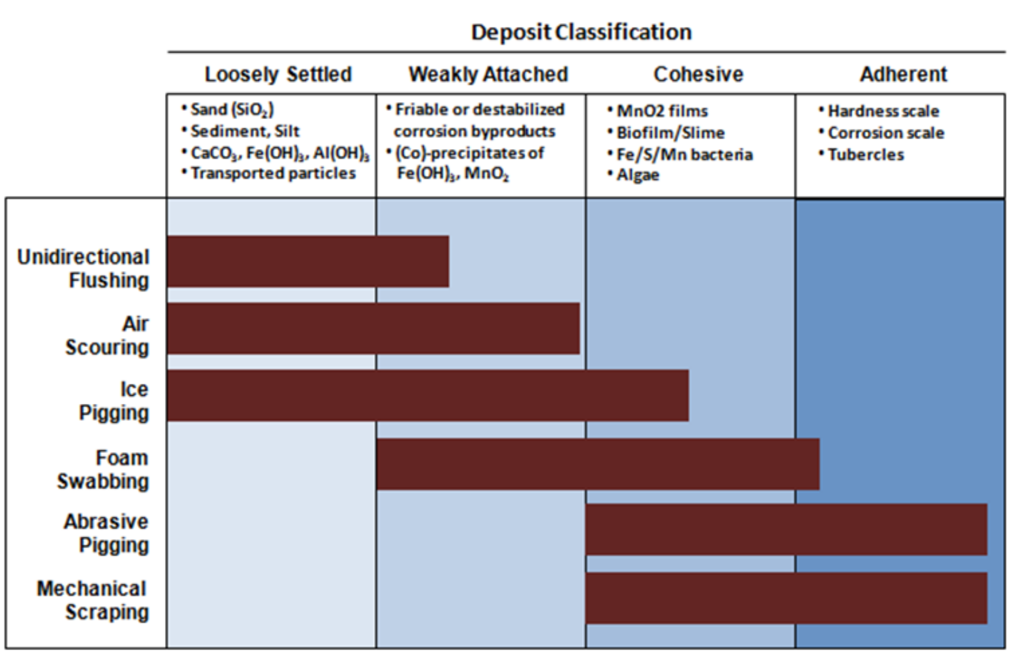
However, flushing alone is not likely to be sufficient. It has notable limitations and, if not conducted properly, can also cause unintended consequences. For example:

- UDF, even at 6 ft/sec velocity, is only effective on loosely-settled particles. **UDF is ineffective at removing cohesive deposits, films, and scales**. Often, these deposits represent a large fraction of the overall deposit mass and are vulnerable to chemical destabilization and release. See case studies for Woodland, CA, and Park City, UT – both utilities experienced prolonged chemical destabilization upset events associated with ORP shifts and source changes despite recent aggressive UDF.
- UDF must be conducted at optimal flushing velocities and durations based on area-specific testing and monitoring, an approach which Confluence pioneered. **Excessively high UDF velocities can damage pipe scales/tubercles**, exacerbating instability and causing red water events (see case study for Longview, WA).

There are several cleaning technique options, which vary in: effectiveness at removing specific types of deposits (**Figure 7**), suitability on different types of pipe, cost, equipment needs, water use, etc. Confluence has extensive experience with each of these techniques and routinely conducts performance demonstrations to assist utilities with crew training and identification of the optimal technique.

For systems/areas with cohesive deposits and biofilm, which are common in un-chlorinated systems, Confluence has demonstrated that foam swabbing is generally the most cost-effective strategy to optimize pipe cleaning. In these cases, swabbing has removed approx. 10x more solids material than high-velocity UDF on the same stretch of pipe and proved to be the critical step to bring a halt to destabilization events associated with source / ORP changes (Friedman and Hill et al., 2016). The case studies provided on the following two pages provide additional details on our assessment and use of swabbing to mitigate re-equilibration upset events in Woodland, CA and Park City, UT. In both cases, Confluence was brought into the project after the system changes and destabilization events had already begun.

***Figure 7**. Main cleaning techniques have different application niches (source: Hill, 2015)*



Case Study 1: City of Woodland, CA

Recent Experience with Surface Water Introduction into a Historical Groundwater System

Background

In 2016, just weeks after introducing treated Sacramento River water into its historical groundwater-only distribution system, the City of Woodland began to experience widespread discolored water and customer complaints due to a distribution system upset. The upset lasted over a year, strained utility resources, and eroded public trust.

Prior to the surface water introduction, the City conducted system preparation activities as recommended by another consultant. However, the recommendations were generic in nature, limited in scope, and ultimately failed to address system-specific conditions or risks present with the City's situation (see table to the right). Due to the complex nature of re-equilibration phenomena, more specialized analyses and measures should have been conducted to prevent this.

Assessment and Mitigation Performed by Confluence

Confluence was subsequently hired to identify the cause and resolve the problem. Through field assessment, modeling, and analytical activities, Confluence determined that the surface water presented destabilizing shifts in both ORP and alkalinity (neither of which were considered by the previous consultant), and these shifts caused gradual chemical release of legacy manganese and biofilm that could not be flushed off the pipes.

Foam swabbing demonstration in Woodland, CA

Confluence developed the most expedient and lowest risk path forward under the circumstances. This included training the City on optimized UDF and aggressive main cleaning practices to accelerate re-equilibration. In chronic problem areas, Confluence demonstrated that swabbing removed substantial deposit mass left behind with prior UDF (e.g., 32 mg/L Mn in swabbing sample vs. 3 mg/L Mn in prior UDF samples).

Previous Recommendations to Woodland … and Their Shortcomings		Confluence's Approach and Recommendations
Desktop and Literature Review	• Over-relied on theory, assumptions, and experiences of other systems. • Did not identify the actual condition of the City's pipes or legacy deposits. • Failed to identify or consider legacy manganese (Mn) presence.	• Harvested native pipe specimens and analyzed deposits/scale to assess composition and surface properties. • Identified key constituents and properties affecting mobility.
Unidirectional Flushing at 5 fps	• Flushing run layouts and flushing velocities were not optimal. • UDF was not the proper method to remove cohesive pipe deposits, Mn, or biofilm, which represented most of the deposit mass on City pipes.	• Provided hands-on training on optimized UDF procedures. • Ensured safe velocity for scales. • Demonstrated swabbing to remove cohesive deposits and developed prioritized program.
Match pH to Groundwater	• Focused solely on pH; failed to consider other significant chemistry shifts with the surface introduction. • Failed to identify or address the destabilizing factors of large drop in Alkalinity/DIC and increase in ORP.	• Conducted chemical equilibria modeling, taking into account all chemistry shifts associated with the new surface supply. • Conduct bench/pilot tests with native pipe to evaluate response to new chemistry and to identify finished water conditions needed to achieve blended WQ stability • Gradual, monitored ramp-up of Cl_2 residual, ORP, and SW:GW blend fraction. • Consider whether limitations and potential drawbacks to orthoPO4 outweigh benefits.
Add OrthoPO4 Inhibitor	• Did not address legacy manganese. • Potential benefit is limited to unlined iron pipe; does not address cement-lined or plastic pipe (which was most pipe in the City's dist. system). • Inadvertently converted system to PO4-based LCR compliance strategy (system now dependent on oPO4).	

Case Study 2: Main Cleaning Evaluation (Water Research Foundation) WaterRF 4509

Final report published in 2016 (Source: Friedman, Hill, Booth, Hallett et al.)

Background

The utility experienced multiple distribution system “upset events” resulting in black/brown water and elevated metal concentrations at customer taps. Colored water events occurred despite pressure filtration systems for removal of Fe/Mn and an aggressive semi-annual unidirectional flushing (UDF) program. The cause was determined to be chemistry-induced destabilization of legacy pipe deposits (primarily manganese films).

Approach

Confluence worked with the utility to plan and conduct full-scale main cleaning trials in two areas of the distribution system to evaluate and compare the cleaning effectiveness of high-velocity UDF, ice pigging, and foam swabbing. The cleaning trials involved controlled demonstrations on adjacent pipe segments with discharge water quality profiling and pipe recovery to characterize the amount and nature of deposits removed per technique.

Key Findings

Figure A: UDF discharge water was visually clear throughout the flush. In contrast, discharges from swabbing and ice pigging were extremely discolored, with TSS levels exceeding 1,000 mg/L.

Figure B: Cement-lined pipe specimens harvested prior to the cleaning trials revealed a black slime/sludge deposit layer. Pipe specimens collected following the cleaning trials revealed that the slime/sludge buildup remained after UDF but was removed with ice pigging and swabbing.

Figure C: Ice pigging and swabbing each removed approximately 10 times more normalized deposit mass than UDF.

Conclusions

UDF – even at high velocities – was ineffective at removing manganese/biofilm and left behind a substantial inventory of metal-rich deposits (which were the source of the colored water events).

The use of controlled field trials provided a robust method to evaluate the cleaning performance of different techniques on a system- and site-specific basis.

***Figure A**: Discharge samples collected per technique*

***Figure B**: Pipe specimen samples*

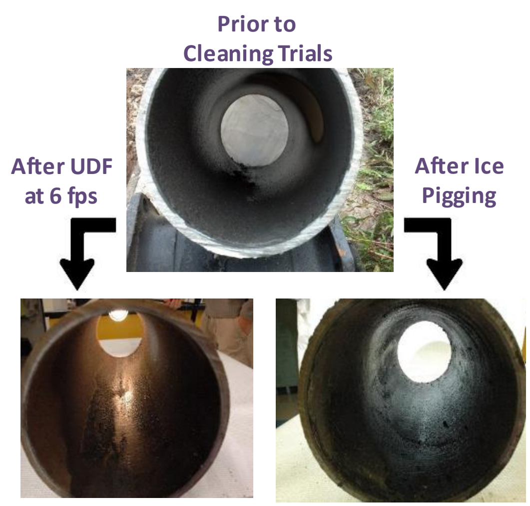
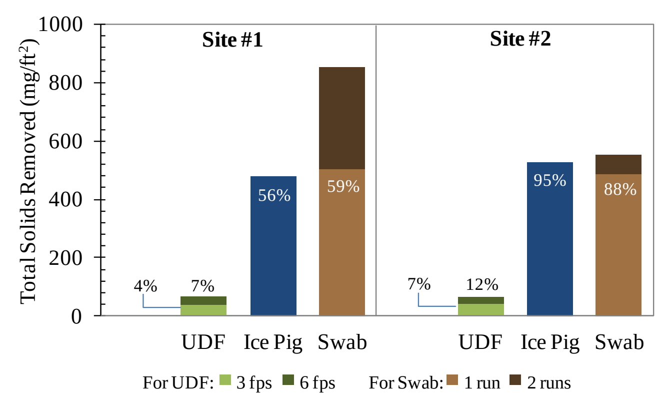


***Figure C**: Comparison of deposit mass removed*



Scope of Work

Task	Key Work Items
Task 1 Project Kickoff and Water Quality Assessments	• Data request and gap analysis • Kickoff, scope confirmation • Surface & groundwater quality comparisons
Task 2 Distribution System Characterization	• System characterization and risk assessment • Pipe harvesting and main cleaning trial • Evaluate surface water hydraulic impacts on DS
Task 3 Distribution System Preparation Plan	• Implement sentinel monitoring program • Bench-scale blending, water quality & CCT testing • Prioritized main cleaning and flushing program
Task 4 Surface Water Implementation Plan	• Adjust sentinel monitoring if needed • Recommend surface water integration methods • Confirm CCT needs for surface water
Task 5 Corrosion Control Treatment Plan	• Develop CCT plan and obtain City approval • Submit plan to City and SWRCB DDW
Task 6 (Optional Task) DS Pipe Loop Study CCT Coupon Study	• Implement pilot-scale pipe loop testing study • Implement corrosion coupon study • Provide data management/analysis support

We propose the following scope of work to help the City successfully navigate both of its major upcoming system changes – system chlorination and surface water integration. As shown in the **table at right**, work has been divided into five recommended tasks and one optional task involving additional bench- and/or pilot-scale studies. It is important to note that our Scope may be more complex given the need to address both major planned chemistry changes.

Although some degree of distribution system re-equilibration is inevitable, our proposed approach will provide the City with a clear roadmap of assessment and preventative management activities to promote smooth transitioning, maintain regulatory compliance, and maximize public satisfaction with water quality. High-level outcomes and benefits from our approach include:

- A system-wide flushing and main cleaning plan with area prioritization based on observed conditions and risk factors;
- Basis for replacement of old cast iron pipe as part of the City's CIP program;
- Bench test-validated guidance regarding gradual/phased introduction of chlorine and surface water to minimize risk of upsets;
- A distribution system sentinel water quality monitoring plan with alert/action levels and a tailored response proto-col that will allow tracking of DS "health" and ensure appropriate measures are taken timely;
- A corrosion control treatment (CCT) plan for submittal to the State Water Resources Control Board (SWRCB) Di-vision of Drinking Water (DDW); and,
- An overall approach to DS management that supports simultaneous compliance with all water quality regulations.

Task 1 – Project Kickoff and Water Quality Assessments

Task 1.1 Prepare Data Request and Review Data

Confluence will provide a data request to capture existing conditions and institutional knowledge. To include: well-specific and DS water quality, complaint records, maps, infrastructure conditions, pipe materials, and key O&M aspects of water supply (such as any operational or planning assessments made for chlorination of groundwater), treatment, and distribution. Additional information may include data from the SRWA water treatment plant project above and beyond what is currently available on-line.

Task 1.2 Project Kick-Off Workshop

Confluence will attend a kick-off workshop at the City to: confirm the project scope of work; discuss water system and source operations with staff (e.g., well usage patterns/constraints, expected planning and engineering for new groundwater chlorination facilities, and expectations of the upcoming SRWA WTP); and visit key facilities important to the study.

Task 1.3 ID Data Gaps and Implement Additional Sampling

It is possible that there are gaps in existing water quality records that need to be fulfilled to support appropriate characterization of individual sources and/or methods for modeling treatment, blending, etc. Confluence will identify key data gaps and provide an operator-friendly plan to the City to pursue collection of the necessary data. Filling these water quality gaps will also support subsequent work (Task 3) that will produce long-term water quality sampling and monitoring protocols.

Task 1.4 Comparison of Groundwater and Future Tuolumne River Water

A full comparison of the City's existing GW will be made to expected finished Tuolumne River water quality produced by the SRWA WTP, with emphasis on identifying differences in key parameters that could impact DS stability and, to some extent, in-home (premise plumbing) water quality. These impacts will include issues such as impact on disinfectant residual stability, organics loading, legacy Fe/Mn deposit stability, scale and corrosion control impacts, and will also be used to frame technical focus that is needed in later work (Tasks 3 and 4).

Task 1 Deliverables:

- Request for additional water quality data and/or information if needed.
- Kickoff Workshop (Workshop 1): Prepare agenda and summary notes.
- Submit TM 1 (Draft and Final): Water Quality Comparison of Groundwater and Anticipated Treated Surface Water.

City responsibilities include the following:

- Provide requested data and information (where available) in the requested format and address follow-up questions on requested data, as needed.
- Participate (as needed) in discussion(s) with SWRCB DDW Regional Engineer.
- Allow appropriate staff to attend Kickoff Workshop to discuss system operations and goals.
- Conduct preliminary monitoring and cover cost for external laboratory fees if needed.
- Review and comment on submitted TMs.

Task 2 – Distribution System Characterization

Key elements of this task include:

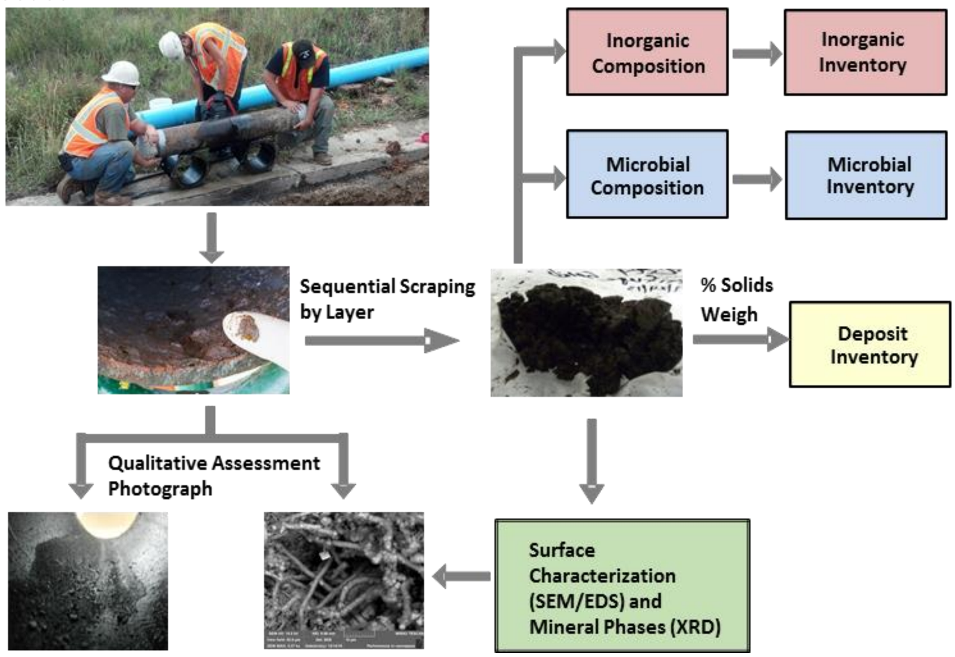
- Completing a DS characterization and risk assessment with water quality impact assessment from hydraulic changes due to receiving new SRWA WTP water;
- Harvesting DS pipe samples to analyze condition and key deposit properties (composition, mobility); and
- Completing flushing and aggressive main cleaning trials to assess hydraulically mobile deposits vs. adhered de-posits.

Task 2.1 System Characterization and Risk Assessment

Confluence will characterize DS conditions and perform a risk assessment to guide recommendations for system preparation activities in Task 3. System characterization will utilize information from multiple sources, i.e., inventories of pipe types, materials, ages, and sizes; pipe condition; pipe specimen analyses; and expected (modeled) changes in flow directions, velocities, and spatial blends as the SW is introduced. The risk assessment will categorize areas of the system based on the magnitude (e.g., high, medium, low) and specific nature of risk(s), thereby allowing for a prioritized approach to system preparation consistent with City resources.

Task 2.2 Pipe Specimen Analysis

Confluence will provide protocols for harvesting pipe specimens of different materials from the DS. From these pipes, legacy deposits/scales will be removed and analyzed to provide a definitive understanding of their composition and properties relevant to potential for mobilization. Through numerous DS field study research projects, Confluence has developed industry- and EPA-approved protocols for collection, preservation, and characterization of pipe samples and has successfully applied these protocols for numerous systems to determine the cause of releases (see **Figure below**).



Task 2.3 Hydraulic Impact Assessment

Confluence will work with the City's hydraulic modeling consultant to develop modeling outputs that identify (a) baseline flow conditions, (b) areas-of-influence for stepping-through an initiation of groundwater chlorination, and (c) hydraulic changes (e.g., flow directions and velocities capable of re-suspending loose deposits) and SW:GW blending regimes for phased SW introduction.

Task 2.4 Flushing and Aggressive Main Cleaning Trials

Confluence will plan and implement main cleaning demonstration trials in the City's DS to: (1) assess cleaning performance of different techniques on the City's pipes/deposits; (2) confirm optimal local cleaning techniques; and (3) provide protocols/SOPs and training to enable City crews to efficiently conduct system-wide flushing and main cleaning. The trials will likely include UDF (or its zero-discharge form, NO-DES) and foam swabbing for more recalcitrant deposits (see **Figure at right**). This work will feed information into the system-wide main cleaning and flushing program to be developed in Task 3.

Adding a swab into the Woodland-Davis (CA) DS (left), swabs before entry (top right) and swab after exiting the DS (bottom right) for a Confluence-led main cleaning trial.

Task 2 Deliverables:

- TM2 (Draft and Final): Distribution System Characterization and Risk Assessment for Groundwater Chlorination and Surface Water Integration. To include:
  - Protocol for pipe harvesting and storage procedures and an estimate of external laboratory fees based on anticipated sampling.
  - Summary of key results from pipe deposit analytical activities, to be appended to TM 2.
  - Main Cleaning Trials Plan to include evaluation of two flushing techniques (likely to be swabbing and UDF, or NO-DES) and summary of findings.
  - Summary of findings from main cleaning trials, to be appended to TM 2.
  - Summary of anticipated hydraulic impacts, to be appended to TM 2.

City responsibilities include the following:

- Provide (from City staff or consultant) DS technical information (pipe age, material, and size) and hydraulic modeling outputs (model outputs may include expected average current flow directions and rates, potential areas-of-influence for step-wise increases of groundwater chlorination and SW introduction; and anticipated flow changes due to future input of treated surface water).
- Submit previous engineering reports that have identified groundwater chlorination needs and dosing recommendations.
- Perform harvesting of pipe specimens over an expected period of 3-4 days.
- Pay laboratory fees for water quality and pipe deposit sampling and analysis.
- Review and comment on submitted TMs.
- Provide crews, equipment, and resources to help conduct small-scale flushing and swabbing trials in portions of the DS. Main cleaning trials are expected to be performed on pre-selected pipe runs over a 4-day period (overlap-ping with period of pipe harvesting and processing).

Task 3 – Distribution System Preparation Plan

Key elements of this task include:

- Developing and initiating a sentinel DS monitoring and response plan,
- Conducting bench-scale testing to assess impact of groundwater chlorination and surface water introduction on native pipes, and
- Developing a prioritized program for main cleaning and pipe replacements.

Task 3.1: Chlorine Introduction Distribution System Water Quality Monitoring Plan

Confluence will develop a water quality monitoring plan to ensure close tracking of DS water quality conditions for planned introduction of chlorine in 2019. Monitoring to track introduction of surface water in 2022 is discussed under Task 4. Separate plans are needed since the introduction of chlorine will fundamentally affect distribution system scales, and time is needed for a new baseline condition to develop. Our plan will simultaneously satisfy DDW requirements and serve as a practical tool for on-going management, assessment, and response decision-making. The plan will include key parameters, methods, locations, and sampling frequencies necessary to detect trends, upsets, and underlying mechanisms; parameter-specific alert and action levels; and an operator-friendly decision tree of response measures based on specific triggers. Our sentinel monitoring approach has been used in numerous locations, most recently for the City of Woodland, CA.

Task 3.2: Bench-Scale Testing: Groundwater Chlorination

Confluence recommends a two-tiered, bench-scale evaluation to identify impacts from beginning chlorination of ground-water as well as from the introduction of surface water as shown in the **Table on the top of the next page**. This recommendation increases the complexity and cost of our proposal, but we believe it is critical to the success of the project. In the event that the City wishes to build upon the knowledge gained by this bench testing and perform more long-term 'confirmatory' pilot-scale pipe-loop tests, an optional scope for pipe loop testing is provided later in

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Task 6. This first sub-task will evaluate chlorination of groundwater.

Sub Task	Testing Purpose	Expected Test Parameters	Approach, Benefits & Example Outputs
3.2	Add Chlorine to GW	• Chlorine demand & decay* • DBP formation potential* • Color, biofilm, scale**	• How to best initiate GW chlorination • Chlorine dose, demand, decay, DBPs • Observe chlorination impacts, minimize upset
3.3	Add SW blends into system	• Chlorine demand & decay* • DBP formation potential* • Color, biofilm & scale**	• Use acclimated materials from Sub Task 3.2 • Quantify SW impacts & minimize upset • Support blend ramp-up & operations planning • Identify unforeseen changes (DBPs, other)

Notes: GW = Groundwater SW = Surface water
* Traditional simulated jar testing procedures
** Incubation jars using harvested samples

Photos below illustrate types of bench tests that may be conducted, depending on findings of Task 2. Bench testing will be conducted at Confluence's laboratory in Seattle (using water shipped from the City). Confluence regularly uses bench-scale testing to rapidly and economically identify how DS water quality and materials react to water treatment and system chemistry changes. This work is tremendously helpful in supplementing desk-top modeling work and producing practical results that illustrate how to operationally introduce changes to the DS (e.g., step-increase chemistry changes to prevent upsets such as scale and/or biofilm release events).

Task 3.3: Bench-Scale Testing: Surface Water Introduction

Bench-scale testing approaches will include traditional simulated DS tests (top picture showing Andy completing chlorine demand and decay tests), tests using harvested pipe samples to evaluate scale upset/release (middle figure showing pipe hot-tap material sample from Woodland-Davis), or tests that may use harvested pipe sections (similar to the bottom picture showing Portland Water Bureau bench tests conducted by Cornwell Engineering as a sub to Confluence).

Bench testing to evaluate the introduction of surface water will be conducted by performing bench-scale filtration of raw surface water and/or performing chemistry alterations of the surface water to create a synthetic version of the water expected to be introduced to the DS (to match key water quality parameters such as organic carbon, chloride, sulfate, pH, alkalinity, and others). Testing will follow traditional simulated jar testing conditions as well as incubation-type tests. This water will be blended into jars containing chlorine-acclimated groundwater coupons to evaluate chemistry changes and potential impacts. These tests will be monitored similarly to those in Task 3.2.

Task 3.4: Main Cleaning and Pipe Replacement Plan

To help prepare the DS for new chlorination and eventual SW introduction, a program will be developed to identify flushing, main cleaning, and pipe replacement needs. This program will prescribe which pipe segments or grouping of pipe materials/ages/locations warrant cleaning vs replacement, and which cleaning method is most appropriate, all in a ranked manner from high to low risk. Unlike generic flushing plans, this approach will allow the City to utilize limited resources by targeting the highest risk areas first and by ensuring use of optimal techniques based on local conditions. Input to developing this program will include results from all the above-mentioned work (source water quality comparisons, DS risk assessment outputs, pipe harvesting, main cleaning trial comparisons, system characterization and hydraulic modeling assessments, sentinel monitoring, and bench-scale testing results).

Task 3 Deliverables:

- Sentinel Water Quality Monitoring Plan.
- Workshop 2: Discuss DS plan recommendations and bench-scale testing needs and planning.
- Prioritized Distribution System Mains Cleaning and Replacement Plan (Note: An introduction to mains cleaning needs have already been provided in TM 2).
- TM 3: Findings from Bench-Scale Testing.

City responsibilities include the following:

- Perform sentinel DS water quality monitoring, upload data, and implement response plan.
- Cover cost for external laboratory fees for water quality monitoring and bench-scale testing samples.
- Review and comment on submitted TMs.
- Appropriate City staff to attend workshop.

- Supply/ship batches of water to Confluence (Seattle, WA) for bench-scale testing work.

Task 4 – Surface Water Implementation Plan

Key elements of this task include:

- On-going management of sentinel monitoring results;
- Developing a prioritized plan for how to best introduce surface water into the City DS to avoid or minimize de-stabilization scenarios; and,
- Perform desktop CCT analysis and modeling for surface water integration.

Task 4.1: Surface Water Introduction Monitoring Plan

The monitoring plan developed under Task 3 will be modified to focus on introduction of surface water to the chlorinated groundwater system (the new baseline). Numeric criteria that will serve as alert/action levels will be developed, capturing conditions that trigger response, and a protocol for recommended responses to triggers. On-going support with data analysis, tracking, and trending will also be provided.

Task 4.2: SRWA WTP Introduction Plan

SRWA WTP start-up needs will be discussed and confirmed with City staff at Workshop 3 to identify the best possible methods of acclimating surface water into the DS. Methods are anticipated to include alternatives for increasing the sur-face water blend over time, meeting acceptable blend percentages and 'holding' for appropriate periods during recommended DS acclimation periods, and possibly introducing surface water to a contained portion of the DS in order to per-form a full-scale evaluation of water quality impacts. Workshop outputs and consensus on the best way forward, including a schedule of implementation activities will be documented in the SRWA WTP Introduction Plan.

Task 4.3: CCT Desk-Top Analysis

The EPA has well established guidelines for determining OCCT, based on water quality and historical lead and copper levels (e.g. EPA, 2003, 2016). However, recent crises in Washington, D.C. and Flint, MI have led to a newer understanding of corrosion mechanisms including impacts of oxidation reduction potential (ORP) and dissolved inorganic carbonate (DIC) on lead speciation and stability. Much of this newer thinking is summarized in AWWA M58 (2nd Edition, 2017), co-authored by Melinda Friedman and Andrew Hill. Additional issues under consideration for the revised Long-Term LCR that will be considered by Confluence and could directly impact the City (NDWAC Report, 2015; LCR Revisions White Paper, 2016) include:

- Development of a more prescriptive regulation, with less discretion/judgment allotted to utilities and states.
- An integrated approach to minimizing lead exposure, considering contributions from water, paint, soil, dust, etc.
- Clarification of sampling requirements,
- Increased OWQP monitoring to verify process control and separation of lead and copper monitoring sites.
- Development of health-based benchmark and household action levels.

It will be imperative to consider recent research findings and potential future revisions along with the existing EPA guidance to provide sound corrosion CCT recommendations that will meet the City's needs and the public's demands for decades to come. The findings of the Task 1 Water Quality Comparison and Task 3 bench-scale testing will be used to identify optimal corrosion control treatment for the chlorinated, blended system, as well as for SRWA WTP finished water. Commercially-available models such as WaterPro!6.50 and Geochemists Workbench will be used to assess solubility and stability of lead and copper and impacts of corrosion control treatment on metals reduction. Should pilot-scale testing be needed, an optional task has been identified in Task 6b. CCT recommendations and the need for additional pilot testing will be discussed at Workshop 3.

Task 4 Deliverables:

- TM 4 - Corrosion Control Treatment Recommendations
- Workshop 3: Surface Water Integration and CCT Recommendations
- Surface Water Integration Plan and Schedule

City responsibilities include the following:

- Appropriate City staff to attend workshop.
- Review and comment on submitted TMs.
- Implement Start-Up Monitoring plan

Task 5 – Corrosion Control Treatment Plan

Key elements of this task include:

- Developing the overall CCT plan to be approved by the City,
- Presenting the CCT to SWRCB DDW regional engineers, if needed.

This task will include a summary of all CCT evaluation results from desktop chemical modeling and bench-scale testing, presenting them to the City for approval, and then providing a comprehensive report that can be used to obtain OCCT approval from SWRCB DDW. Confluence has extensive experience developing CCT plans for many utilities and work will meet all State and Federal requirements, as well as allow the City to have a plan that is practical and cost effective. Furthermore, Confluence has been in communication with California regulators that are currently revising the State's LCR regulations. Our approach to developing OCCT will match what the State is currently developing, allowing final recommendations to meet the City's needs for many years to come.

Task 5 Deliverables:

- OCCT Recommendation Report.

City responsibilities include the following:

- Facilitate communications with DDW staff.
- Review and comment on submitted TMs.

Task 6 – (Optional Task) Pilot-Scale Pipe-Loop Study

Bench-scale testing outlined in Task 3 will provide significant insight into how the City's DS can be properly prepared for current and proposed future operational changes. However, using pilot-scale pipe-loop systems to apply project knowledge to possibly perform tests (e.g., ramping up chlorine levels and/or introducing batches of treated surface water and/or evaluation of corrosion control treatment) may further help fine-tune operational approaches. Some past Confluence pipe-loop projects are shown in the **Figure above**.

Examples of pilot test rigs and studies that we have designed, constructed, provided training, and been involved with over the years.

If the City decides to conduct this pipe-loop study, Confluence will develop an approach, procedures to harvest the most appropriate pipe sections based on the previously developed risk assessment in Task 2, design how the system should be constructed and operated such that the proper level of automation is incorporated, develop a testing plan with monitoring parameters that support desired outcomes, and provide construction support of pipe segments and associated plumbing and control equipment. It is possible that a flow-through or batch-feed system (see figure at right) could be used; Confluence will provide guidance on testing trade-offs (approach options compared to actual reliability of data), cost:benefit, and ease of construction and operation for various options. If needed, Confluence can help develop an approach that can start introducing a synthesized treated surface water before the SRWA WTP is constructed, in order to confirm bench testing results in how the distribution system will respond to the integration of surface water.

As this is an optional task, it is not yet clear what level of testing will be desired. Confluence has budgeted a tentative fee of $100,000 for design, construction, and initial operations support for a 3 to 6-leg DS pipe loop rig that is partially automated. The City would need to cover day-to-day operations for up to 12 months.

A second optional task would involve coupon studies to verify optimum CCT (OCCT) conditions after surface water is introduced. A placeholder fee of $100,000 is suggested.

Quality Assurance / Quality Control and Project Management

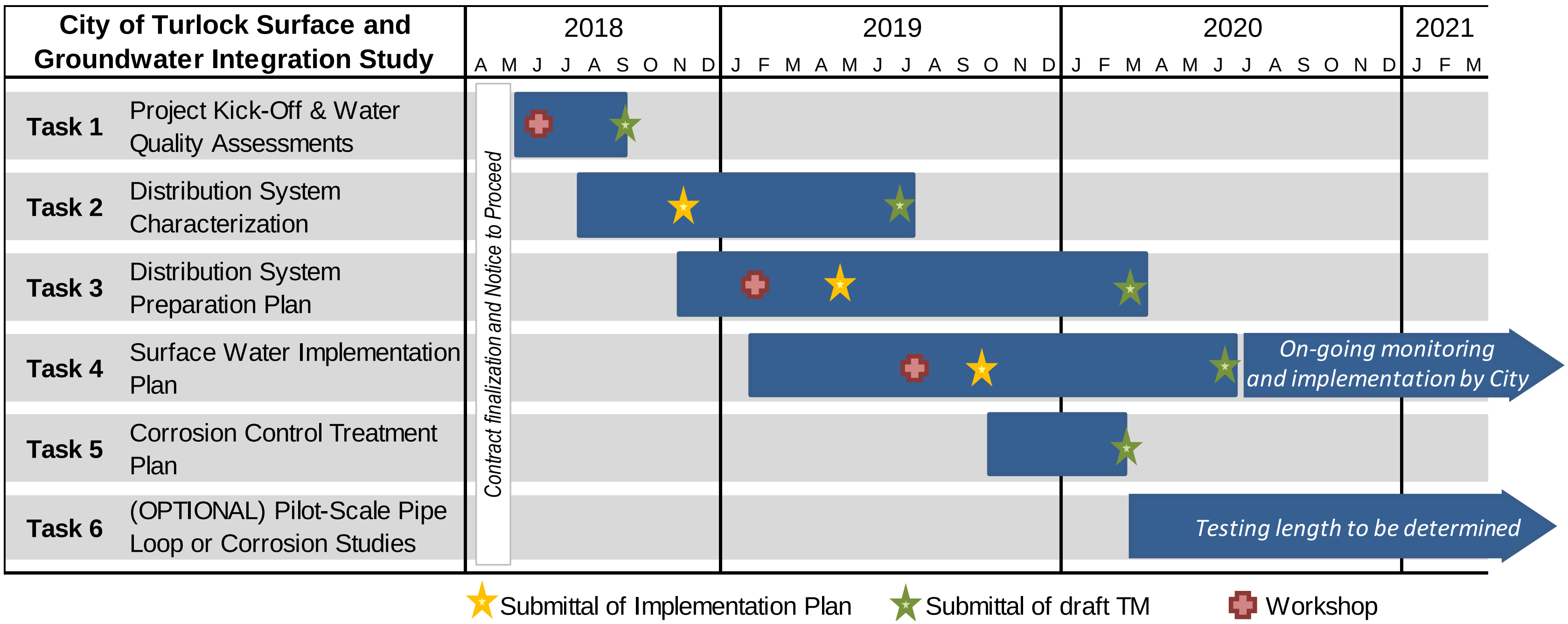
Each task is supported by Confluence's routine quality assurance and quality control (QA/QC) procedures for technical reviews and administrative management / review to maintain schedule and budget.

Confluence has well-established in-house QA/QC procedures that are implemented for all project deliverables, supporting calculations, drawings, cost estimates, technical memorandum, and reports. These procedures have been developed based on the rigorous standards that conform to project reporting requirements for the Water Research Foundation and Quality Assurance Project Plan (QAPP) requirements set forth by the USEPA. As a small firm, the senior project management teams routinely perform internal reviews of each-others' work and complete checks for completeness, accuracy, and consistency.

To properly administrate and maintain the project's budget and schedule, Confluence's project manager will remain in constant contact with the City's project manager. There will be regular (at least monthly) project manager meetings where progress, planning, and expected work outcomes will be addressed. Each month, Confluence will also prepare a summary project progress report along with a detailed project invoice, summarized by task, in order to illustrate where work was conducted, who conducted the work, and what work activities are planned in the next month. This multi-tiered system of project administration allows for minimized (if any) schedule delays and for both the City and Confluence project man-ages to easily identify when and if project changes may be needed.

Project Schedule

The approximate project schedule is illustrated below. This schedule will require confirmation after review from the City and discussion during the project kick-off in Task 1. It is anticipated all deliverables can be provided such that inputs needed for implementation of groundwater chlorination (anticipated mains cleaning and/or ramping of chlorination) and for SRWA WTP start up (mains cleaning needs, corrosion control chemicals if needed, and ramping-up of surface water blends in the DS) will meet the schedules for those projects.



Project Fee

The project fee breakdown is provided on the next page. The total fee is $325,324, including all labor and other direct costs. The optional Task 6 (pipe loop and bench-scale CCT testing), if needed, are given a placeholder fee of $100,000 each.

We would like to emphasize that our scope may be more complex and our fee higher than other bidders due to the fact that we view this project as involving two major chemistry changes which are (a) introduction of chlorine to a historically unchlorinated system, and (b) introduction of surface water to a historically groundwater system. The RFP language focuses on the integration of surface water, but we believe that the introduction of chlorine, if not properly addressed, could pose an equivalent or even greater risk for upset.

Also, it should be noted that depending on system conditions, the fee could decrease. It is not possible to know at this point the degree, nature, and volume of legacy deposits that have accumulated over the years given the variety of groundwater source, pipe materials, ages, and demands.