Hazen *Technical Memorandum*

January 21, 2020

To: Town of Culpeper

From: Hazen and Sawyer

Water Quality Recommendations

DRAFT

Results from the Water Quality Analysis were used to prioritize recommendations for system optimization to further minimize episodic aesthetic water quality issues. The objectives of this Water Quality Recommendations technical memorandum consist of the following:

- Summarize and prioritize water quality objectives.
- Develop strategies to achieve water quality objectives.
- Prioritize recommendations to enable the Town to implement operational changes and upgrade infrastructure in a methodical and practicable manner.

Recommendations are presented in three sections: Near-term Optimization Recommendations, Proactive Water Quality Enhancement Strategies, and Master Planning for the Future. Implementation guidance was developed for near-term recommendations to describe a methodical stepwise approach for implementing recommendations and monitoring the results before planning or implementing future actions.

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1. Introduction

The Town of Culpeper (Town) retained Hazen and Sawyer (Hazen) to perform an independent Water System Assessment. A Water System Study evaluating source water, treatment and distribution was performed as part of the Assessment, and the results are summarized in three technical memoranda: (1) Water System Evaluation; (2) Water Quality Analysis; and (3) Water Quality Recommendations. The objectives of each memorandum are detailed in **Figure 1-1.**

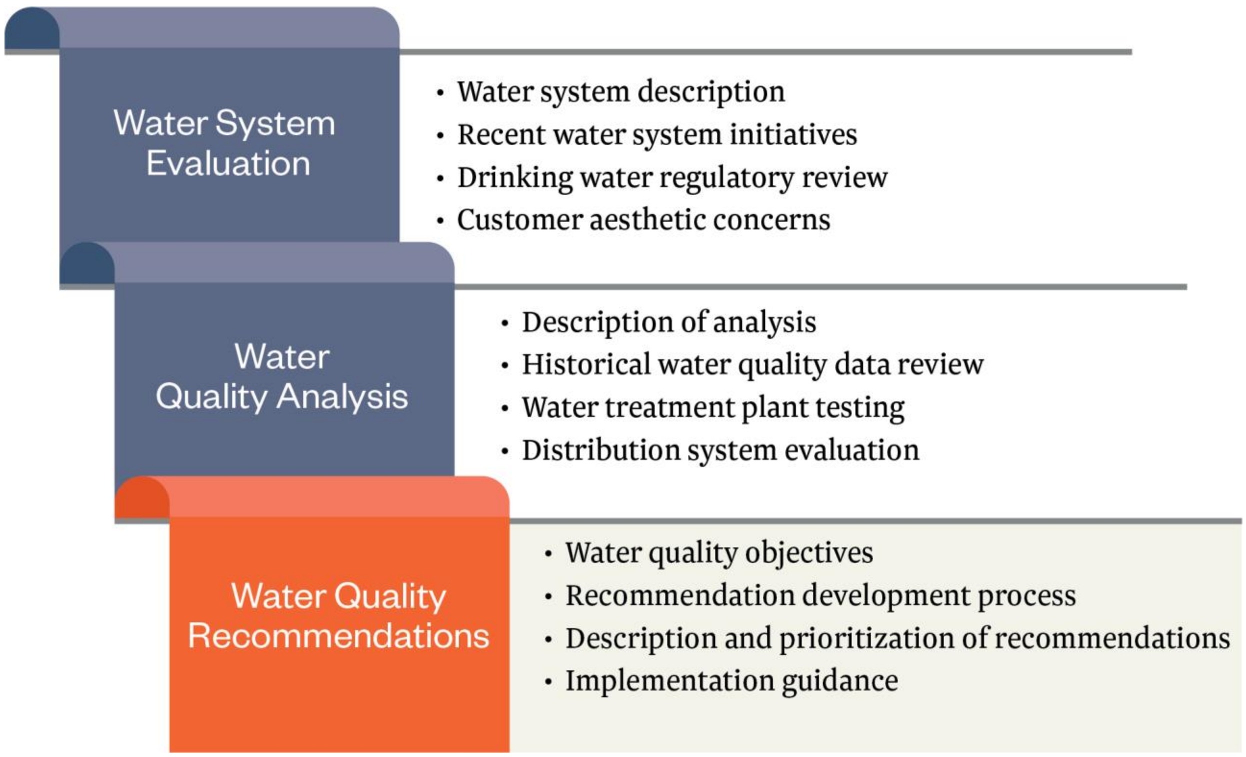

Figure 1-1. Summary of Water System Study Tasks and Objectives

This memorandum presents the Water System Recommendations generated as part of the Water System Study. Recommendations were based upon results from the Water System Evaluation and Water Quality Analysis. This memo addresses the following objectives:

- To summarize and prioritize water quality objectives.
- To develop strategies to achieve water quality objectives.
- To organize implementation strategies over time to enable the Town to perform operational changes and upgrade infrastructure in a methodical and practicable manner.

1.1 Recommendation Development Approach

The results of the water quality data analysis concludes that the Town is meeting all state and federal primary drinking water quality regulations for water treatment and distribution as it pertains to public health and safety. Analysis of the available data suggests periodic exceedances of secondary MCLs – non-enforceable guidelines – indicative of potential aesthetic issues with finished water. Consumer water quality reports also cite aesthetic issues, primarily associated with water discoloration, taste and odor, and hardness. Based on the data analysis, opportunities to optimize water quality to address these aesthetic issues were identified. This memo presents recommended strategies to further optimize the treatment process and distribution assets to address these aesthetic concerns.

The recommendations build upon the many ongoing efforts in place at the Town to protect public health, maintain regulatory compliance, operate and maintain aging infrastructure and facilities, and plan for future water supply and capacity needs. These efforts must remain the priority for the Town while implementing recommendations to address secondary aesthetic issues.

1.2 Report Organization

This technical memorandum consists of the following sections:

- **Section 1** – Introduction: This section describes the objectives and approach used to generate Water System Recommendations.
- **Section 2** –Water Quality Objectives: This section describes the approach used to prioritize water quality objectives, for which recommendations were developed.
- **Section 3** – Developing and Prioritizing Recommendations: Recommendations were prioritized into near-term recommendations, potential proactive water quality enhancement strategies, and master planning considerations.
- **Section 4** – Near-term Optimization Recommendations: These recommendations consist of distribution system optimization and water treatment optimization opportunities, and implementation guidance is presented to ensure a methodical approach to implementation.
- **Section 5** – Proactive Water Quality Enhancement Strategies: This section presents additional proactive water quality enhancement strategies to be considered by the Town to further improve water quality aesthetics.
- **Section 6** – Master Planning for the Future: This section presents a description of recommended additional master planning activities, including potential long-term system upgrades that should be evaluated in the Town's future master planning efforts.
- **Section 7** – Summary: This section summarizes the recommendations to further improve water quality aesthetics in the Town.

The following appendices are referenced in the memorandum and provide additional detail on the recommendations.

- Appendix A: Study Descriptions

2. Water Quality Objectives

Based on the results of the data analysis, key water quality objectives were developed to address the aesthetic concerns of discolored water and taste and odor. Although high hardness levels are present in the Town's groundwater supplies, hardness levels are consistent with those found in other water systems, and water hardness complaints constituted a minority of public water quality reports. Significant reduction in hardness would necessitate decreased groundwater consumption, which would reduce water supply resiliency and could cause adverse water quality effects such as increased DBP levels, or capital-intensive groundwater treatment upgrades for softening. For these reasons, reducing hardness was not prioritized as a key water quality objective in the Town.

To address discolored water, recommendations include distribution system optimization and proactive treatment enhancements. To address taste and odor proactive treatment enhancement are recommended. **Table 2-1** summarizes the water quality objectives and details the justification for selecting these objectives based on the results of the water quality analysis.

Table 2-1. Summary of Water Quality Objectives

Aesthetic Concern	Water Quality Objective	Justification

Discolored Water	Distribution System Optimization	• Data analysis provides evidence of:
		  • Periodic release of legacy deposits in the distribution system that may contribute to water discoloration
		  • Corrosion of iron distribution system mains and premise plumbing materials may contribute to water discoloration
		  • Variable distribution system water quality conditions and hydraulic patterns associated with source water blending

	Treatment Optimization and Proactive Treatment Enhancements	• Data analysis suggests that:
		  • Lake Pelham water periodically contains high levels of iron and manganese
		  • Historical iron and manganese levels in finished water have occasionally exceeded common industry goals
		  • pH and orthophosphate variability may influence water discoloration due to iron corrosion in the distribution system
		  • Disinfection byproduct (DBP) levels at one location in the distribution system have been recently elevated, indicating potential limitations for iron and manganese treatment strategies
		• The revised Lead and Copper Rule, due for release in 2020, will soon require many water systems to optimize corrosion control for lead and copper

Taste and Odor	Proactive Treatment Enhancements	• Data analysis suggests that Lake Pelham water may periodically contain high levels of DBP forming organics and taste and odor causing compounds. • Algae growth in Lake Pelham may contribute to episodic taste and odor complaints

3. Developing and Prioritizing Recommendations

Once the water quality objectives were identified, recommendations to address them were developed and prioritized into the following categories: near-term recommendations to be completed as soon as possible; proactive water quality enhancement strategies to be considered based upon the outcomes of the near-term recommendations; and, lastly, master planning for the future. **Figure 3-1** summarizes this approach.

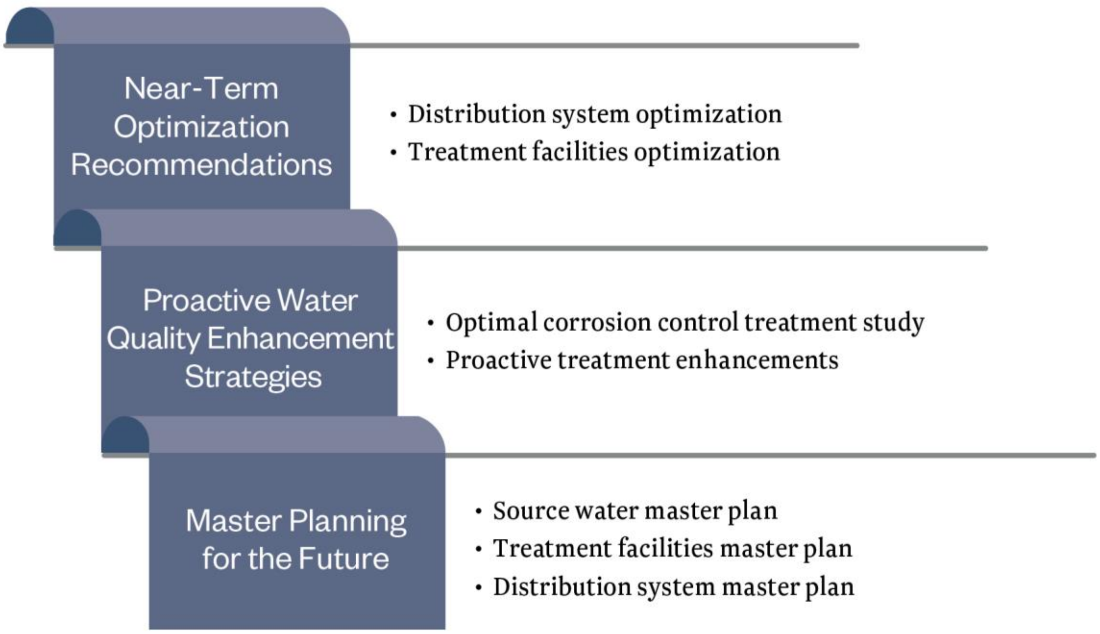

Figure 3-1. Summary of Recommendation Prioritization

Each recommendation category is summarized as follows:

- **Near-term Optimization Recommendations:** These improvements and recommendations can be implemented in the near-term to further improve water quality aesthetics by optimizing operations of the existing system without major capital improvements. The goals of the recommended optimization strategies include:
  - ***Distribution System:*** This includes flushing and cleaning to remove iron and manganese legacy deposits and optimizing current corrosion control approaches to decrease the potential for future iron corrosion and disturbance of pipe scales and deposits.
  - ***Treatment Facilities:*** This includes filtration optimization to minimize future accumulation of distribution system iron and manganese deposits and finished water chemical feed monitoring improvements to enhance process control and improve stability.

  These strategies must be implemented methodically to ensure improvement in water quality and avoid potential unintended consequences. Each strategy will be carefully implemented and monitored to review the performance and assess the need for additional enhancement and/or optimization measures before proceeding to the next step. Assuming a program start date in 2020, it is anticipated that these near-term recommendations can be initiated within one year and completed within three years.

- **Proactive Water Quality Enhancement Strategies:** The need for or scale of these improvements and recommendations may change contingent on performance of the implemented optimization strategies. The recommended proactive water quality enhancement strategies include:
    - ***Distribution System:*** Driven by forthcoming revisions to the Lead and Copper Rule (LCR) (anticipated in 2020), a corrosion control study should be performed to identify and implement an optimal corrosion control treatment strategy, while incorporating additional focus on iron corrosion control to address episodic water discoloration.
    - ***Treatment Facilities:*** In the event that the results of the near-term optimization strategies result in the need to further alter WTP operations to ensure ongoing compliance with applicable regulations (particularly increased DBPs) or significant and recurring taste and odor challenges from Lake Pelham occur, the following studies may need to be performed:
        - A proactive evaluation of permanganate dosing and possible implementation of liquid sodium permanganate should be performed to optimize iron and manganese control and minimize DBPs.
        - An evaluation of taste and odor (T&O) control, focused on monitoring for T&O compounds and evaluating Powdered Activated Carbon improvements, should be performed to optimize WTP response to the intermittent T&O challenges.

The degree to which these strategies must be implemented will be directly affected by the results of the near-term optimization strategies and the ultimate schedule set by the revised Lead and Copper Rule, which is anticipated to be finalized in 2020.

- **Master Planning for the Future:** To build upon the Town's existing long-term planning efforts and recent initiatives, this phase consists of master planning to guide the selection of potential future capital improvements and operational improvements. Planning activities will focus on ensuring adequate water quantity and quality, while addressing current and future regulatory and water quality drivers, both health-based and aesthetic. The focus of these planning efforts will be heavily impacted by the outcomes of the optimization and enhancement strategies, along with future regulatory, economic and population drivers. The goals of the future water planning efforts include:
    - ***Source Water:*** It is recommended that the Town continue to explore diversification of source water resources and develop plans for monitoring and maintaining quality of sources currently utilized.
    - ***Treatment Facilities:*** Planning efforts should address opportunities to expand water treatment capabilities to serve an increasing population. It is also anticipated that new regulatory drivers may require additional treatment technologies, either conventional or advanced.
    - ***Distribution System:*** A master plan addressing conveyance to an expanding population while maintaining high water quality, performing necessary maintenance and replacement, and addressing infrastructure resiliency should be performed.

Conceptual planning-level costs are presented for each recommendation and are intended only to screen and evaluate recommended strategies. Additional site-specific factors and design criteria during detailed design may impact project scope and cost. Planning-level costs reflect 2020 dollars, and future costs may vary depending on market conditions at the time of implementation.

4. Near-term Optimization Recommendations

This section describes recommendations for near-term optimization of the system, which are summarized in **Table 4-1** below. These optimization recommendations focus on the distribution system and the water treatment facilities. Assuming a start year of 2020, it is anticipated that implementation of these strategies will begin within one year and can be completed within three years. This section also presents flow charts which summarize key recommendations and provide guidance for methodical stepwise implementation of recommendations in the distribution system optimization and water treatment optimization categories.

Table 4-1. Summary of Near-Term Optimization Recommendations

Recommendation	Description	Planning-Level Cost
	Distribution System Optimization	
Systemwide Unidirectional Flushing (UDF)	• High-velocity flushing at strategic locations in the distribution system to clean pipes • Field inspections to confirm valve and hydrant operability and locations to inform UDF planning	*See Note 1*
Storage Tank Inspection and Cleaning	• Inspection and cleaning of distribution system storage tanks to remove deposits	*See Note 1*
Maintain Consistent Corrosion Control Treatment	• Increase finished water pH at all facilities to 7.6, consistently within 7.4 to 7.8 • Add sodium hydroxide at groundwater facilities using existing feed systems • Maintain consistent corrosion inhibitor doses, equivalent at all treatment facilities, of current product	*$4,000/year*
Distribution System Water Quality Monitoring	• Water quality monitoring before, during, and after UDF and treatment changes to adjust finished water pH and corrosion inhibitor feed	$30,000
	Treatment Facilities Optimization	
Filter Optimization	• Routinely monitor chlorine residuals in each individual filter effluent • Perform a pre-filter chlorine demonstration study to evaluate DBP impacts of increased chlorine doses • Maintain a constant filter effluent residual of at least 0.5 mg/L to enhance iron and manganese removal • Maintain consistent plant operations during backwash cycles	$70,000 *$5,000/year*
Improved Finished Water Chemical Feed Control	• Install a readily accessible sample tap on the post-filter conveyance pipeline prior to the clearwells, to be used for chemical dosing, monitoring of pH, chlorine residual, and orthophosphate	$45,000
		Total Capital Cost = $145,000 *Total Annual Cost = $9,000*

Notes:
1. It is assumed that these recommendations will be implemented internally by the Town and will not require costs for third-party assistance.

4.1 Distribution System Optimization

Optimizing the distribution system is important to reduce the potential for future water discoloration via distribution system iron corrosion or accumulation of iron or manganese deposits in the distribution system deposits over time. This section presents recommendations to clean the distribution system piping, inspect and clean storage tanks, modify corrosion control techniques, and continue system water quality monitoring.

Figure 4-1 presents the implementation approach for near-term recommendations related to distribution system optimization. The flow chart provides a methodical, stepwise approach to implement optimization recommendations, monitor the results, and assess performance before proceeding to additional potential enhancement strategies. It is recommended that the Town first implement unidirectional flushing (UDF) and cleaning of storage tanks to remove legacy deposits from the system. Next, it is recommended that the Town adjust its current corrosion control treatment strategy to provide a consistent treatment approach at all entry-points. Based on the outcome of these steps, the Town can consider additional proactive water quality enhancement strategies. The following sections provide detail on each key recommendation.

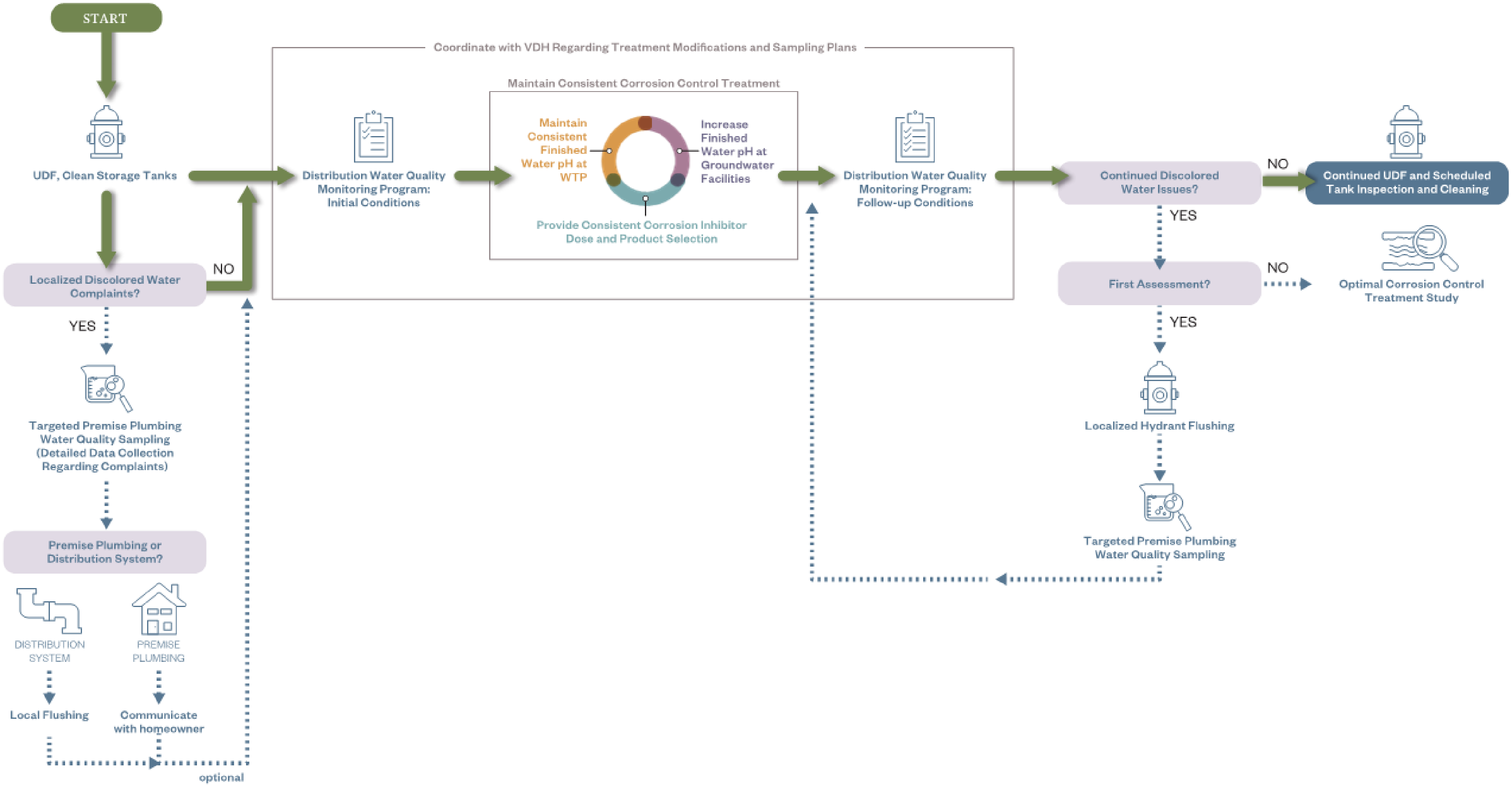

Figure 4-1. Near-Term Distribution System Optimization: Remove Legacy Deposits and Control Discoloration

4.1.1 Systemwide Unidirectional Flushing

The Town requested that Hazen develop a UDF program for the distribution system. UDF involves targeted high-velocity flushing at strategic locations in the distribution system to clean pipes. UDF consists of flushing “sequences” in which isolation valves are positioned to achieve high-velocity flow by opening a specific hydrant. Flushing sequences are developed using the distribution system hydraulic model to identify optimal locations for flushing and predict flow velocity. UDF is typically performed in phases from the point-of-entry to the distribution system to the extremities of the distribution system. UDF should be performed systemwide for pipes less than 12 inches in diameter to remove distribution system deposits.

UDF is considered an industry best practice for distribution system maintenance and can remove legacy deposits, loose sediments, pipe scales, and biofilms. A flushing velocity of 6 to 8 feet per second may be needed for removal of adherent coatings and biofilms. Despite these high velocities, UDF may not be fully effective for adherent manganese coatings on certain pipes (Friedman, 2012). While it has been reported that UDF has varying results for removal of biofilms (Friedman, 2012), it is anticipated that UDF will provide some benefits for controlling biofilm growth in distribution system mains with rough or tuberculated interior surfaces, providing additional benefits for control of discolored water and potential taste and odor issues associated with biofilms. While UDF is expected to provide long-term benefits for improving water quality aesthetics, disruption of existing pipe scales could contribute to temporary discolored water episodes during initial implementation, especially in portions of the system with cast iron or galvanized iron pipe.

UDF is best suited for cleaning mains up to 12 inches in diameter where high flushing velocities can be achieved. For the 18-inch diameter finished water main near the WTP, UDF is not expected to achieve adequate flow velocity for effective pipe cleaning. As a result, cleaning the 18-inch finished water main using physical techniques such as pigging, swabbing, or ice pigging is recommended. Achievable flushing velocities will be analyzed during development of the Town’s UDF program, and alternate cleaning methods such as pigging, ice pigging, or swabbing should be considered for any other large pipes with low predicted flow velocities; however, pigging may require pipe relining after cleaning. These techniques can require excavation of launching and retrieval stations, and excavation of the pipe is necessary if the device becomes stuck.

It is recommended that the Town perform an assessment of distribution system isolation valves and hydrants. Many isolation valves and hydrants will need to be operated during implementation of UDF; therefore, the development of flushing sequences is aided by the confirmation of valve and hydrant functionality. Any valves that cannot be located or operated during UDF may impact the UDF program by requiring a re-evaluation of the flushing sequence and delaying the schedule. Furthermore, distribution system valves in unanticipated positions may compromise achievable UDF velocities for pipe cleaning.

For cost planning purposes, it was assumed that valve assessments and UDF can be performed by Town staff. The level of effort for implementation will depend on the quantity of flushing sequencesthe condition of valves and hydrants, and necessary flushing durations encountered in the field.

4.1.2 Storage Tank Inspection and Cleaning

In 2016, the Town collected water quality samples at distribution system storage tanks. These samples intermittently contained elevated manganese levels above the SMCL. Accumulation of deposits containing iron and manganese in storage tanks may create the potential for episodic discolored water from release of legacy deposits. While UDF will remove deposits from distribution system mains, separate tank cleaning procedures would be needed to remove deposits and biofilms in tanks and maintain a clean distribution system after implementation of UDF. Routine tank inspection and cleaning is considered a best practice for distribution system management.

The Town has historically performed tank inspection and cleaning. It is recommended that the Town continue its tank inspection and cleaning program to ensure that any and all sediment deposits are removed. The AWWA Manual M42 recommends that water systems clean storage tanks at least once every three years or more frequently in systems that experience sediment accumulation. Based on these guidelines, it is recommended that the Town clean storage tanks at least every three years.

It is assumed for cost planning purposes that storage tank inspection and cleaning can be performed internally by Town staff and will not require a third-party contractor.

4.1.3 Maintain Consistent Corrosion Control Treatment

Ensuring consistent and stable water quality after treatment will stabilize water quality entering the distribution system, especially pH and orthophosphate levels, and is consistent with recommended best practices for minimizing distribution system iron corrosion and release of legacy deposits (Friedman et al., 2010; Brandhuber, 2013)

To optimize the Town's existing corrosion control treatment strategy, it is recommended that a consistent pH and corrosion inhibitor dose be maintained at all treatment facilities. Further corrosion testing would be necessary prior to any further action, including changing the type of corrosion inhibitor, implementing significant changes to pH or alkalinity, introducing alternate water sources, or implementing alternate treatment strategies. Treatment process adjustments to optimize the Town's existing corrosion control strategy include the following:

- It is recommended that the Town increase the finished water pH at all treatment facilities to approximately 7.6 and maintain the pH within a consistent finished water pH in the range of 7.4 to 7.8. At the WTP this will require a slight increase in the lime dose added to the filter effluent. At the groundwater facilities, this will require a low dose of sodium hydroxide. Existing chemical feed facilities at the groundwater treatment facilities can add this chemical dose.

- The corrosion inhibitor dose should be carefully adjusted to maintain stable, consistent and equal orthophosphate concentrations at all entry-points, including the WTP and groundwater treatment facilities. Initially, corrosion inhibitor doses should be maintained consistent with recent doses, until an optimal corrosion control treatment study, including corrosion testing, is performed to evaluate alternate corrosion inhibitors. For example, in early 2019, the corrosion inhibitor dose at each treatment facility was approximately 3 mg/L as product, which equates to an orthophosphate dose of approximately 0.5 mg/L as PO_4. Routine finished water orthophosphate monitoring is recommended to confirm that concentrations are within target ranges.

- Furthermore, it is recommended that the Town select and maintain a single corrosion inhibitor product as changes to the proprietary corrosion inhibitor could alter the polyphosphate formulation and other chemical characteristics, impacting performance and scale formation.

- In accordance with LCR requirements, it is recommended that the Town notify and seek the approval of the Virginia Department of Health (VDH) prior changing pH and corrosion inhibitor dose.

These operational adjustments will not require major capital improvements and will only slightly increase annual chemical purchase costs. It is estimated that the additional annual chemical cost to adjust pH for lime at the WTP with lime will be approximately $1,000, and the additional annual chemical cost for caustic at the groundwater facilities will be approximately $3,000, for a total of $4,000 per year.

4.1.4 Distribution System Water Quality Monitoring

Together with UDF, storage tank inspections and cleaning, and iron corrosion control steps, it is recommended that the Town continue routine distribution system water quality monitoring and evaluate the results to assess the performance of these recommendations. Sampling should carefully monitor pH, alkalinity, hardness, orthophosphate, chlorine residual, iron, and manganese in each sample. The data collected from these efforts can be utilized in the development of the distribution system master plan described in Section 6.3. A budget of approximately $30,000 is included to cover water quality sampling efforts and analysis of results.

4.2 Treatment Facilities Optimization

Optimizing the WTP operations presents the opportunity to reduce the potential for future water discoloration via distribution system iron corrosion or accumulation of iron or manganese deposits. Optimizing the WTP will complement recommendations to address distribution system legacy deposits and further reduce the potential for episodic discoloration.

This section presents recommendations to optimize filter performance for removal of iron and manganese at the WTP and provide for consistency in finished water chemical dosing (i.e., finished water chlorine, corrosion inhibitor, and pH). **Figure 4-2** summarizes the recommended implementation process for near-term WTP optimization. First, the impacts of increasing the pre-filter chlorine dose on iron and manganese removal and DBP formation should be evaluated. Based on the outcome of these steps, additional proactive water quality enhancements, such as optimizing the permanganate feed strategy or evaluating alternate pre-oxidants, can be considered.

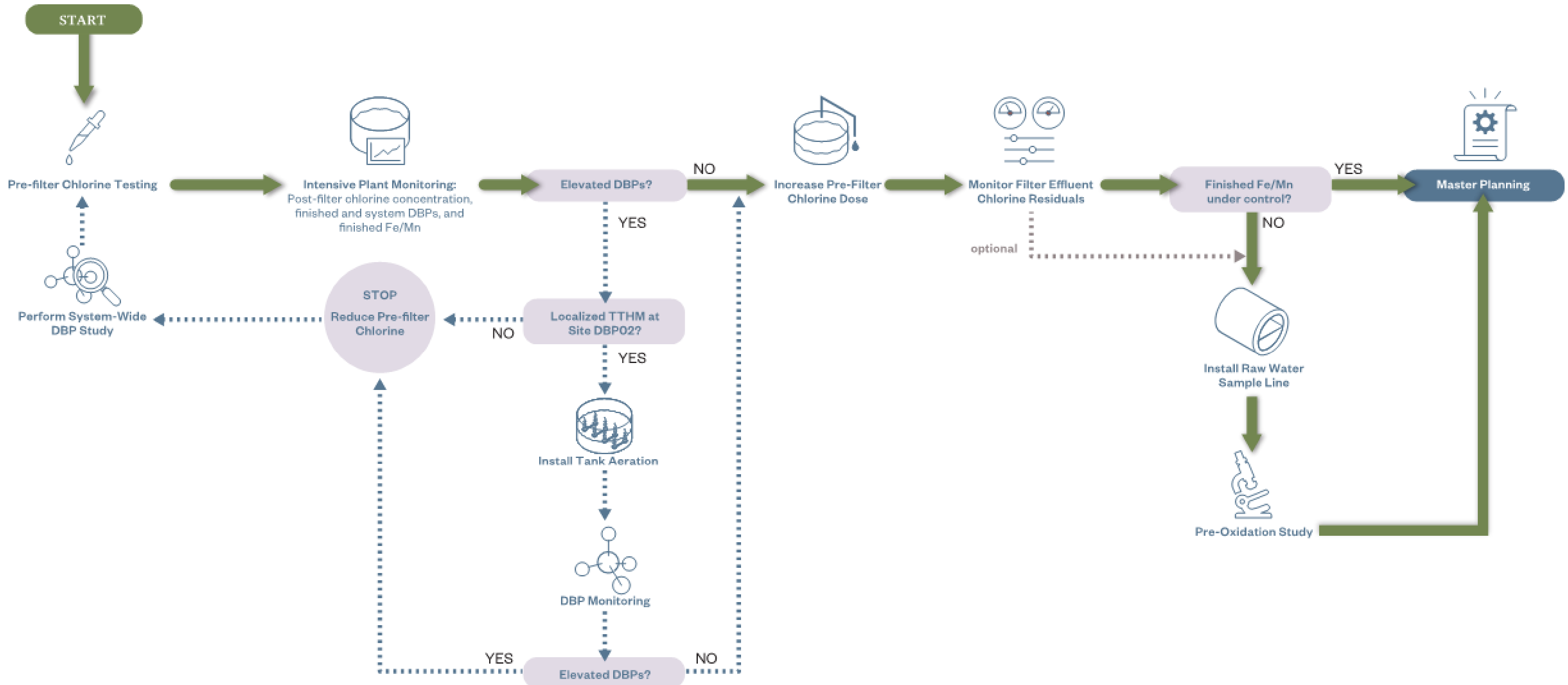

Figure 4-2. Near-Term Treatment Plant Optimization: Control Water Discoloration

4.2.1 Filter Optimization

Adjustment of pre-filter chlorine doses and monitoring of individual filter effluent chlorine residuals is recommended to further enhance iron and manganese removal at the WTP. Sorption of dissolved iron and manganese to manganese oxide coated filter media in the presence of free chlorine is a common treatment strategy for iron and manganese removal and is often paired with permanganate pre-oxidation strategies for iron and manganese control. However, the strategy relies upon constant and consistent levels of free chlorine throughout the entire depth of each filter bed. To ensure the success of the process, it is critically important to be able to provide consistent and accurate chlorine dosing, and frequent measurement of post-filter chlorine for each of the filters.

The WTP has historically added free chlorine to the channel between the sludge blanket clarifiers and the filters, and the free chlorine residual has been monitored in the filter influent just downstream of the point of chemical addition. The filter effluent chlorine residual has not been monitored prior to dosing additional chlorine in the filter effluent weir chamber for disinfection. However, grab sampling of filter influent and effluent conducted as part of this study revealed inconsistent top-of-filter chlorine levels and low free chlorine residuals in the filter effluent.

In order to optimize filter performance for iron and manganese removal, it is recommended that the Town methodically increase free chlorine levels prior to filtration to maintain a post-filter chlorine concentration in each filter of at least approximately 0.5 mg/L.

4.2.1.1 Pre-Filter Chlorine Demonstration Study

While this limited and controlled increase is not expected to significantly increase DBPs, the adjustment must be performed with testing to ensure DBPs remain as low as possible and within regulatory limits. Additionally, in an effort to reduce DBPs, the Town previously reduced pre-filter chlorine levels to minimize DBP formation. Recognizing the criticality of balancing these water quality needs, it is recommended the Town first perform a pre-filter chlorine demonstration study consisting of bench-scale testing, full-scale testing, and frequent monitoring to establish an approach that ensures compliance with multiple water quality goals. Iron and manganese removal should also be evaluated in full-scale testing to confirm treatment benefits. The major components of the pre-filter chlorine demonstration study are presented in Appendix A. A planning-level cost for a pre-filter chlorine demonstration study is approximately $20,000.

4.2.1.2 Filter Operational Modifications

To optimize filter operation, additional investments should be made for the following:

- Mixing and dispersion of chlorine added to the filter influent should be improved to ensure equal chlorine residuals on all filters. Currently, pre-filter chlorine is provided via a chlorine diffuser pipe in the filter influent channel. It is recommended that the diffuser be inspected and cleaned as needed to remove any deposits that could affect chlorine dispersion. Additionally, it is recommended that mixing of the pre-filter chlorine be improved via a post-injection mixing baffle.

- Routine individual filter chlorine residual monitoring should be performed. While an online chlorine residual analyzer can be used for instantaneous monitoring and tied into SCADA for process control, regular and frequent (e.g. 2-hour intervals) post-filter chlorine residual sample collection and monitoring for each individual filter can also be utilized as effective process control, without capital investment.

- The post-filter sample tap locations should be adjusted allow stabilization of filter effluent chlorine residuals and turbidity during filter ripening and filter-to-waste before placing a backwashed filter back in service. The current post-filter sample tap is not in a location capable of monitoring during filter-to-waste. The individual post-filter sample taps should be relocated to facilitate monitoring of filter effluent turbidity and chlorine residual during the filter-to-waste cycle.

- The filters should be routinely drained and inspected, with physical removal of accumulated solids from the top of the filter media. New anthracite media should be added to the top of the filters as needed to replenish any media removed during scraping and to maintain media depth. Additional filter testing can be performed to quantify the extent of floc retention throughout the depth of the media bed and evaluate media condition to further optimize filter performance. No capital cost is carried in the analysis for this improvement.

The cost of the improvements installing a filter influent mixing baffle and relocating post-filter sample taps is approximately $50,000 as shown in **Table 4-2**.

Table 4-2. Filter Effluent Chlorine Analyzers and Filter Influent Mixing Baffle Budget Cost Estimate

Description	Installed Cost
Pre-filter mixing improvements	$25,000
Post-filter sample tap improvements	$7,000
Subtotal=	$32,000
Contractor's Overhead and Profit (20%)=	*$6,400*
Contingency (35%) =	*$11,200*
Total Planning-Level Capital Cost=	**$50,000**

Assuming a long-term incremental increase in pre-filter chlorine dose of 1 mg/L, the additional annual chemical purchase cost is approximately $5,000.

4.2.2 Improve Finished Water Chemical Dosing

Consistent finished water chemical dosing provides many benefits for ensuring water quality. Data analysis has indicated the Town's water system could benefit from consistent finished water pH, chlorine, and corrosion inhibitor levels. Current finished water chemical dosing relies upon chemical feed in post-filtered water, and the post-filter monitoring location is nearly the same as chemical injection points. As a result, staff rely on finished water monitoring to adjust the chemical feed, resulting in delays in chemical adjustment to meet target levels. To address this, the Town is working to add a pre-clearwell sampling location significantly downstream of the filter effluent chemical feed to allow for sufficient mixing prior to measurement. In this location, operations response time can be greatly improved, and finished water chemical dosing can be better controlled. The pH, chlorine residual, and orthophosphate concentration, at a minimum, should be monitored at this location. Addition of the pre-clearwell sample tap will provide particular benefits for maintaining consistent corrosion control treatment, including finished water pH and orthophosphate.

Development of a chemical system standard operating procedure (SOP) is recommended to improve finished water consistency. The SOP should describe procedures for manual adjustment of chemical doses at each point in the process, effective water quality response monitoring, and process control.

The cost of the finished water chemical feed improvements and installing a new pre-clearwell process monitoring sample tap is approximately $45,000 as shown in **Table 4-3**.

Table 4-3. Pre-Clearwell Sample Tap Budget Cost Estimate

Description	Installed Cost
Site/Civil	$2,000
Post-filter Pipe Tapping	$10,000
Sample Line Piping and Valves	$5,000
Sample pump structure	$3,000
Electrical Service Extension	$5,000
Subtotal=	$25,000
Contractor's Overhead and Profit (20%)	*$5,000*
Contingency (35%) =	*$9,000*
Engineering, Design, Permitting (15%) =	*$6,000*
Total Planning-Level Capital Cost=	**$45,000**

Depending on the outcome of these recommended improvements, the Town could consider installation of a post-clearwell sodium hydroxide feed system to further improve pH control capabilities. After implementation of these recommendations, it is recommended that the Town evaluate whether the existing chemical feed facilities provide the capability to consistently maintain finished water pH with an range of +/- 0.2 pH units. Should additional pH control be needed, a post-clearwell caustic feed system is expected to provide benefits for plant operability and process control.

5. Proactive Water Quality Enhancement Strategies

This section presents potential strategies that can be implemented following the near-term optimization recommendations and additional data collection efforts. Implementation of these proactive water quality enhancement strategies is dependent on the outcome of near-term optimization recommendations.

Table 5-1. Summary of Proactive Water Quality Enhancement Recommendations

Recommendation	Description	Cost
	Optimal Corrosion Control Treatment Study	
Optimal Corrosion Control Study	• Perform corrosion testing to evaluate optimal corrosion control strategy used at all treatment facilities • Test a corrosion inhibitor with a higher orthophosphate and lower polyphosphate content • Implement gradual adjustments to system-wide optimal corrosion control, in accordance with USEPA recommendations	$250,000
	Proactive Treatment Enhancements	
Pre-Oxidation Study	• Evaluate benefits of optimizing permanganate dosing • Evaluate liquid sodium permanganate	$50,000
Powdered Activated Carbon (PAC) Study	• Monitor and understand magnitude of reservoir taste and odor challenges, and develop optimized response strategies • Conduct bench-scale testing to determine best performing PAC product and dosing strategy to maximize T&O removal in treatment	$80,000
Raw Water Sample Tap	• Install raw water sample tap prior to permanganate addition to quantify raw water quality and guide chemical addition	$90,000

5.1 Proactive Optimal Corrosion Control Treatment Study

The Town should consider performing a corrosion control treatment study to determine the optimal corrosion inhibitor type and dose through pilot-scale corrosion testing prior to full-scale implementation. The study should evaluate treatment alternatives to minimize lead release, in accordance with LCR requirements, while also improving control of water discoloration by improving iron corrosion control. Iron corrosion testing should include harvested cast iron and galvanized iron pipe in the pilot system. Due to the variable nature of the interior surface of galvanized pipe, customized corrosion testing is often necessary to determine an effective corrosion control treatment strategy for galvanized iron pipe (Tang et al, 2018), which is present in the Town's distribution system. Scale analysis of cast iron pipe can be used to identify scale layers that influence iron release to drinking water and may provide insight on opportunities to further enhance corrosion control treatment.

The planning-level budget for an optimal corrosion control treatment study, including pilot-scale corrosion testing for up to one year, is $250,000. Actual testing costs may vary depending on the type of testing apparatus, the quantity of test conditions, and the duration of corrosion testing. Additional details on the study approach are presented in **Appendix A.**

5.1.1 Potential Corrosion Inhibitor Alternatives

The Town adds a blended phosphate corrosion inhibitor containing 50% orthophosphate and 50% polyphosphate for corrosion control treatment. Orthophosphate can provide benefits as a corrosion inhibitor for reducing release of lead, copper, and iron to drinking water. Polyphosphate sequesters dissolved iron, manganese, and calcium; however, the use of polyphosphates should be limited due to the potential for polyphosphate to sequester lead and copper into drinking water.

Corrosion control can potentially be improved by increasing the dose of orthophosphate while maintaining or decreasing the polyphosphate dose. For example, the Town has used Shannon Chemical SLI-5250 with 50% orthophosphate in 2018 and 2019. Shannon Chemical also offers product SLI-5270 which contains the same formulations of orthophosphate and polyphosphate with 70% orthophosphate, and other products with higher orthophosphate content.

Based on prior research regarding corrosion control for iron, a higher orthophosphate dose up to 3 mg/L as PO_4 may be beneficial for further reducing iron release from distribution system pipes and premise plumbing materials (AWWA and DVGW, 1996; Sarin et al, 2003; Lytle et al, 2005; Tang et al, 2018). However, increasing polyphosphate dose above 0.5 mg/L is not recommended, and corrosion testing is recommended prior to significantly increasing orthophosphate concentrations to confirm the benefits for reducing iron release and evaluate impacts on lead and copper corrosion. Additional tools such as laboratory analysis of iron pipe scales could be conducted to enhance corrosion control.

5.1.2 Potential Corrosion Inhibitor Selection Options

For planning purposes, potential corrosion inhibitor options for further testing were identified. **Table 5-2** presents a comparison of potential corrosion inhibitor dose scenarios for corrosion testing. After changing the corrosion inhibitor product, it is recommended that the Town gradually increase the orthophosphate dose to a concentration in the range of 1 to 3 mg/L as PO_4 in accordance with USEPA recommendations (USEPA, 2016). As a result of these changes, polyphosphate doses should remain equal to or lower than antecedent treatment conditions (**Table 5-2**). It is recommended that equivalent corrosion inhibitor doses be added at all treatment facilities to maintain consistent orthophosphate concentrations in the distribution system.

Polyphosphate could be included in blended phosphate corrosion inhibitors selected for corrosion testing to provide sequestration of any dissolved iron and manganese to help reduce the potential for discolored water. If polyphosphate is minimized or eliminated in the corrosion inhibitor to optimize corrosion control, alternate strategies to control water discoloration may need to be considered.

Modifying the corrosion inhibitor type and dose is expected to slightly increase annual chemical purchase costs. Actual chemical costs may vary depending on the selected orthophosphate dose and market factors associated with chemical bids. These operational adjustments will not necessitate major capital improvements, as existing corrosion inhibitor feed systems are present at each facility.

Table 5-2. Potential Corrosion Inhibitor Dose Scenarios

Parameter	Average WTP Dose [1]	Corrosion Inhibitor A	Corrosion Inhibitor B
Inhibitor Orthophosphate Content	50%	70%	90%
Orthophosphate (mg/L as PO_4)	0.56	1.2	3.0
Polyphosphate (mg/L as PO_4)	0.56	0.5	0.33

1. *Estimated based on reported corrosion inhibitor dose as product in WTP monthly operating reports and chemical strength for January 2017 to February 2019.*

5.1.3 Future Implementation Considerations

Upon evaluation and selection of an alternate corrosion inhibitor type and dose, the corrosion inhibitor dose should be carefully adjusted to maintain a stable orthophosphate concentration at each entry-point. Routine finished water orthophosphate monitoring is recommended to confirm that concentrations are within target ranges; online orthophosphate analyzers are also available to provide real-time tracking of orthophosphate levels.

Due to the potential for distribution system water quality impacts associated with abrupt corrosion inhibitor dose changes, a startup plan for the new corrosion inhibitor should be developed as part of the study. The orthophosphate dose should be adjusted gradually from typical recent levels to the selected dose over a period of approximately 12 months.

In accordance with LCR requirements, it is recommended that the Town notify VDH and obtain written approval in advance of implementing this treatment change. The corrosion testing plan should be submitted to VDH for review prior to testing. VDH may require increased lead and copper compliance monitoring after full-scale implementation to demonstrate optimal corrosion control treatment. It is recommended that the Town of Culpeper increase both water quality and lead and copper monitoring before, during, and after making any changes to corrosion control treatment.

5.1.4 Targeted Premise Plumbing Sampling

It is recommended that targeted premise plumbing sampling to evaluate water discoloration episodes be included as part of the optimal corrosion control treatment study. Privately-owned premise plumbing includes interior piping and fixtures and the portion of the service line past the meter on private property; however, no data was available in the Water System Study to characterize water quality in premise plumbing during discolored water episodes. Targeted premise plumbing sampling will allow the Town to evaluate the impacts of service line and premise plumbing corrosion on water discoloration at the tap and to quantify the concentrations of iron, manganese, and other metals in discolored water. This data would be beneficial for planning corrosion testing materials and test conditions to address iron corrosion and reduce water discoloration associated with iron.

In addition to iron and manganese, the premise plumbing sampling program should test the concentrations of manganese, lead, copper, zinc, barium, arsenic, and nickel, as these constituent may co-occur with iron and manganese in samples of discolored water collected from premise plumbing (McFadden et al, 2011; Masters et al, 2015; Trueman et al, 2016; Trueman et al, 2019; Clark et al, 2015; Hill, Friedman et al, 2010).

5.2 Proactive Treatment Enhancements

This section details several additional proactive treatment enhancements at the WTP which were identified as potential strategies to assist the Town in further improving water quality aesthetics, including the following:

- A pre-oxidation study would allow the Town to develop an optimal oxidant dosing strategy or identify an alternate pre-oxidant for iron and manganese control.
- A powdered activated carbon (PAC) optimization study would be advantageous for proactive taste and odor management. The study should include raw water monitoring for taste and odor compounds MIB and geosmin, as well as testing to optimize the type, dose, and feed location for PAC.
- Installation of a raw water sample tap would allow the Town to better quantify raw water quality characteristics to guide the addition of a pre-oxidant, PAC, and other treatment chemicals.

5.2.1 Pre-oxidation Study

Addition of permanganate as a raw water pre-oxidant has been a primary iron and manganese treatment strategy at the Culpeper WTP. Permanganate oxidizes dissolved iron and manganese to form particles which can be removed in the sludge blanket clarifiers or filters at the WTP. It is recommended that the Town perform a study to develop an optimal pre-oxidant dosing strategy for treating dissolved iron manganese present in raw water.

Initially, full-scale testing of permanganate is recommended to determine if permanganate doses can be reduced after pre-filter chlorine doses are increased, which will provide a second barrier for iron and manganese removal on the filters (refer to **Figure 4-2**). Pending confirmation of DBP impacts, optimizing free chlorine doses on the filters may provide the opportunity to reduce permanganate doses. Reducing permanganate doses would decrease the overall manganese loading to the WTP, decrease the rate of manganese accumulation in the sludge blanket, and reduce the risk of a permanganate residual or manganese oxide colloids in the filter influent. Reducing permanganate doses while increasing pre-filter chlorine for iron and manganese control would also provide significant chemical cost savings. The study will allow the Town to develop an optimal dosing strategy that promotes iron and manganese removal while minimizing the permanganate dose.

Additionally, the Town should evaluate sodium permanganate for pre-oxidation in lieu of potassium permanganate. Potassium permanganate is prepared from a dry product into a batch of solution near the raw water intake. Sodium permanganate offers similar performance as potassium permanganate, provided that doses are adjusted based on molar weight differences, and the liquid product provides operational and process control benefits compared to dry potassium permanganate. Changing from potassium permanganate to sodium permanganate at equivalent molar doses would not impact other water quality parameters.

A study consisting of bench-scale and full-scale permanganate testing is recommended; additional detail on the study approach is presented in **Appendix A**. The budgetary cost for a pre-oxidation study is approximately $50,000.

5.2.2 PAC Optimization Study

Algae growth occurs seasonally in Lake Pelham, and the Town treats algae with a peroxide-based algaecide. Algae growth can cause unpleasant tastes and odors in drinking water, especially “earthy”, “musty” or “moldy” tastes associated with MIB and geosmin. The Town currently has limited historical data available to characterize and quantify algae growth in the reservoir. Additionally, the Town has limited data to characterize reservoir stratification, which can influence water quality, algae growth, and taste and odor issues.

It is recommended that the Town monitor MIB and geosmin in raw water to establish baseline levels and monitor MIB and geosmin levels during periods with algae growth in the reservoir. MIB and geosmin should also be tested in response to increases in customer complaints of earthy, musty, and moldy tastes and odors to determine if source contributes to customer complaints. Furthermore, collecting data on the range of concentrations of MIB and geosmin in raw water will allow the Town to identify the optimal treatment approach for removal of these organic compounds, such as addition of powdered activated carbon at the WTP. In addition, it is recommended that the Town monitor the raw water in the reservoir for cyanobacteria and actinomycetes, which can be identified through microscopic examination, to determine the extent to which these organisms may contribute to taste and odor issues derived from surface water.

The concentrations of MIB and geosmin and the level of natural organic matter may influence the type and dose of PAC necessary for removal of taste and odor compounds from surface water. A variety of PAC products are commercially available and can have varying performance for sorption of organic compounds. A study to evaluate optimal PAC doses and PAC type is recommended to improve control of taste and odor compounds and facilitate effective treatment adjustments when taste and odor compounds are observed in source water. The study should consist of bench-scale testing to evaluate removal of taste and odor compounds at the WTP and to determine the optimum PAC product and dose-response characteristics for removal of taste and odor compounds. Additional detail on the study approach is presented in Appendix A. The budgetary cost for a PAC Optimization Study including raw water monitoring for MIB and geosmin is approximately $80,000.

5.2.3 Raw Water Sample Tap

Accurate characterization of raw water quality is critical for determining optimal pre-treatment, including raw water oxidation, PAC addition, and even coagulant addition. This is particularly important during periods with rapidly changing raw water quality. The WTP currently monitors raw water quality from a sample tap at the WTP site after permanganate addition at the reservoir, with no raw water sample tap prior to pre-oxidation available. Currently, addition of permanganate influences observed water quality observations of raw water entering the WTP.

As a precursor to performing water quality enhancement studies, it is recommended that the Town install a readily-accessible sample tap on the raw water pipeline near the permanganate building prior to the point of chemical addition. It is recommended that raw water samples be collected from the this tap on a daily basis, or more frequently when necessitated by raw water quality conditions, to quantity raw water quality, including sampling for iron, manganese, organic DBP precursors (UV_{254}), taste and odor compounds. With knowledge of raw water quality, WTP staff can alter the treatment approach to optimize treatment. The anticipated implementation budget for installation of a raw water sample tap at the reservoir is approximately $90,000 as shown in **Table 5-3**.

Table 5-3. Raw Water Sample Tap Budget Cost Estimate

Description	Installed Cost
Site/Civil	$15,000
Raw Water Main Tapping	$10,000
Sample Line Piping and Valves	$10,000
Electrical Service Extension	$15,000
Subtotal=	$50,000
Contractor's Overhead and Profit (20%)	*$10,000*
Contingency (35%) =	*$18,000*
Engineering, Design, Permitting (15%) =	*$12,000*
Total Planning-Level Capital Cost=	**$90,000**

6. Master Planning for the Future

The Town has recently performed several planning initiatives focused on maintaining regulatory compliance, protecting public health, operating and maintaining aging infrastructure and facilities, as well as planning for future water supply and capacity needs. The Town has augmented its surface supply with groundwater to proactively plan for potential future demands and provide water supply resiliency by cultivating an additional water supply source.

To build upon the Town’s long-term planning efforts, it is recommended that the Town develop a master plan to balance water system capacity, quality, and resiliency objectives and develop a framework to expand and upgrade the water system to meet the Town's long-term needs. Critical decisions regarding water quality and treatment, including potential capital improvements to water treatment infrastructure, depend on projected customer demands and planned future water sources. The outcome of the master plan will allow the Town to make informed, methodical decisions regarding possible future investments for water infrastructure that are consistent with the Town’s long-term vision for water supply and water quality.

In addition, the water quality master plan should consider emerging water quality issues and possible future regulatory requirements. This will allow the Town to further optimize water quality and aesthetics while positioning for future regulatory compliance.

The master planning efforts have been categorized into the following tasks which are summarized as follows:

- **Source Water Master Plan** – The source water master plan should evaluate quantity, quality, and resiliency aspects of the Town’s water supply. The master plan should evaluate water demand projections and identify the Town’s planned future water sources, including additional groundwater or surface water supplies, to develop a long-term strategy for source water management and supply. The master plan should evaluate source water quality characteristics and strategies to maintain source water quality. In particular, the source water master plan should evaluate opportunities to enhance the Town’s current algae management program for Lake Pelham.

- **Treatment Facilities Master Plan** – The treatment facilities master plan should evaluate potential future changes to the Town’s treatment facilities based on capacity needs and regulatory drivers. The master plan should consider goals for maintaining water quality aesthetics, anticipated future regulatory issues, and an evaluation of potential alternate treatment technologies, including conventional and advanced treatment. In particular, the master plan should evaluate 24-hour operation of existing treatment facilities and potential long-term capital upgrades.

- **Distribution System Master Plan** – The distribution system influences system capacity, pressure, fire flow, and water quality. The master plan should evaluate opportunities to optimize distribution system water quality as the distribution system is expanded and renewed in the future to serve the Town’s customers. The Town is currently performing ongoing distribution system pipe replacement efforts, and the master plan provides an opportunity to augment the Town's current pipe replacement efforts into a methodical replacement approach with defined replacement rate goals and budgets. In particular, the distribution system master plan should evaluate potential changes to the source water blending strategy to optimize the distribution system.

Key aspects of each master plan category are described in the following subsections. The anticipated cost for a master plan covering these topics is approximately $500,000.

6.1 Source Water Master Plan

It is recommended that the source water master plan evaluate the quantity, quality, and resiliency of the Town's source water supply portfolio. The Town has implemented significant upgrades to the quantity and resiliency of its source water portfolio by introducing groundwater supply. The source water master plan should include water demand projections for a 30 to 50-year planning horizon. This information will allow the Town to identify long-term water sources, including groundwater or surface water, to augment the Town's supply. Critical decisions regarding future upgrades to treatment facilities and distribution system infrastructure depend on the identification of the Town's long-term water sources. For example, treatment and distribution infrastructure should be expanded and upgraded based on the Town's vision on the relative use of surface water and groundwater in the future.

In addition, the source water master plan should evaluate reservoir algae management and in-situ reservoir treatment as potential strategies to enhance source water quality in Lake Pelham.

6.1.1 In-Situ Reservoir Treatment

Effective in-situ reservoir treatment, such as aeration or oxygenation, should be evaluated in the master plan, as it has the potential to significantly reduce dissolved iron and manganese levels entering the WTP, assist with control of algae growth, and reduce taste and odor issues associated with surface water.

Release of dissolved manganese from benthic sediments in surface water can occur with anoxic conditions in lower levels of the reservoir. Thermal stratification of the reservoir during warm summer conditions can result in depletion of dissolved oxygen in the hypolimnion, especially with increased loading of organic matter on the bottom of the reservoir. Managing anoxic conditions through in-situ treatment may provide additional benefits for reducing internal phosphorus loading in the reservoir and can be part of a long-term management strategy for algae.

Several in-situ reservoir treatment technologies are available manage reservoir water quality, including destratification, aeration, and hypolimnetic oxygenation. An aeration system typically consists of a network of fine bubble diffusers installed near the bottom of the reservoir and compressors to deliver air into the air at specified rates, with a pipe that can be filled with air to buoy to the aeration grids for maintenance. Aeration system design and configuration must be customized for each reservoir based on reservoir bathymetry, flow patterns, and water quality.

Reservoir depth profiling should be considered as part of the master plan to characterize the occurrence of thermal stratification in Lake Pelham and support the evaluation of a possible future in-situ reservoir treatment system. As part of the planning, the impacts of in-situ treatment on the concentration of natural organic matter in raw water should be evaluated, as control of organics in raw water is critical for maintaining low DBP formation at the WTP.

6.1.2 Algae Management Plan

Development of an algae management plan would allow the Town to protect source water quality by identifying opportunities to control algae growth through timed application of algaecides and in-situ reservoir treatment. As the Town is currently applying a peroxide-based algaecide, the algae management plan would augment the Town’s efforts to control algae growth. Through intensive algae data collection and analysis, an optimal algae treatment strategy can be developed to control algae populations and minimize harmful algae blooms.

As part of the plan, a cyanotoxin monitoring and response plan should be considered, which will position the Town to meet EPA Health Advisories and potential future regulatory requirements for cyanotoxins. The plan should describe raw water monitoring for cyanotoxins, the treatment strategy for removal of cyanotoxins, finished water monitoring for cyanotoxins, and notification procedures.

6.2 Treatment Facilities Master Plan

Key aspects of the treatment facilities master plan are described in the following subsections.

6.2.1 Treatment Facility Operation Schedule

As part of the master plan, it is recommended that the Town evaluate changing facility operations to maintain WTP operation 24 hours per day. This operational adjustment will provide benefits for WTP process performance as well as distribution system water quality. As 24-hour operation facility operation would allow the Town to produce a greater capacity of water at the WTP, this change should also be evaluated relative to projected customer demands and future source water supplies in the master plan.

Operating the WTP continuously for 24 hours per day provides an opportunity to improve WTP performance by reducing hydraulic loading rates to treatment processes and minimizing abrupt changes to flow rate that may adversely affect the sludge blanket clarifiers. Operating treatment facilities on a continuous basis at consistent flow rates will also stabilize blending patterns in the distribution system, which may provide benefits for reducing the release of legacy deposits due to hydraulic disturbances and promoting the formation of stable iron corrosion scales to reduce iron release in drinking water.

Additional analysis of impacts to distribution system operation is recommended as part of the master plan prior to changing to 24 hour operation. Based on current operations, turnover occurs in the Route 522 Standpipe during the night while the WTP is not in operation. Continuous operation of the WTP may prevent turnover of the Route 522 Standpipe, resulting in excessive hydraulic residence time in the tank that could negatively affect DBP formation. An alternate tank operating strategy should be developed to facilitate 24 hour treatment facility operation.

Additionally, it is anticipated that 24 hour operation of the water treatment plant will increase operator staffing requirements and result in increased operational costs for the WTP, and internal staffing considerations should be reviewed as part of the planning process. The Town is currently coordinating with VDH regarding potential pending changes to water regulations that may reduce the number of operators required to be on site at the WTP during certain shifts. These potential changes to operator staffing requirements would make 24 hour treatment facility operation more cost effective and feasible to implement.

6.2.2 Potential Treatment Facility Upgrades

The treatment facilities master plan should also evaluate future treatment technologies, including conventional and advanced treatment techniques, to meet anticipated future regulatory requirements and maintain favorable water aesthetics. Potential long-term treatment facility upgrade alternatives that may be beneficial for further improving water quality aesthetics were identified and are described in this section. These potential treatment upgrades should be considered in the master plan, as well as additional treatment technology alternatives to meet future regulatory requirements and water quality objectives. All treatment facility upgrade alternatives should be considered holistically to methodically develop a long-term treatment process plan for the WTP.

6.2.2.1 Pre-Oxidation Facility Upgrades

A Pre-Oxidation Study was identified as a proactive water quality enhancement strategy, and depending on the outcome of the study, upgrades to the existing potassium permanganate feed system or conversion to sodium permanganate may provide benefits for iron and manganese removal. Pre-oxidation facility upgrades may include changes to the type of pre-oxidant chemical, changes to the chemical feed location, or a combination of both. These potential pre-oxidation upgrades should be considered relative to other treatment alternatives as part of the master plan.

6.2.2.2 Powdered Activated Carbon Facility Upgrades

A PAC Study was identified as a potential proactive treatment enhancement, and depending on the outcome of the study, PAC system upgrades may be warranted to allow the WTP to optimize removal of MIB, geosmin, and other organic compounds, which may contribute to taste and odor issues. PAC upgrades should be evaluated in the master plan based on the results of source water monitoring for MIB and geosmin if the existing treatment process does sufficiently remove these constituents to minimize taste and odor issues. The existing sludge blanket clarifiers retain PAC in the blanket for adsorption of organic compounds. PAC upgrades would allow the WTP to relocate the feed location to further increase raw water contact time or feed higher PAC doses if necessary.

6.2.2.3 WTP Clarification Improvements

Potential capital and /or additional operational improvements associated with the WTP clarification process should be evaluated during the master plan if necessary to achieve the Town's water quality objectives. At this time two aspects of the clarification process may warrant evaluation as part of the master planning efforts. First, if higher PAC feed to the existing sludge blanket clarifiers is found to be desirable, then the sludge blanket should be assessed relative to solids management (e.g., blowdown cycle optimization). Secondly, if 24-hour operation is implemented, consideration of options to manage potential thermal differences in the clarifiers is warranted. Temperature variation over the course of a 24 hour period can impact the solids blanket, particularly on sunny, warm days with cool evenings. Some utilities have chosen to cover the clarifiers or provide some screening to avoid direct sunlight on the basins. As noted previously, whether these two concepts need to be evaluated depends on the outcomes of earlier optimization activities and the findings of other master planning activities.

6.2.2.4 Filter Backwash System Upgrades

Upgrades to the filter backwash system would provide the capability to monitor and control the backwash flow rate and would eliminate variations in filter effluent flow caused by the existing system design that may contribute to water quality variability. Optimizing filter performance and backwash is an important strategy to maintain optimal removal of iron and manganese, including sorption of dissolved manganese to filter media. Modifications to the backwash system to facilitate direct pumping of backwash water into the underdrains and adjustment of the backwash flow rate would enhance operational flexibility to optimize filter performance. These potential filter upgrades should be evaluated in the master plan.

6.3 Distribution System Master Plan

This section describes key aspects of the distribution system master plan. Measured upgrades and expansions to the distribution system should be planned based on the Town's projected customer demands, future source water portfolio, and long-term water quality objectives.

6.3.1 Distribution System Asset Management Plan

As part of the master plan, the Town should consider developing a distribution system asset management framework to plan and prioritize replacement of select distribution system pipes to renew aging infrastructure and optimize distribution system water quality. A combination of water quality objectives and pipe condition and useful service life data should be evaluated to prioritize pipe replacement, including distribution system water quality monitoring data described in Section 4.1.4 (e.g., chlorine residuals, iron levels, reduced fire flow from periodic field tests, etc.). Pipe replacement can be prioritized according to defined failure modes based on water quality, pipe age, condition, criticality, and risk of failure. The asset management program includes a desktop analysis of available information on distribution system assets and a geospatial criticality analysis to determine the consequence of failure for each asset. It is anticipated that the Town will need to identify existing pipe materials and installation dates based on analysis of historical drawings and field investigations. Main break records can be analyzed to identify pipe characteristics with greater risk of failure. Based on this information, a distribution system main condition assessment plan should be developed to collect additional information on the condition of critical assets through in-situ and nondestructive testing as necessary to guide pipe replacement planning. A proactive asset management framework will allow the Town to determine an appropriate funding level for pipe replacement.

6.3.2 Targeted Distribution System Pipe Replacement

It is understood that the Town has planned to replace galvanized iron mains in the distribution system and has already begun working on replacement of galvanized iron mains. As part of the master plan, the Town should update its plans for renewal of aging distribution system assets as informed by the distribution system asset management plan described in Section 6.3.1 above. Development of a distribution system pipe replacement program would allow the Town to replace aging tuberculated cast iron and galvanized distribution system mains to provide water quality and infrastructure service life benefits, with a focus on replacing priority pipe segments as informed by ongoing water quality monitoring and periodic fire flow testing. Galvanized iron pipe is an antiquated pipe material and can present risks of corrosion byproduct release to drinking water, tuberculation, and pipe failure (AWWA and DVGW, 1996; Tang et al, 2018).

6.3.3 Distribution System Blending Optimization

Implementing controlled blending of source waters or isolating separate groundwater and surface water zones in the distribution system provides the opportunity to further improve iron corrosion control and minimize disruption of legacy deposits. Controlling blending would also attenuate higher levels of hardness, sulfate, and silica present in groundwater, providing a favorable blended water quality. Water quality data analysis and distribution system hydraulic model simulation results indicate that the majority of the Town’s distribution system receives a variable blend of surface water and groundwater, often on a daily basis.

Optimization of blending patterns in the distribution system presents an opportunity to enhance distribution system water quality while retaining the water supply and resiliency benefits of the Town’s groundwater supply. Potential strategies to optimize blending, reduce water quality variability, and maintain consistent hydraulic patterns in the distribution system include implementation of controlled blending of source waters at a centralized location or isolation of distribution system zones for surface water and groundwater supply. Changes to distribution system blending or isolation of zones may create other challenges that should be evaluated in the master plan. As blending of groundwater currently provides benefits for DBP compliance in the Town, changes to the blending strategy could increase DBP levels in portions of the system. Distribution system blending changes would also need to be evaluated to confirm impacts on hydraulics, pressure, and fire flow to determine if system operational changes are feasible. It is recommended that these controlled blending optimization strategies be evaluated as part of the distribution system master plan.

7. Summary

The Town has maintained compliance with all health-based Primary Drinking Water Standards. The system has occasionally experienced elevated levels of iron and manganese, consistent with consumer reports of episodic and localized discolored water. Recommendations to further optimize water quality aesthetics associated with water discoloration, taste, and odor were developed. The recommendations build upon the many on-going efforts in place at the Town to protect public health, maintain regulatory compliance, operate and maintain infrastructure and facilities, and plan for future water supply and capacity needs. These efforts are critical and indispensable aspects for effectively managing a water distribution system and need to remain a priority for the Town while implementing recommendations to address secondary aesthetic issues.

This technical memorandum presents near-term recommendations and possible future water quality enhancement strategies to assist the Town in further improving water quality aesthetics associated with water discoloration and taste and odor. Implementation guidance was developed for near-term recommendations to describe a methodical stepwise approach for implementing recommendations and monitoring the results before planning future upgrades. The anticipated capital cost of near-term recommendations is approximately $145,000, and the additional annual cost associated with chemical feed is $9,000 per year. Additional proactive water quality enhancement strategies are dependent upon the outcome of near-term recommendations and present opportunities to further enhance water quality aesthetics. Master planning is recommended to develop a long-term vision for water system capacity, water quality, and resiliency.

Appendix A: Study Descriptions

Hazen

Pre-Filter Chlorine Demonstration Study

The purpose of the pre-filter chlorine demonstration study is to evaluate the impacts of free chlorine added between the clarifiers and the filters on iron and manganese removal in the filters and formation of disinfection byproducts (DBPs). Maintaining a free chlorine residual of 0.5 to 1.0 mg/L in the filter effluent can remove dissolved manganese through adsorption to oxide-coated filter media. Although pre-filter chlorine is added after removal of natural organic matter (DBP precursors) through coagulation, increased chlorine doses and contact time could affect DBP formation at the WTP.

- Perform bench-scale testing to evaluate impacts of increased chlorine dose on DBP formation at a range of different doses and contact times representative of the filters
- Develop a water quality monitoring plan, including:
  - Filter chlorine residuals, including individual filter influent chlorine residuals in each filter and individual filter effluent chlorine residual;
  - Iron and manganese, including testing of raw water, filter influent, and filter effluent iron and manganese concentrations;
  - DPBs, including finished water and multiple distribution system locations.
- Perform full-scale demonstration testing, including:
  - Part 1 – Operate the WTP with pre-filter chlorine doses consistent with typical historical levels (e.g. 0.5 mg/L) and perform chlorine residual, iron and manganese, and DBP monitoring
  - Part 2 – Operate the WTP with higher pre-filter chlorine doses as needed to achieve a filter effluent chlorine residual of at least 0.5 mg/L and perform chlorine residual, iron and manganese, and DBP monitoring
  - Part 3 – Operate the WTP with higher pre-filter chlorine doses as needed to achieve a filter effluent chlorine residual of at least 1.0 mg/L and perform chlorine residual, iron and manganese, and DBP monitoring
- Analyze demonstration testing data to evaluate impacts of pre-filter chlorine on iron and manganese removal
- Evaluate relative changes in DBP formation and potential impacts on State 2 Disinfectants and Disinfection Byproducts Rule compliance, if any

If the results show benefits for iron and manganese removal and also reveal significant DBP compliance concerns, the Town should perform a system-wide DBP study. The study should evaluate alternate strategies to control DBP formation, potentially including tank aeration for TTHM stripping, tank pumping to increase turnover and decrease residence time, distribution system operations to reduce water age, changes to clearwell operation to reduce DBP formation while maintaining disinfection, or treatment modifications to enhance removal of DBP precursors. These alternate DBP control strategies may allow the Town to attain iron and manganese removal benefits associated with pre-filter chlorination while maintaining DBP compliance.

Hazen

Optimal Corrosion Control Treatment Study

The purpose of the optimal corrosion control treatment study is to identify the preferred treatment technique for compliance with the Lead and Copper Rule Revisions, released in draft form in October 2019, while further optimizing iron corrosion control to reduce discoloration episodes associated with iron corrosion by-product release and balancing potential polyphosphate sequestration objectives. The study includes an analysis of historical treatment and water quality data, premise plumbing water quality sampling, and pilot-scale corrosion testing.

Corrosion Control Analysis

The purpose of the corrosion control data analysis task is to evaluate potential corrosion control treatment alternatives, identify opportunities to improve corrosion control through facility operations, and plan effective pilot-scale corrosion testing. This task includes the following activities:

- Characterize premise plumbing materials present in the Town to identify sources of lead, copper, and iron in drinking water
- Evaluate historical Lead and Copper Rule (LCR) compliance data and sampling locations in the Town; evaluate finished water quality data for each source; evaluate distribution system water quality trends
- In accordance with draft LCR Revisions requirements, develop a service line inventory to characterize service line materials and demonstrate the absence of lead service lines; characterize the prevalence of galvanized iron service lines
- Coordinate laboratory scale analysis of iron distribution system and service line materials to characterize pipe scales and inform selection of corrosion control treatment strategies
- Perform targeted investigative premise plumbing sampling to evaluate causes of discoloration, iron and manganese levels, and lead and copper levels; evaluate trends and correlations, if any, for iron, manganese, and lead levels. The premise plumbing sampling results will inform aspects of the study related to corrosion testing of cast iron and galvanized iron and associated corrosion control treatment objectives.
- Evaluate the impacts of blending of surface water and groundwater on portions of the system; identify opportunities to improve corrosion control by adjusting blending patterns to achieve a favorable and consistent blended water quality.
- Evaluate polyphosphate risks for corrosion control and potential benefits for iron and manganese sequestration; examine strategies to maintain control of water discoloration if polyphosphate is eliminated, especially in groundwater supplies.
- Identify corrosion control treatment alternatives, including, but not limited to, addition of orthophosphate at a dose of 1 mg/L as PO_4 or 3 mg/L as PO_4 in accordance with the draft LCR Revisions
- Evaluate unintended consequences and secondary impacts of treatment alternatives

- Determine if bench-scale testing is warranted to reduce the quantity of treatment alternatives to be evaluated using a pilot-scale apparatus, in accordance with requirements in the draft LCR Revisions
- Coordinate with the Virginia Department of Health to obtain approval for treatment alternatives and testing approach.

Corrosion Control Testing

The corrosion control testing task includes pilot-scale corrosion testing to examine preferred corrosion control alternatives. It is anticipated that the duration of the testing phase will be approximately 6 to 18 months depending on the alternatives selected and initial testing results. This task includes the following activities:

- Identify pipe materials to be included in the pilot system, including, but not limited to, copper pipe with lead solder, leaded brass, cast iron mains, and galvanized iron pipe.
- Develop a written testing plan and pilot system design consisting of a recirculating or flow-through apparatus
- Develop testing procedures for surface water, groundwater water, and blended water supplies, including multiple representative blending ratios
- Construct pilot-scale corrosion testing apparatus including chemical feed systems; obtain harvested pipe segments and treatment chemicals
- Operate pilot system to provide conditioning and testing phases, and coordinate laboratory analysis of metals release
- Analyze metals release data from standing overnight samples
- Develop a report documenting the pilot test results and recommendations for corrosion control treatment
- Coordinate with VDH to obtain approval for implementation of corrosion control treatment

Water Treatment Plant Pre-Oxidation Study

The purpose of the Pre-Oxidation Study is to evaluate the optimal feed strategy and type of pre-oxidant at the WTP. The WTP has historically added potassium permanganate near the raw water intake to maximum contact time. Raw water contains dissolved iron and manganese, and pre-oxidation is beneficial to precipitate iron and manganese particles that can be removed in the WTP. The Study will evaluate alternate pre-oxidants and examine the optimal feed location and dosing strategy. The Study includes development of a standard operating procedure (SOP) for pre-oxidant addition.

Bench-Scale Testing

Bench-scale jar testing will be performed to evaluate the performance of each pre-oxidant at multiple potential feed locations and a range of doses. This task includes the following activities:

- Evaluate impacts of each raw water pre-oxidant on iron and manganese oxidation
- Evaluate impacts of raw water contact time prior to coagulation on oxidation of iron and manganese
- Evaluate impacts of coagulation and sludge blanket effects on iron and manganese removal
- Evaluate potential benefits of permanganate for disinfection byproduct control
- Assess potential impacts of permanganate on taste and odor control
- Evaluate impacts of permanganate on manganese accumulation in the sludge blanket clarifiers and potential associated risks

Potassium Permanganate Optimization Testing

Full scale testing of potassium permanganate will be performed to augment the WTP's permanganate dosing strategy. Testing should be performed after installing a raw water sample tap to monitor raw water quality prior to the addition of permanganate and after increasing pre-filter chlorine feed and monitoring filter effluent chlorine residuals, subject to confirmation of DBP impacts. In particular, the testing will focus on identifying permanganate doses to reduce manganese accumulation in the sludge blanket clarifiers and reduce chemical costs. Is it anticipated that full-scale testing will last approximately one month.

- Develop permanganate dosing strategy alternatives (e.g. based on measured raw water iron, manganese, TOC, and other parameters).
- Monitor iron and manganese levels in raw water, settled water, and filter effluent on a daily basis while implementing each dosing strategy
- Characterize relative impacts of clarifiers and filters for iron and manganese removal
- Evaluate relative changes in settled water and filter effluent iron and manganese as permanganate doses are decreased

- Develop a SOP providing operational guidelines for permanganate doses based on the results of bench-scale and full-scale testing

Pre-Oxidant Feed System Evaluation

If the results of bench-scale and full-scale testing suggest that an alternate chemical product or feed location may provide significant benefits for iron and manganese, disinfection byproducts, taste and odor, or plant operations, an evaluation study of the pre-oxidant feed system should be performed. This task includes development of a conceptual design, initial equipment sizing, facility location, and preliminary construction costs. The results should be coordinated with the findings of the Powdered Activated Carbon Study to identify preferred feed locations for both raw water chemicals to achieve multiple treatment objectives. Subject to the findings of the evaluation, the Town could consider proceeding with design and construction of a new pre-oxidation system.

Hazen

Powdered Activated Carbon (PAC) Study

The purpose of the PAC Study is to evaluate the optimal type, feed location, and dosing strategy for PAC. The WTP has historically added PAC upstream of the rapid mix basin to remove organics and taste and odor causing-compounds through adsorption. The existing sludge blanket clarifiers retain PAC and increase the overall contact time with PAC. This study will evaluate strategies to optimize the use of PAC for control of taste and odor.

Process Monitoring

The dose and type of PAC will depend on the concentrations of raw water constituents to be removed by PAC. Raw water MIB and Geosmin levels should be characterized to inform subsequent PAC testing.

- Develop a raw water monitoring approach for potential raw water taste and odor compounds including MIB and geosmin
- Perform raw water monitoring to characterize season MIB and geosmin levels relative to algae growth rates
- Monitor MIB and geosmin levels in the WTP process (e.g. settled water) to characterize baseline removal rates under current operations
- Establish treatment goals for MIB and geosmin reduction from PAC treatment

Bench-Scale Testing

Bench-scale jar testing should be performed to evaluate the effectiveness of PAC for controlling taste and odor

- Identify multiple PAC products from different manufacturers with different performance characteristics for taste and odor control
- Evaluate the effectiveness of each PAC product for MIB and geosmin adsorption
- Evaluate the impacts of raw water contact time and sludge blanket clarifier retention to simulate potential feed locations just prior to the rapid mix basin, near the raw water pump station, or near the Lake Pelham intake, to further increase the contact time prior to retention of PAC in the sludge blanket
- Perform jar testing to simulate the effects of PAC in the sludge blanket clarifier
- Evaluate PAC impacts on formation of disinfection byproducts associated with removal of DBP precursors (NOM) from raw water.

PAC Facility Feasibility Study

If the study findings indicate that an alternate feed location would provide significant benefits or a higher dose of PAC warrants an upgrade to the existing system, a feasibility study should be performed to develop a concept for a new PAC facility. The conceptual design should include initial equipment location, facility location and footprint, and preliminary construction cost.