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SUPPLEMENTAL APPENDIX: CENTRALIZED TREATMENT COST ESTIMATE METHODOLOGY

LAST UPDATED: JUNE 2024

This supplemental appendix is related to the Drinking Water Needs Assessment's Cost Assessment Component. Learn more here: Appendix: Cost Assessment Methodology.

CONTENTS

INTRODUCTION

The *Drinking Water Needs Assessment's* Cost Assessment methodology utilizes a model to estimate the financial costs of both necessary interim measures and longer-term solutions to bring Failing list systems into compliance, address the challenges faced by High-Risk state small water systems and domestic well as identified via the Risk Assessment. The goal of the Cost Assessment is to inform the prioritization of the spending of existing funding sources, particularly via the SB 200-mandated annual *Safe and Affordable Drinking Water Fund Expenditure Plan*, as well as to identify potential additional funding sources to leverage, and to estimate the size of the current funding gap to continue to advance the Human Right to Water for all Californians.

Centralized treatment is one of many possible long-term solutions modeled in the Cost Assessment. "Centralized treatment" means treating water at a central place before conveying it through a dedicated distribution system to customers.

The centralized treatment methodology detailed in this supplemental appendix was developed to identify potential centralized treatment projects for estimating statewide funding needs for water systems failing for water quality-related challenges. The Cost Assessment results include two cost estimates related to modeled centralized treatment:

Capital Cost Estimate: Includes all estimated costs associated with the construction and installation of modeled centralized treatment technologies. In addition to the estimated equipment cost, the capital cost estimate also includes costs associated with electrical expenses (wiring), engineering services design fees, project management and administrative activities, construction contingency, contractor's labor, business overhead, and California Environmental Quality Act (CEQA) related costs.

Operations and Maintenance (O&M) Cost Estimate: Includes the estimated 20-year annual expenses associated with operating and maintaining the modeled centralized treatment technologies. Annual O&M estimates may account for consumables, labor, power, and waste discharge fees.

It is important to note that the Cost Assessment is not intended to identify actual community solutions. The purpose of the Cost Assessment is to estimate drinking water costs to provide safe, potable, and wholesome drinking water. An evaluation of each system will be needed to identify and cost a range of solutions.

CENTRALIZED TREATMENT METHODOLOGY DEVELOPMENT

The Cost Assessment Model's development and enhancement process is designed to encourage public and stakeholder participation, providing opportunities for feedback and recommendations. The centralized treatment analysis included in the Cost Assessment Model has gone through two iterations, incorporating feedback from 16 public workshops. The first centralized treatment analysis was conducted for the *2021 Drinking Water Needs Assessment*. The second iteration of the centralized treatment analysis was updated and enhanced for the *2024 Drinking Water Needs Assessment*. The following sections provide an overview of the work.

VERSION 1.0 (2021)

The first iteration of the centralized treatment analysis conducted for the *2021 Drinking Water Needs Assessment* was developed by the State Water Board, in partnership with the University of California, Los Angeles Luskin Center for Innovation, Corona Environmental Consulting, and Sacramento State University Office of Water Programs. Three public workshops were hosted to solicit public feedback on the Cost Assessment Model methodology and underlying cost assumptions:

May 10, 2019: *Cost Analysis Workshop*

- Public Notice
- Agenda
- Webcast Recording
- Consolidation-Related Presentation PDFs:
    - SWRCB DDW, D. Polhemus
    - Corona Environmental Consulting, T. Henrie
    - UCLA, Y. Cohen
    - Los Angeles County Sativa, D. Lafferty

August 28, 2020: *Cost Estimate: Overview of Approach and Update*

- Public Notice
- White Paper
- Webinar Recording

November 20, 2020: *Cost Estimate: In-Depth Cost Methodology Discussion Webinar*

- Public Notices: English | Spanish
- White Paper
- Presentation
- Webinar Recording

In addition to the public feedback solicited during the workshops, the State Water Board received a handful of comment letters throughout this effort and some adjustments to the Cost Methodology were made as a result. Additional details that were requested in the comment letters were added to this 2021 Cost Assessment Methodology Appendix.[1]

More information can be found on the State Water Board's Drinking Water Needs Assessment website.[2]

VERSION 2.0 (2024)

From 2022 – 2023, the State Water Board hosted a series of four webinar workshops to solicit stakeholder feedback on updates and enhancements to the Cost Assessment Model. The workshop dates and corresponding white papers, presentations, and webinar recording are

[1] 2021 Drinking Water Needs Assessment:
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2021_needs_assessment.pdf
[2] Drinking Water Needs Assessment Website
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/needs.html

provided below. The third workshop was solely focused on the proposed updates to the centralized treatment analysis; however, many of the other workshops included some information related to the centralized treatment analysis.

August 8, 2022: *Proposed Changes for the Cost Assessment*

- Public Notices: English | Spanish
- White Paper
- Presentation
- Webinar Recording

July 14, 2023: *Proposed Updates to the Drinking Water Cost Assessment Model – Workshop 1: Physical Consolidation Analysis*

- Public Notices: English | Spanish
- White Paper
- Presentation
- Webinar Recording

October 5, 2023: *Proposed Updates to the Drinking Water Cost Assessment Model – Workshop 2: Modeled Treatment Analysis*

- Public Notice: English | Spanish
- White Paper
- Presentation
- Webinar Recording

December 20, 2023: *Proposed Updates to the Drinking Water Cost Assessment Model – Workshop 3: Other Essential Infrastructure, Administrative Needs, and Interim Solutions*

- Public Notice: English | Spanish
- White Paper: *See preliminary centralized treatment analysis results starting on Page 18. Also, refer to Appendix D for public feedback on the Modeled Treatment Analysis white paper.*
- Presentation
- Webinar Recording

Below is a summary of the changes made to the centralized treatment analysis compared to the methodology used in the 2021 Cost Assessment:

- Utilizing additional information about each Failing water system to better identify which systems to include in the treatment analysis and better match potential modeled treatment to the Failing system's violations. For example, systems that are Failing for multiple monitoring and reporting violations will not have treatment modeled as a potential long-term solution.
- The sustainability and resiliency assessment[3] used in the 2021 Cost Assessment was removed to accommodate the new approach for matching potential long-term model

[3] Sustainability and Resiliency Assessment, 2021 Needs Assessment Report, Pg. 272. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2021_needs_assessment.pdf

solutions to each system based on their challenges identified by Failing criteria or the Risk Assessment for state small water systems and domestic wells.

- Lowering the viability threshold used by the Cost Assessment Model when determining water system capacity to implement centralized treat vs. decentralized treatment. The threshold for Failing public water systems was decreased from 200 to 20 service connections for most, but not all contaminants. This means more water systems will be assessed for centralized treatment over decentralized treatment.
- Enhancing underlying capital and O&M cost estimate assumptions to reflect current market prices utilizing updated U.S. Environmental Protection Agency (U.S. EPA) treatment models, vendor-provided quotes, data from State Water Board funded projects, and staff recommendations.
    - Internal research and outreach included a thorough review of projects funded by the State Water Board and consultations with knowledgeable staff. External research and outreach consisted of a literature review, as well as consultations with water systems, vendors, manufacturers, service providers, and/or consultants.

SUMMARY OF CURRENT CENTREALIZED TREATMENT ANALYSIS METHODOLOGY

A core component of the Cost Assessment Model is the selection and cost estimation of centralized treatment technologies for Failing public water systems[4] where modeled physical consolidation is not viable as a *Joining*[5] system.

- At-Risk public water systems are excluded from the long-term modeled treatment analysis. Depending on the At-Risk public water system's economic status and size, the system may be assessed for an Administrator, technical assistance, and other essential infrastructure in the Cost Assessment Model.[6] Learn more here: Appendix: Cost Assessment Methodology.[7]
- State small water systems and domestic wells that are High-Risk in the *Water Quality* category of the Risk Assessment may be assessed for decentralized treatment if modeled physical consolidation is not viable. Learn more here: Supplemental Appendix: Decentralized Treatment Cost Estimate Methodology.[8]

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[4] Failing for water quality and treatment technique violation related criteria only. Systems failing for monitoring and reporting violations are excluded from the centralized treatment analysis.

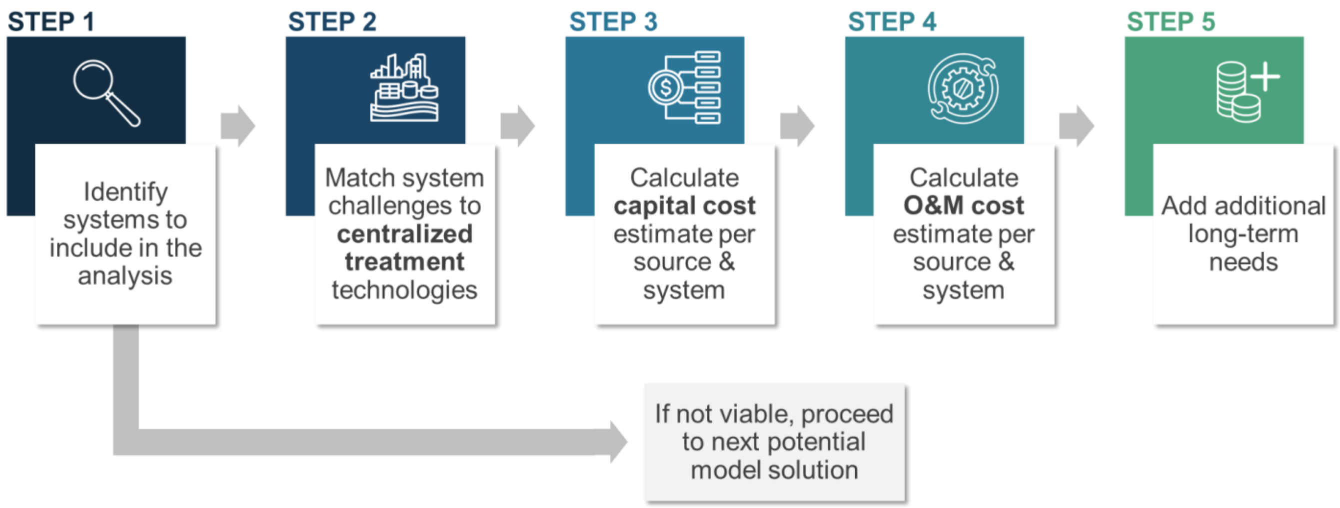
[5] Joining Systems: Commonly smaller public water systems, state small water systems, and domestic wells that are dissolved into an existing Receiving public water system and are no longer responsible for providing water to their own customers.

[6] The Cost Assessment Model's methodology and cost assumptions for Administrator, technical assistance, and other essential infrastructure was explored in the December 2023 White Paper and public webinar workshop.

[7] Appendix: Cost Assessment Methodology
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment-methodology.pdf

[8] Cost Assessment Supplemental Appendix: Decentralized Treatment Cost Estimate Methodology
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment-decentralized-treatment.pdf

Figure 1: Steps for Centralized Treatment Analysis



The following is a summary of the steps taken by the Cost Assessment Model to conduct the centralized treatment analysis:

> **STEP 1**: Identification of Systems to Include in the Modeled Centralized Treatment Analysis
>
> **STEP 2**: Matching System Challenges to Modeled Centralized Treatment Technologies
>
> **STEP 3**: Calculate Estimated Modeled Centralized Treatment Capital Costs
>
> **STEP 4**: Calculate Estimated Modeled Centralized Treatment Operations & Maintenance (O&M) Costs
>
> **STEP 5**: Estimate Additional Needs: New Public Well, Administrator; Technical Assistance; and Other Essential Infrastructure

The following sections in this Appendix detail the current centralized treatment analysis methodology and cost assumptions.

CENTRALIZED TREATMENT ANALYSIS METHODOLOGY

STEP 1: IDENTIFICATION OF SYSTEMS TO INCLUDE IN CENTRALIZED TREATMENT ANALYSIS

The Cost Assessment Model only assesses the viability of centralized treatment as a long-term solution for Failing water systems with primary maximum contaminant level (MCL), secondary

MCL, *E.coli*, and/or treatment technique violations. Where centralized treatment may not be viable due to the system's size, modeled decentralized treatment is assessed.

FAILING PUBLIC WATER SYSTEMS

Since 2021, the State Water Board has expanded the Failing criteria for public water systems to include treatment technique violations, monitoring and reporting violations, and *E. coli* violations.[9] The Cost Assessment models long-term treatment for Failing water systems with water-quality related violations (Table 1) where modeled physical consolidation as a *Joining* system is not viable. Failure due to monitoring and reporting violations will be assessed for potential Administrator and/or technical assistance in Cost Assessment Model. Additional modeled long-term solutions are detailed in Supplemental Appendix: Additional Long-Term Modeled Solutions Cost Estimate Methodology.[10]

Table 1: Failing Public Water Systems Assessed for Modeled Long-Term Treatment in the 2024 Cost Assessment

Failing Water System Criteria	Systems Included
Failing systems where modeled consolidation is viable	Included, but only where the modeled consolidation *Receiving* system[11] is Failing for a primary MCL, secondary MCL, *E. coli*, or treatment technique violation. Treatment is not modeled for *Joining* Failing systems.
Failing systems where modeled consolidation is NOT viable	
Primary MCL	Included
Secondary MCL	Included
E. coli MCL	Included
Treatment Technique	Included
Monitoring & Reporting	Excluded

[9] Failing Water Systems Criteria: https://www.waterboards.ca.gov/water_issues/programs/hr2w/docs/hr2w_expanded_criteria.pdf

[10] Cost Assessment Supplemental Appendix: Additional Long-Term Modeled Solutions Cost Estimate Methodology https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment-add-longterm-solutions.pdf

[11] Receiving system are commonly larger public water systems that expand to subsume Joining systems and provide water supply to both of their customers.

STEP 2: MATCHING SYSTEM CHALLENGES TO MODELED CENTRALIZED TREATMENT TECHNOLOGIES

The Cost Assessment Model utilizes Failing water system information regarding water quality violations and associated contaminants to identify potential long-term treatment solutions when modeled physical consolidation as a *Joining* system is not viable. Best Available Technologies (BAT) will be identified by the Cost Assessment Model that can reduce contaminant concentrations that exceeded the MCL.

The Cost Assessment Model includes multiple modeled centralized treatment solutions based on Title 22 California Code of Regulations (CCR).[12] Title 22 defines applicable BATs as the technologies identified by the State Water Board as the best available technology, treatment techniques, or other means available for achieving compliance with MCLs. While selecting BATs for contaminants of concern, many factors should be taken into consideration such as feasibility, availability, economic viability, and environmental wastes or impacts.

CENTRALIZED TREATMENT TECHNOLOGIES INCLUDED

Centralized drinking water treatment is when a water system extracts water from one or more sources and treats that water before conveying it through a distribution system to its customers. In the Cost Assessment Model, centralized treatment is modeled for Failing public water systems. Compared to decentralized treatment, centralized treatment can often result in cost savings by treating a larger volume of water at a more central location and distributing potable water to customers. By centralizing treatment, less labor and materials may be required to maintain the treatment technologies and practices compared to decentralized treatment. Furthermore, centralized treatment technologies often can remove many more contaminants that otherwise cannot be removed with decentralized treatment.

In the Cost Assessment Model, centralized treatment is modeled for Failing water systems with 20 service connections or greater for most contaminants. The Cost Assessment Model excludes state small water systems and domestic wells from modeled centralized treatment due to its higher capital and O&M costs compared to decentralized treatment.

There are many centralized treatment technologies that are available to reduce contamination; however, the State Water Board designed the Cost Assessment Model to include modeled treatment technologies that have lower operational costs and are easier to maintain. This decision was, and continues to be, driven by the high percentage of Failing water systems that are small (less than 3,000 service connections). Small water systems often have less financial capacity to sustainably operate more sophisticated and resource-intensive treatment technologies.

Due to the high expenses associated with waste disposal for certain types of contaminants, the Cost Assessment Model assumes that liquid stream residuals disposal is not available on-site for the Failing water systems included in the analysis. This assumption eliminated treatment technologies like reverse osmosis and electrodialysis from the Cost Assessment Model

[12] California Code of Regulations, Title 22, Article 12, Table 64447.2-A, Table 64447.3-A, Table 64447.4-A https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I799B50E05B6111EC9451000D3A7C4BC3&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default)

because the residuals volume requiring disposal would be physically and cost prohibitive. Further, while processes like lime softening may be effective for some contaminants, they are rarely implemented for Failing water systems. Therefore, the Cost Assessment Model only includes the bolded technologies in Table 2. Table 3 summarizes the drinking water BATs applied for each violation type.

Table 2: Summary of Drinking Water BATs for Common Water Quality Violations

Violation-Related Contaminant	Chemical Class	BAT
Arsenic	Inorganic	• Activate Alumina • Ion Exchange • **Coagulation/Filtration**[13] • Lime Softening • Reverse Osmosis • Electrodialysis • Oxidation Filtration
1,2,3-Trichloroproproane (1,2,3-TCP)	Organic	• **Granular Activated Carbon**
Nitrate	Inorganic	• **Ion Exchange** • Reverse Osmosis • Electrodialysis
Uranium (Combined)	Radionuclides	• **Ion Exchange** • Coagulation/Filtration • Lime Softening • Reverse Osmosis
Combined Radium-226 and Radium-228	Radionuclides	• **Ion Exchange** • Lime Softening • Reverse Osmosis
Fluoride	Inorganic	• **Activate Alumina**

Table 3: Failing Water System Modeled Centralized Treatment Criteria

Treatment Technology	Modeled For
Granular Activated Carbon (GAC)	Failing public water systems ≥ **20** service connections and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminants: • Dibromochloropropane (DBCP) • Ethylene Dibromide (EDB) • 1,2,3- Trichloropropane (1,2,3-TCP) • 1,1-Dichloroethylene (1,1-DCE) • Disinfection Byproducts (DBPs) ○ Total Trihalomethanes (TTHM)

[13] Adsorption is assumed for systems with less than 500 service connections due the relatively simple operations when compared to coagulation/filtration.

Treatment Technology	Modeled For
	○ Haloacetic Acids (five) (HAA5)
Adsorption	Failing public water systems with service connections between **20** ≤ N < **500** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminant: • Arsenic influent conc. < 50 µg/L
Coagulation Filtration	Failing public water systems with service connections ≥ **500** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminant: • Arsenic influent conc. ≥ 50 µg/L
Filtration	Failing public water systems (regardless of size) and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminants: • Iron • Manganese
Regenerable Resin Anion Exchange	Failing public water systems with service connections ≥ **20** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminant: • Nitrate[14]
Regenerable Resin Cation Exchange	Failing public water systems with service connections ≥ **20** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminant: • Radium 226 and 228
Single-Use Ion Exchange	Failing public water systems with service connections ≥ **20** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminants: • Uranium • Perchlorate

[14] In cases where nitrate concentration exceeds 25 mg/l or sulfate exceeds 250 mg/l, the Cost Assessment models nitrate selective resin instead of the strong base resin to accommodate the high load of contaminants.

Treatment Technology	Modeled For
	• Gross Alpha
Activated Alumina	Failing public water systems with service connections ≥ **20** and modeled physical consolidation as a *Joining* system is not viable. Failing Contaminant: • Fluoride
4-log Virus Treatment	Failing public water systems and modeled physical consolidation as a *Joining* system is not viable. • Groundwater sources. Failing Contaminants: • Fecal contaminants (microorganisms) ○ *E. coli*
Surface Water Treatment Package Plant *4-log Virus Treatment included*	Failing public water systems and modeled physical consolidation as a *Joining* system is not viable. • Surface water sources. Failing Contaminants: • Aluminum • Turbidity • Fecal contaminants (microorganisms) ○ *E. coli*

IDENTIFYING SOURCES IN NEED OF MODELED CENTRALIZED TREATMENT

In the Cost Assessment Model, water sources are assumed to be far enough apart from each other so that separate treatment is needed for each contaminated source. Given that assumption, the Cost Assessment Model selects modeled treatment technologies per contaminated source, rather than per water system with exceptions for disinfection byproduct treatment, turbidity, aluminum, Surface Water Treatment Rule (SWTR), and groundwater rule related treatments.

For purposes of the Cost Assessment only, the State Water Board has developed a methodology to estimate which sources may be contributing to the violation(s) leading the water system included in the analysis to be on the Failing list. Learn more in Appendix A.

ADDRESSING CO-OCCURRING CONTAMINATION

Some Failing water systems have one or more active sources that have multiple (co-occurring) contaminants exceeding an MCL. The Cost Assessment Model utilizes the following decision criteria to determine how to model treatment for those sources. Learn more in Appendix B.

- If the co-contaminants can be removed with the same treatment technology and have the same modeled treatment costs; then, the Cost Assessment Model will only include the cost of **a single treatment technology** per source.
- If the co-contaminants can be removed with the same treatment technology, but each contaminant has different modeled annual O&M costs; then the Cost Assessment Model will select the single treatment technology with the **highest** annual O&M cost.
- If the co-contaminants cannot be removed with the same treatment technology; then, the Cost Assessment Model will **combine** the costs of multiple treatment technologies.
- If co-contaminants have different potential modeled treatment technologies when they are occurring individually, but can be removed with the same treatment technology as an alternative; then the Cost Assessment Model matches the same modeled treatment technology suitable for all contaminants when co-occurring.

STEP 3: CALCULATE ESTIMATED MODELED CENTRALIZED TREATMENT CAPITAL COSTS

The Cost Assessment Model utilizes a set of assumptions to develop estimates for long-term centralized treatment capital costs when modeled physical consolidation is not viable. The Cost Assessment Model's underlying cost assumptions were updated in 2023 to reflect current market values. Learn more in the white paper: Proposed Changes for Modeled Long-Term Treatment.[15]

It is worth noting that the Cost Assessment Model utilizes estimated Maximum Daily Demand (MDD[16]), rather than Average Daily Demand (ADD) in calculating estimated capital costs. MDD allows the Cost Assessment Model to accommodate or "size" modeled treatment technologies for potential population increases or account for any seasonal supply variances. The calculation methodology is detailed in Appendix C.

For some contaminants, U.S. EPA's work breakdown structure (WBS) Model[17] has been utilized to calculate total capital costs or itemized unit cost estimates. Special attention was made to ensure cost assumptions were tailored to reflect California pricing as much as possible.

The Cost Assessment Model's estimated treatment technology capital costs are adjusted using several multipliers as summarized Table 4. Refer to Appendix: Cost Assessment Methodology[18] for additional details about the multipliers used in the Cost Assessment.

[15] October 5, 2023 White Paper: Proposed Changes for Modeled Long-Term Treatment https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/docs/2023/modeled-treatment-draft-whitepaper.pdf

[16] Estimated MDD is the assumed largest daily volume of water needed to be delivered to the system. It is developed based on utilizing an assumed average day demand of 150 gallon/capita/day multiplied by population served, and a peaking factor of 2.25.

[17] Older U.S. EPA's WBS Model versions are not available online and are regularly replaced with newer versions. Most recent U.S. EPA WBS models is from March, 2023: https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

[18] Appendix: Cost Assessment Methodology https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment-methodology.pdf

Table 4: Capital Cost Adjustments

Adjustment	Adjustment Purpose
Engineering News Recorded Construction Cost Index (ENR CCI)[19]	Account for changes in construction expenses and projects future construction cost.
Regional Multiplier	Account for price differences between rural, suburban, and urban areas.
Inflation	Account for rising prices.
Electrical	Account for electrical wiring fees.
Planning & Construction	Account for a wide array of indirect capital costs.[20]
Engineering services	Account for design services.
Legal & Admin	Account for construction administration fees.
Contingency	Account for construction contingency.
Overhead	Account for expenses for the contractor's labor and business overhead costs.
Permitting / Environmental	Account for CEQA and/or permitting fees.

STEP 4: CALCULATE ESTIMATED MODELED CENTRALIZED TREATMENT O&M COSTS

The Cost Assessment Model includes an estimation of long-term operations and maintenance (O&M) costs for the modeled centralized treatment technologies when physical consolidation is not viable. The State Water Board includes estimated O&M expenses related to modeled long-term technologies because SAFER program funding can support qualifying O&M expenses.[21] Therefore, for planning purposes, it is important for the Cost Assessment to estimate how much O&M assistance may be needed by Failing water systems to operate a new treatment.

The Cost Assessment Model's O&M methodology includes cost estimates capturing four cost category components: consumables, waste discharge, labor, and electricity. For purposes of the Cost Assessment Model, labor and electricity cost estimates utilize the same methodology and assumptions across all centralized treatment technologies. The Cost Assessment Model's

[19] Construction Cost Index (CCI) is calculated by Engineering News Record (ENR) which tracks the change in price for a specific combination of construction labor, steel, concrete, cement and lumber using data from 20 cities across the United States: https://www.enr.com/economics

[20] Indirect capital costs for site civil work, equipment installation, delivery, and planning may include expenses for site preparation, finishing, installation materials, equipment rental, transportation of various components (such as pipes, vessels, towers, valves, pumps, blowers, and mixers), as well as inspection and testing services.

[21] FY 2022-23 Fund Expenditure Plan (pp. 3-4) https://www.waterboards.ca.gov/water_issues/programs/grants_loans/docs/2022/final-2022-23-sadw-fep.pdf

estimated treatment technology O&M costs are adjusted with inflation and regional multipliers. Learn more in Appendix: Cost Assessment Methodology.[22]

It is important to note that the Cost Assessment Model's O&M estimates are not representative of the total O&M costs needs to sustainability run a drinking water system. They only represent the estimated cost associated with the new modeled treatment.

CONSUMABLES

Water treatment systems require parts and chemical products to be replenished or replaced to properly achieve their intended purpose. Depending on the modeled treatment technology, O&M estimates may account for:

- Chemical Replacement
  - Regeneration salt
  - pH adjustment (caustic soda)
  - Disinfectant
  - Coagulant (ferric chloride)
- Part Replacement
  - Virgin Granular Activated Carbon
  - Adsorption media
  - Membranes
  - Ion exchange resins
  - Cartridge filters

Appendix C2.C provides an in-dept overview of which consumables are included in the centralized treatment technology O&M estimates.

WASTE DISCHARGE

Water treatment processes generate waste, both solid and liquid, that must be disposed of properly to avoid direct or indirect contamination of drinking water or the environment. Waste disposal can significantly increase the operational cost associated with certain treatment technologies. For example, waste disposal can be very expensive due to restrictions and requirements related to its transportation and receiving facility. There are optimization opportunities where water system waste streams can be eliminated (GAC re-use for non-drinking water applications) or minimized (wastewater or backwash can be disposed on-site rather than off-site; eliminating transportation costs). Learn more in Appendix C.

LABOR

Operators are responsible for a variety of tasks involving running and maintaining the system to provide an adequate and safe water supply to their customers. Permitted treatment facilities are assigned a minimum operator grade level by the State Water Board. The operator grade level corresponds with the level of operator expertise and knowledge needed to safely operate

[22] Appendix: Cost Assessment Methodology
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment-methodology.pdf

and maintain the treatment facility. Labor cost estimates are based on the operator grade per treatment technology. Learn more in Appendix C.

ELECTRICITY

General power supply is needed to run the treatment plant, mainly to pump water and overcome head loss due to friction and elevation changes. The Cost Assessment Model uses an equation that calculates the assumed electrical needs based on the assumed annual production per source. The Cost Assessment Model's estimated electrical costs reflect the higher electricity rates observed in California, compared with other states. Learn more in Appendix C.

20-YEAR O&M ESTIMATION

The Cost Assessment Model includes a lifecycle O&M Net Present Value (NPV) cost estimate for each modeled treatment technology. All NPVs are developed based on a 20-year period and an annual 4% interest rate.

Equation 1: O&M NPV Calculations

O&M NPV = Total Annual O&M x [(1+i) ^n-1] / [i x (1+i) ^n]

where,

Total Estimated Annual O&M = (Consumables + Waste Discharge + Labor + Electricity)

i = 4% interest rate

n = 20-year life cycle

STEP 5: MODEL ADDITIONAL NEEDS

Systems that have long-term modeled centralized treatment will also be assessed for additional interim solutions, other essential infrastructure needs, technical assistance, Administrator assistance, etc. These additional costs are included in the final statewide Cost Assessment results. Learn more here: Appendix: 2024 Cost Assessment Results.[23]

[23] Appendix: 2024 Cost Assessment Results
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024costassessment.pdf

APPENDIX A: METHODOLOGY FOR DETERMINING CONTAMINATED SOURCES FOR MODELED TREATMENT

DETERMINING CONTAMINATED SOURCES

Currently, the State Water Board's violation and enforcement action data does not include information, in machine-readable format, about which source(s) contributed to a water quality-related violation. Therefore, for purposes of the Cost Assessment only, the State Water Board has developed the following methodology to identify which water system sources may be contributing to the water quality-related violation(s) leading it to be on the Failing list. This estimation is intended to improve the Cost Assessment's accuracy by trying to identify the most probable sources with contamination instead of assuming all the Failing system's sources require modeled treatment. The results of this analysis are for estimating purposes only, and may not be an accurate representation of current water quality of a Failing water system's source(s).

The Cost Assessment Model's centralized treatment analysis only models treatment for a system's contaminated sources. It does not assume treatment is needed for all the system's sources.

STEP 1

Utilizing the Failing water system list inventory included in the Cost Assessment Model's treatment analysis, pull the violation details related to the system's Failing status to identify what contaminants the system is failing for.

Table 5: Example Structure of Data Pull for Step 1

Water System Name	Failing Contaminant	Total # of Active Sources
System A	**Nitrate**	3
System A	**Manganese**	3
System B	**1,2,3-TCP**	1
System C	**Arsenic**	2

STEP 2

Identity and join all active sources to each Failing water system included in the analysis. Each row in the data set represents a water system, their source, and the failing-contaminant the query will look for. Table 6 provides an example of how this dataset is structured. System A has two contaminants related to the violations it is on the Failing list for. System A has a total of three active sources. Therefore, the dataset has six rows of data related to this system.

Table 6: Example Structure of Data Pull for Step 2

Water System Name	Failing Contaminant	Source	Source Activity Status
System A	Nitrate	**001**	**Active**
System A	Nitrate	**002**	**Active**
System A	Nitrate	**003**	**Active**
System A	Manganese	**001**	**Active**
System A	Manganese	**002**	**Active**
System A	Manganese	**003**	**Active**
System B	1,2,3-TCP	**001**	**Active**
System C	Arsenic	**001**	**Active**
System C	Arsenic	**002**	**Active**

STEP 3

Step three identifying the most recent violation end date associated with each failing contaminant. A Failing water system may have accrued multiple violation for the same contaminant. The query pulls the most recent end date of the violation to determine which time-period of water quality data should be analyzed.

Table 7: Example Structure of Data Pull for Step 3

Water System Name	Failing Contaminant	Source	Recent Violation End Date
System A	Nitrate	001	**12.31.2022**
System A	Nitrate	002	**12.31.2022**
System A	Nitrate	003	**12.31.2022**
System A	Manganese	001	**03.17.2023**
System A	Manganese	002	**03.17.2023**
System A	Manganese	003	**03.17.2023**
System B	1,2,3-TCP	001	**01.27.2017**
System C	Arsenic	001	**11.03.2019**
System C	Arsenic	002	**11.03.2019**

STEP 4

The query will go through a series of different water quality data calculations to approximate which source(s)[24] contributed to the water quality-based violation leading the system to be on the Failing list.

Criteria 1: Determine if the active source(s) has a one-year average concentration, prior to the violation end date, of the failing contaminant that is greater than the MCL.

- If at least one active source meets this criteria, then this method of analyzing historical water quality data is used to estimate the count of sources modeled for centralized treatment for the contaminant of concern.
- If no active source(s) meets this criteria, then criteria 2 is examined.

Criteria 2: Determine if the active source(s) has a one-year maximum concentration, prior to the violation end date, of the failing contaminant that is greater than the MCL.

- If at least one active source meets this criteria, then this method of analyzing historical water quality data is used to estimate the count of sources modeled for centralized treatment for the contaminant of concern.
- If no active source(s) meets this criteria, then criteria 3 is applied.

Criteria 3: If no Active source has water quality data meeting any of the criteria above, then it is assumed the system has **one** contaminated source associated with the failing-contaminant.

Table 8: Example Structure of Data Pull for Step 4

Water System Name	Failing Contaminant	Source	Active 1-Yr. Avg.	Active 1-Yr. Max
System A	Nitrate	001	**12.5 mg/l**	
System A	Nitrate	002	**11.1 mg/l**	
System A	Nitrate	003	N/A	N/A
System A	Manganese	001	No result found	**75 µG/l**
System A	Manganese	002	No result found	**100 µG/l**
System A	Manganese	003	N/A	N/A
System B	1,2,3-TCP	001	**0.006 µG/l**	No result found
System C	Arsenic	001	No result found	No result found
System C	Arsenic	002	No result found	No result found

[24] Standby and inactive sources are excluded from the analysis.

STEP 5

Assign the criteria met per source per contaminant. Create a summary of the number of sources that will be modeled per system, per failing-contaminant. In the example provided below, because System C had no exceedance found using Criteria 1 through 3 for both of its active sources, the Cost Assessment Model will assume System C requires modeling centralized treatment for one source only for arsenic.

Table 9: Example Structure of Data Pull for Step 5

Water System Name	Failing Contaminant	Source	Exceedance Method Selected	Exceedance Value
System A	Nitrate	001	**Active 1-Yr. Avg.**	**12.5 mg/l**
System A	Nitrate	002	**Active 1-Yr. Avg.**	**11.1 mg/l**
System A	Manganese	001	**Active 1-Yr. Max**	**75 µG/l**
System A	Manganese	002	**Active 1-Yr. Max**	**100 µG/l**
System B	1,2,3-TCP	001	**Active 1-Yr. Avg.**	**0.0006 µG/l**
System C	Arsenic	001	**No exceedance found**	**No result found**
System C	Arsenic	002	**No exceedance found**	**No result found**

Table 9: Summary of Sources Modeled for Centralized Treatment

Water System Name	Failing Contaminant	# Sources Modeled for Treatment
System A	Nitrate	2
System A	Manganese	2
System B	1,2,3-TCP	1
System C	Arsenic	1

APPENDIX B: METHODOLOGY FOR MODELING TREATMENT FOR CO-CONTAMINANTS

COMBINED TREATMENT COST ASSUMPTIONS

The Cost Assessment Model estimates capital and operations and maintenance (O&M) treatment costs for Failing water systems with water quality violations for multiple contaminants within one or more source when modeled physical consolidation is not viable. The Cost Assessment Model employs a set of decision-making criteria to determine the best modeled treatment technology(ies) to address co-occurring contaminants. Table 9 summarizes the decision criteria for a set of frequent co-contaminant combinations.

Table 9: Determination of Final Modeled Treatment Cost Estimate for Co-Contaminants

Criteria	Model Decision	Co-Contaminants
• Co-contaminants can be removed with the same treatment technology; and • Have the same modeled treatment costs.	The Cost Assessment Model will only include the cost of **a single treatment technology** per source.	• Iron + Manganese • TTHM + HAA5 • Nitrate + Nitrite • Uranium + Gross Alpha • SWTR-related Contaminants
• Co-contaminants can be removed with the same treatment technology; but • Each contaminant has different modeled annual O&M costs.	The Cost Assessment Model will select the single treatment technology with the **highest** annual O&M cost estimate.	• VOC[25] + VOC • Uranium + Perchlorate • Nitrate + Perchlorate • Nitrate + Uranium or Gross Alpha[26] • Nitrate + Radium
• Co-contaminants cannot be removed with the same treatment technology.	• The Cost Assessment Model will combine the costs of **multiple treatment technologies** determined per contaminant. • Refer to Table 2 & Table 3 for the treatment	• Arsenic + 1,2,3-TCP • Arsenic + Uranium • Arsenic + Fluoride • Uranium + 1,2,3-TCP • Nitrate + Iron/Manganese

[25] VOC means volatile organic chemical.

[26] State Water Board staff recommend selecting single-use ion exchange resin over regenerative resin, for Nitrate + Uranium or Gross Alpha contamination, regardless of high-cost constraint. This is due to the fact that uranium and gross alpha, being radioactive contaminants, may carry the risk of leaching out into the treated water if not regenerated properly.

Criteria	Model Decision	Co-Contaminants
	technology per contaminant.	
• Co-contaminants would have different modeled treatment technologies if they are occurring individually; and an alternative modeled treatment technology suitable for all co-occurring contaminants is available.	• The Cost Assessment Model will select single treatment technology that can remove all co-occurring contaminants.	***Example*** • Arsenic + Iron/ Manganese: Coagulation Filtration is chosen as a modeled treatment technology for both arsenic and iron/manganese. Filtration would be selected for iron/manganese if it is not co-occurring with arsenic.

APPENDIX C: LONG-TERM CENTRALIZED TREATMENT CAPITAL & O&M COST ASSUMPTIONS

The sections below detail the **capital** and **operations and maintenance (O&M)** cost methodology for each treatment technology utilized in the Cost Assessment Model. The capital cost estimates include infrastructure costs incurred by installing treatment. The O&M cost estimates represent the core estimated costs associated with sustaining ongoing treatment.

The Cost Assessment Model O&M cost estimates capture four cost category components: consumable costs, waste discharge costs, labor costs, and electricity costs. Consumable costs and waste disposal costs vary depending on each modeled treatment technology. The Cost Assessment Model's assumptions and calculation methodologies for these components are detailed in each treatment technology section within this Appendix. The electricity and labor O&M cost estimates associated for each modeled treatment utilize the same underlying assumptions and calculations methods. Therefore, to reduce redundancy in this Appendix's documentation, the cost assumptions and calculation methodology for electricity and labor O&M estimates are summarized below. The estimated labor and electricity O&M component costs will be calculated and added to the consumable and water disposal costs calculated for each treatment type.

GENERAL CENTRALIZED TREATMENT MODEL ASSUMPTIONS

ESTIMATING WATER DEMAND AND FLOW RATES

The development of estimated water demand for each water system is required to calculate capital and O&M costs within the Cost Assessment Model. Historically, the State Water Board has collected annual demand data from public water systems through the electronic Annual Report (eAR). However, due to limitations in the eAR's survey design, many public water systems have reported annual demand data in the wrong units of measure or have submitted data that does not meet the Cost Assessment's standards for data quality. Therefore, the Cost Assessment Model utilizes a standard demand estimation formula to estimate a water system's Average Daily Demand (ADD) and Maximum Day Demand (MDD).[27]

AVERAGE DAILY DEMAND

Annual water production in million gallons is estimated based on average daily demand, which is used to compute estimated annual O&M costs. Based on the assumptions in the *Initial*

[27] California Code of Regulations, Title 22, Division 4, Chapter 16, Section 64554 https://govt.westlaw.com/calregs/Document/I7BDD51A85B6111EC9451000D3A7C4BC3?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)

Statement of Reasons for the1,2,3-Trichloropropane Maximum Contaminant Level Regulations in Title 22, California Code of Regulations, the following equations are utilized:

Equation 2: Estimating Average Daily Demand (ADD)

Average Daily Demand (ADD) in Gallons per Day (GPD) = Population[28] x 150 gallons/person/day[29]

Equation 3: Converting ADD in Million Gallons (MG) To Estimate Annual Water Production

Annual Water Production in Million Gallons (MG) = (Average Daily Demand (ADD) in Gallons per Day (GPD) x 365 days/year) ÷ 1,000,000

MAXIMUM DAILY DEMAND

The maximum daily demand with a 2.25 peaking factor[30] is used to estimate the capital costs to meet the dry season's water demand. To ensure that the proposed treatment capacity is conservative and to recognize that it is unrealistic to assume a source continuously operates 24 hours per day, treatment capacity is calculated by assuming the MDD must be produced over 16 hours a day. Hence, the following equations are utilized to estimate MDD in gallons per minute.

Equation 4: Estimating Maximum Daily Demand (MDD)

Maximum Daily Demand (MDD) in Gallons per Day (GPD) = Average Daily Demand (ADD) in Gallons per Day (GPD) x 2.25

Equation 5: Converting MDD in Gallons per Minute (GPM)

MDD in Gallons per Minute (GPM) = Maximum Daily Demand (MDD) in Gallons per Day (GPD) ÷ (16 hours/day x 60 minutes/hour)

GENERAL O&M ASSUMPTIONS: ELECTRICITY AND LABOR

ELECTRICAL COST

Water treatment systems require electricity for all or part of their processes, especially to pump water and overcome head loss due to friction and elevation changes. The Cost Assessment Model utilizes an electrical rate to reflect the higher rate of electricity consumption in California.

[28] Population data is obtained from Safe Drinking Water Information System (SDWIS).
[29] This ADD is based on the water usage provided to the State Water Board by 386 California urban water suppliers in June 2014 with an additional 10% demand.
[30] A peaking factor of 2.25 is a common practice to scale an average demand to a maximum demand.

Equation 6: Electrical Cost

Electricity Cost = (0.746[31] x flow x head loss x electrical rate) / (3,960[32] x pump efficiency x motor efficiency)

Table 10 below summarizes the electrical cost equation components and assumptions.

Table 10: Electrical Cost Components and Assumptions

Cost Component	Assumption[33]
Flow in Million Gallons (MG)	Estimated annual production for each Failing system
Head loss (ft)	23.07
Electrical Rate ($/kWh)	0.30[34]
Pump Efficiency	0.8
Motor Efficiency	0.9

LABOR COST

Treatment operators are responsible for maintaining treatment facilities, equipment, and processes to ensure water supplied to the public meets all regulatory standards and is at all times pure, wholesome, and potable. Treatment facilities are required to be permitted by the State Water Board prior to operation or upon change to the design capacity or treatment process within a treatment facility. The State Water Board assigns a minimum shift and/or chief treatment operator grade to each permitted treatment facility. The required treatment operator grade corresponds with the level of operator expertise and knowledge needed to safely operate and maintain the treatment facility. The grade level is determined using a point system defined in Title 22 of the California Code of Regulations.[35] The minimum treatment operator grade level and point range is summarized in Table 11.

Table 11: Minimum Treatment Operator Grade[36]

Total Points	Minimum Operator Grade Level
Less than 20	T1
20 through 39	T2

[31] Unit constant to convert mechanical horsepower to kilowatts.
[32] The constant 3,960 is obtained by dividing the number of foot-pounds for one horsepower (33,000) by the weight of one gallon of water (8.33 pounds).
[33] These assumptions were developed by Corona Environmental and utilized in the 2021 Cost Assessment Model. All assumptions have been re-verified by State Water Board staff.
[34] This rate represents the average consumption rate utilizing California rate comparison tool for the available counties. External outreach and research also indicated that the average residential electricity rate in California is between 30-33 ¢/kWh, which is 77% higher than the national average rate of 19 ¢/kWh. https://www.cpuc.ca.gov/RateComparison
[35] Title 22 Code of Regulations, Chapter 13, Article 2. Operator Certification Grades, § 64413.1.
[36] Title 22 California Code of Regulations, Chapter 15, Article 2. Operator Certification Grades, § 64413.1

Total Points	Minimum Operator Grade Level
40 through 59	T3
60 through 79	T4
80 or more	T5

Operator salaries typically correlate with the operator's grade level. The higher the grade, the higher the operator's salary. State Water Board staff researched operator salaries from online job postings[37] throughout California in 2023 (Table 12).

Table 12: Treatment Operator Salary Per Grade

Operator Grade[38]	Salary Estimate
T1	$105,000
T2	$123,192
T3	$127,992
T4	$137,280
T5	N/A[39]

In the Cost Assessment Model, treatment operator grade is selected based on general assumptions, such as treated source type, labor time intensity, and number of treated contaminants in order to estimate generalized operator costs. Table 13 below matches the operator grade with the treatment technology.

Table 13: Operator Grade Per Treatment Technology

Treatment Technology	Operator Grade	Operator Time Intensity (% of Annual Salary)[40]
Granular Activated Carbon	T2	10%
Adsorption	T2	10%
Coagulation Filtration	T2	20%
Filtration	T2	10%
Anion Exchange	T2	25%
Cation Exchange	T2	25%

[37] LinkedIn, ZipRecruiter, and CareerBuilder

[38] T5 is not listed in this table because there is no identified need for this grade level in the Cost Assessment Model.

[39] T5 operator grade treatment technologies are not included in the Cost Assessment Model.

[40] Operator time intensity is the fraction of the annual operator salary corresponding to the percentage of the annual operator time spent while running and maintaining the treatment plant, The percentages listed in the table were developed by Corona Environmental and utilized in the 2021 Cost Assessment Model, these assumptions have been re-verified by State Water Board staff.

Treatment Technology	Operator Grade	Operator Time Intensity (% of Annual Salary)[40]
Single-Use Ion Exchange	T2	20%
Activated Alumina	T2	20%
4-log Virus Treatment	T2	10%
Surface Water Treatment	T3	25%

If a water system treats multiple contaminants using different treatment technologies, then the next higher treatment operator grade will be selected by the Cost Assessment Model to account for the increased operational difficulty.

INDIVIDUAL TREATMENT TECHNOLOGY CAPITAL & O&M ASSUMPTIONS

GRANULAR ACTIVATED CARBON

A clean carbon surface has a strong attraction for organic compounds and other non-polar contaminants. Thermal activation of carbon significantly improves its pore volumes, surface area, and structure, thus a filter with granular activated carbon (GAC) is a proven option to remove certain chemicals, particularly organic chemicals, from water. In the Cost Assessment Model, GAC is the assumed treatment technology for volatile or synthetic organic chemicals, and two types of disinfection byproducts (DPBs) as listed in Table 14.

DBPs are formed when disinfectants react with natural organic matter (NOM) which is present in all water sources. NOM is measured as total organic carbon (TOC). DBPs can be controlled by either removing the precursor (*i.e.*, TOC) or removing DPBs after they are formed. While GAC has been proven to effectively remove both the TOC and DBPs, removal of DBPs from drinking water was the preferred approach in the Cost Assessment Model rather than TOC removal from source water. This decision is driven by two reasons: removing DBPs from finished water is deemed to be more efficient than treating the raw water for the precursor removal; and there potentially are water systems receiving treated water from consecutive systems.

Table 14: Contaminants Treated by GAC in the Cost Assessment Model

Contaminants	System Criteria

• **Dibromochloropropane (DBCP)**
• **Ethylene Dibromide (EDB)**
• **1,2,3- Trichloropropane (1,2,3-TCP)**
• **1,1-Dichloroethylene (1,1-DCE)**
• **Disinfection Byproducts (DBPs)**
  ○ **Total Trihalomethanes (TTHM)**
  ○ **Haloacetic Acids (five) (HAA5)**
	• Failing systems with an MCL exceedance; and
	• Service connections ≥ 20.

GAC CAPITAL COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model utilizes multiple quotes provided by multiple vendors for water treatment vessels, which were originally solicited between 2015 and 2018. The original quotes have been adjusted to current dollars using Construction Cost Indices (CCI) published by Engineering News Record (ENR) and averaged by vessel size.

For DBP removal, the Cost Assessment Model applies an additional capital cost accounting for a booster pump station that is required to overcome the head loss caused by the GAC treatment. A regression equation is used for estimating booster pump costs based on pump capacity. The regression analysis utilizes vendor-provided quotes adjusted for current ENR CCI. Table 15 summarizes the Cost Assessment Model's GAC capital cost estimate components.

Table 15: Summary of GAC Capital Costs

Cost Element	Cost Estimate Method
Components	
Treatment Vessel	• Based on multiple quotes from multiple vendors, solicited between 2015 – 2018. • Adjusted to current ENR CCI[41] and averaged by vessel size. • Refer to Table 16 for the cost by flow range.
Booster Pump[42]	Utilize a regression cost equation to estimate the costs based on pump capacity.
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%

[41] ENR CCI as of August 2023: 13,472.56
[42] Only applied in DBPs removal.

Cost Element	Cost Estimate Method
Permitting / Environmental[43]	2%

Regional multiplier, inflation, and all other cost adjustments listed in Table 15 are applied to the basic capital cost (i.e., equipment & material) as illustrated in the equation below.

Equation 7: GAC Installed Capital Cost

GAC Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.32 (regional)[44] + E x 0.031 (inflation) + E x 0.1 (electrical) + E x 0.2 (planning & construction) + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

The following sections provide additional details on each cost component included in GAC capital cost estimate.

Treatment Vessel

Internal and external research conducted by State Water Board staff suggests that vessel costs can be wide ranging, depending on vendors, location, design parameters, scope of installation work, and many other site-specific circumstances. In the Cost Assessment Model, a lead-lag configuration is assumed with the vessel pairs that have diameter of either 6, 8, or 12 feet (ft).[45] Different sizes of vessels were translated into the flow rates that each vessel size can accommodate. In the cases where the flow rate is greater than the capacity of a single pair of the largest unit, a configuration with multiple vessels was assumed. Within the vendor-provided cost estimates, the largest unit was capable of running up to 875 gallons per minute (gpm) and the cost for the flow rate of 876 - 1,750 gpm was assumed to be twice the 875-gpm vessel. Table 16 illustrates the Cost Assessment Model's treatment vessel cost estimates, adjusting to current ENR CCI, by flow rate.

Table 15 summarizes the Cost Assessment Model's capital cost estimates for GAC treatment vessel for different ranges of flow rate.

[43] For CEQA.
[44] Regional multiplier assuming an urban county.
[45] 2021 Cost Assessment. ATTACHMENT C3: Treatment Cost Methodology Details (pp. 1-3) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf

Table 16: Summary of GAC Treatment Vessel Capital Cost by Flow Rate Range

Diameter (ft)	Flow Rate (gpm)	Modeled Cost Estimates	
		Equipment Cost	Installed Capital Cost[46]
6	1 – 250	$214,000	$507,000
8	251 – 425	$263,000	$624,000
12	426 – 875	$365,000	$865,000
Two Pair-12	876 – 1,750	$730,000	$1,731,000

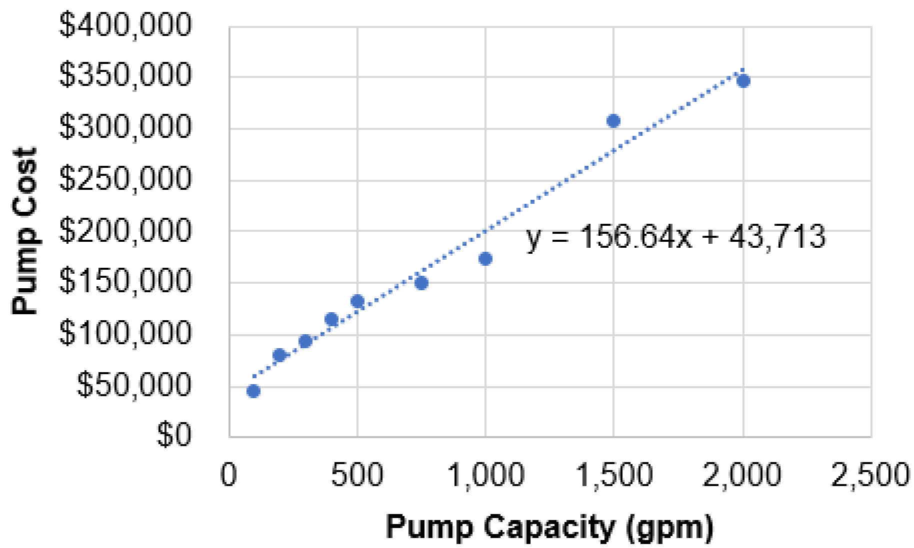
Booster Pump Station

The Cost Assessment Model assumes a booster pump station is needed when modeled GAC is selected for DBP removal. Internal and external research conducted by State Water Board staff suggests that pump costs often vary depending on the pump's size. Pump size is affected by various site-specific parameters, such as flow rate, minimum/maximum pressure required in the water main, etc.

Rather than applying a static cost estimate, the Cost Assessment Model estimates booster pump station costs based on estimated pump capacity using a cost equation. Vendor-provided quotes[47] were adopted to perform a linear regression analysis with an adjustment for current ENR CCI. Figure 2 shows the regression chart and the equation derived. The distribution of estimated booster pump costs by estimated pump capacity utilizing the cost equation are summarized in Table 17.

[46] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for GAC treatment vessels in suburban or rural regions.
[47] Costs provided by QK, an engineering design firm in the Central Valley.

Figure 2: Booster Pump Costs Regression



Equation 8: Booster Pump Station Cost Estimate

$$y = 156.63x + 43{,}709$$

where, y = Booster Pump Station Cost ($)

x = Maximum Daily Demand (MDD) in gallons per minute (gpm)[48]

Table 17 summarizes the Cost Assessment Model's capital cost estimates for booster pump for different pump capacity.

Table 17: Booster Pump Station Costs Estimated by Cost Assessment Model

Pump Capacity (gpm)	Modeled Pump Cost Estimates	
	Equipment Cost	Installed Capital Cost[49]
100	$59,000	$140,000
200	$75,000	$178,000
300	$91,000	$216,000
400	$106,000	$251,000
500	$122,000	$289,000
750	$161,000	$382,000

[48] For the Cost Assessment Model purposes, MDD in gpm is estimated based on the population served and daily water consumption per capita with a peaking factor of 2.25, assuming 16-hour of daily operation (*i.e.*, [population x 150 gallons/day x 2.25] ÷ [16 hours/day x 60 minutes/hour]).

[49] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for booster pumps in suburban or rural regions.

Pump Capacity (gpm)	Modeled Pump Cost Estimates	
	Equipment Cost	Installed Capital Cost[49]
1,000	$200,000	$474,000
1,500	$279,000	$662,000

GAC O&M COST COMPONENTS & ASSUMPTIONS

The O&M cost comprises of three components as summarized in Table 18.

Table 18: Summary of GAC O&M Costs

Cost Element	Cost Estimate Method
Components	
Operational Cost	• Utilize a standard production cost formula for estimating ongoing GAC operational cost. ○ Refer to the cost formula for each individual contaminant provided in Table 20.
Electrical Cost	Utilize Equation 6
Labor Cost	• 10% of T2 grade operator salary ○ $123,192 x 0.1 = $12,319
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

Regional multiplier and inflation adjustments are applied to the basic O&M cost (i.e., sum of operational, electrical, and labor cost) as illustrated in the equation below.

Equation 9: GAC O&M Cost

GAC O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[50] + (Operational + Electrical + Labor) x 0.031 (inflation)

The primary component of ongoing GAC operational costs is the periodic replacement of virgin GAC, including transportation and installation, and disposal of the spent GAC media. Thus, the

[50] Regional multiplier assuming an urban county.

cost can be wide ranging from site to site depending on GAC change-out frequency, which is mainly affected by water quality, amount of GAC per change-out, and regionally varying unit cost.

Standard Production Costs for Treated Water

The Cost Assessment Model utilizes a formula for estimating the ongoing GAC operational cost for each individual contaminant. The production cost estimate is in dollars ($) per thousand gallons of water produced for removal of each contaminant.

As shown in Equation 10 and Equation 11, the key information in deriving the standard water production costs is the throughput estimated in number of bed volumes (BV).[51] BV numbers vary between contaminants, and normally depend on water quality input (not only the target contaminant but also other competing chemicals potentially present in the raw water) and many other site-specific design parameters. For modeling purposes, the Cost Assessment Model assumes a static BV number for each contaminant applied to all water systems regardless of the site-specific inputs. As an example, a throughput-estimate of 38,200 BV[52] is used for 1,2,3-TCP assuming it can cover a wide variety of water quality conditions for purposes of the water production cost estimation. External outreach to a GAC manufacturer and water systems that have GAC treatment in-place helped validate the assumed BV numbers.

Table 19 summarizes the Cost Assessment Model's GAC O&M cost estimate components.

Table 19: Summary of GAC Operational Costs per Pound-GAC

Cost Components	Cost Estimate
Virgin GAC	$1.95
Transportation	$0.20
Reactivation	$0
Change-out Service	$0.30
Total	**$2.45**

Applying the assumed BV numbers, standard water production cost can be estimated for each contaminant. Detailed calculation methodology is provided below.

Equation 10: Water Production per Pound of GAC (gal-water/lb-GAC)

BV number (gal-water/gal-GAC) x Carbon specific volume (0.0297 ft^3-GAC/lb-GAC) x Conversion factor (7.48 gal-GAC/ft^3-GAC)

[51] The volume of water passing through the media up to the breakthrough point divided by volume of GAC media.
[52] As cited in the U.S. EPA Drinking Water Treatment Technology Unit Cost Models https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Equation 11: Standard Water Production Cost ($/kgal-water)

Total operational cost ($/lb-GAC) ÷ Water production per pound of GAC (gal-water/lb-GAC) x Conversion factor (1,000 gal/kgal)

Example calculation for 1,2,3-TCP:

- Water Production per Pound of GAC = 38,200 x 0.0297 x 7.48 = 8,486 gal-water/lb-GAC
- Standard Water Production Cost = 2.45[53] ÷ 8,486 x 1,000 = $0.29/kgal-water

Applying the respective BV numbers for other contaminants in Equation 8, the standard water production cost can be derived for each individual contaminant. Table 20 illustrates the standard production costs updated for each contaminant.

Table 20: GAC Throughput Estimates and Std. Production Costs by Contaminant

Contaminants	BV Numbers	Standard Production Costs ($/kgal-water)[54]
DBCP	65,000	$0.17
EDB	60,000	$0.184
1,2,3-TCP	38,000	$0.29
1,1-DCE	10,000	$1.10
TTHM / HAA5	5,000	$2.21

The following sections provide additional details on each component included in the GAC operational cost estimate. Labor and electricity are applied as separate budgetary items consistent with all other treatments.

Virgin GAC

GAC is manufactured from a variety of raw materials with porous structures including bituminous coal, lignite coal, coconut shell, etc. and virgin GAC cost can vary depending on the base material used to manufacture it. The Cost Assessment Model assumes $1.95/lb-GAC, which is based on an average of bituminous coal-based GAC price quotes collected by GAC vendors in 2023.

Transportation

The Cost Assessment Model assumes $0.20/lb-GAC for transportation costs. This cost estimate was derived from an external quote collected in 2023.[55]

[53] Refer to Table 19.
[54] This represents the GAC operational costs needed for treating 1,000-gallons of water contaminated with each chemical.
[55] Calgon Carbon: https://www.calgoncarbon.com

Spent GAC Disposal vs. Reactivation

When activated carbon's adsorptive capacity is exhausted, it can be sent to reactivation service site where the adsorbed organic compounds are destroyed with thermal reactivation followed by off-gas treatment. The reactivated carbon can be recycled for continued use and thus, through reactivation, the cost associated with spent GAC disposal can be eliminated. The reactivated carbon can be returned to the original drinking water treatment facility or can be sold to other users for industrial application. The Cost Assessment Model assumes the reactivation followed by re-using for industrial applications.

In the Cost Assessment Model, GAC reactivation excludes GAC disposal costs from the GAC O&M estimate. The Cost Assessment Model assumes GAC reactivation[56] has no incurred cost.[57]

Change-out Service

The Cost Assessment Model assumes GAC media change-out service costs are $0.30 per pound of GAC. This cost assumption was developed by averaging external quotes for this service collected in 2023.[58]

ADSORPTION

Arsenic removal from drinking water can be accomplished using a variety of technologies and each has drawbacks and benefits, particularly in terms of effectiveness and cost. Adsorption is a passive treatment approach where untreated water flows through pressure vessels loaded with media. Due to its low cost and simple operational process, adsorption technology can be considered the best method of removing arsenic from small flows. For arsenic removal, iron-based adsorptive media is commonly used.

The Cost Assessment Model is designed to select either **adsorption** or **coagulation filtration** technology for arsenic treatment, depending on Failing system characteristics as further detailed below.

Adsorption

The Cost Assessment Model selects adsorption for Failing systems meeting both criteria listed below.

- Failing systems with 20 to 500 service connections due to operational efficiency. This criterion also aligns with the regulatory threshold for system size for coagulation filtration to be selected as a BAT for chemical removal. Current California drinking water regulation,[59] specifies that coagulation filtration is not a BAT for water systems with less than 500 service connections; and

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[56] It specifically means the reactivation followed by re-use for industrial applications.
[57] Based on consultation with a reactivation service provider.
[58] Calgon Carbon: https://www.calgoncarbon.com
Costs are varied depending on scope of the work.
[59] Title 22 CCR § 64447.2
https://govt.westlaw.com/calregs/Document/I79A737D05B6111EC9451000D3A7C4BC3?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)

- Failing systems with a raw water arsenic concentration exceeding the MCL but less than 50 µg/L per source.

Coagulation Filtration
The Cost Assessment Model selects coagulation filtration for Failing systems meeting either one of criteria listed below.

- Failing systems with 500 service connections or greater; or
- Failing water systems with a raw water arsenic concentration of 50 µg/L or greater per source.[60]

Table 21 summarizes the criteria for matching Failing water systems to modeled adsorption technology as the long-term solution within the Cost Assessment Model.

Table 21: Contaminant Treated by Adsorption in the Cost Assessment Model

Contaminant	System Criteria
Arsenic	Failing systems with an MCL exceedance • 20 ≤ Service connections < 500; and • Raw water arsenic conc. < 50 µg/L.

To determine the raw water arsenic concentration to be used in selecting the modeled treatment technology for a Failing water system, source water quality monitoring data for one compliance cycle (*i.e.*, nine years)[61] is analyzed. After examining various options[62] for calculation method, 75th percentile of all monitoring results was found to be a reasonable option to calculate the arsenic concentration.[63]

ADSORPTION CAPITAL COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model utilizes the GAC capital cost estimate methodology as a surrogate for estimating adsorption capital costs. Due to the relative simplicity of this treatment approach, the current ENR CCI is applied to adjust the cost to current price.

Table 22: Summary of Adsorption Capital Cost Methodology

Cost Element	Cost Estimate Method
Components	

[60] This criterion requires meeting the minimum system size threshold to be assigned a centralized treatment, which is 20 service connections or greater.
[61] This is based on the consideration that monitoring schedule for inorganic chemicals varies between water systems depending on water source type, compliance history, laboratory capacity, etc.
[62] Examined methods: maximum, average, average plus standard deviation or 75th percentile of all monitoring results, or average of monitoring results exceeding MCL.
[63] Several systems failing for arsenic were selected and tested for comparison of various concentration calculation methods. The concentration calculated by each method was plugged into the Cost Assessment Model. Among those methods compared, “75th percentile of all monitoring results” produced the operational costs falling somewhere in middle.

Cost Element	Cost Estimate Method
Treatment Vessel	***GAC capital cost methodology was used as a surrogate.*** • Based on multiple quotes from multiple vendors, solicited between 2015 – 2018. o Adjusted to current ENR CCI[64] and averaged by vessel size. o Refer to Table 23 for the cost by flow range.
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%
Permitting / Environmental[65]	2%

Regional multiplier, inflation, and all other cost adjustments listed in Table 22 are applied to the basic capital cost (i.e., equipment & material) as illustrated in the equation below.

Equation 12: Adsorption Installed Capital Cost

Adsorption Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.32 (regional)[66] + E x 0.031 (inflation) + E x 0.1 (electrical) + E x 0.2 (planning & construction) + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

Treatment Vessel

All the configuration and specifics for pressure vessels associated with arsenic adsorption align with the methodology used by the Cost Assessment Model for GAC capital cost

64 ENR CCI as of August 2023: 13,472.56
65 For CEQA.
66 Regional multiplier assuming an urban county.

estimates. As detailed in GAC section above, the Cost Assessment Model's pressure vessel costs are based on multiple quotes from more than one vendor collected between 2015 to 2018. These quotes are adjusted to current ENR CCI and then averaged by vessel size. Since the capital cost estimate for adsorption includes a single component, treatment vessel, the capital cost estimate is equivalent to the vessel cost.

Table 23 summarizes the Cost Assessment Model's capital cost estimates for adsorption for different ranges of flow rate.

Table 23: Summary of Adsorption Capital Costs by Flow Rate Range

Diameter (ft)	Flow Rate (gpm)	Modeled Cost Estimates	
		Equipment Cost	Installed Capital Cost[67]
6	1 – 250	$214,000	$507,000
8	251 – 425	$263,000	$624,000
12	426 – 875	$365,000	$865,000
Two Pair-12	876 – 1,750	$730,000	$1,731,000

ADSORPTION O&M COST COMPONENTS & ASSUMPTIONS

The O&M cost comprises of three components as summarized in Table 24.

Table 24: Summary of Adsorption O&M Costs

Cost Element	Cost Estimate Method
Components	
Operational Cost	Utilize Equation 14
Electrical Cost	Utilize Equation 6
Labor Cost	• 10% of T2 grade operator salary ○ $123,192 x 0.1 = $12,319
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

[67] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for adsorption treatment in suburban or rural regions.

Regional multiplier and inflation adjustments are applied to the basic O&M cost (i.e., sum of operational, electrical, and labor cost) as illustrated in the equation below.

Equation 13: Adsorption O&M Cost

Adsorption O&M Cost ($) = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[68] + (Operational + Electrical + Labor) x 0.031 (inflation)

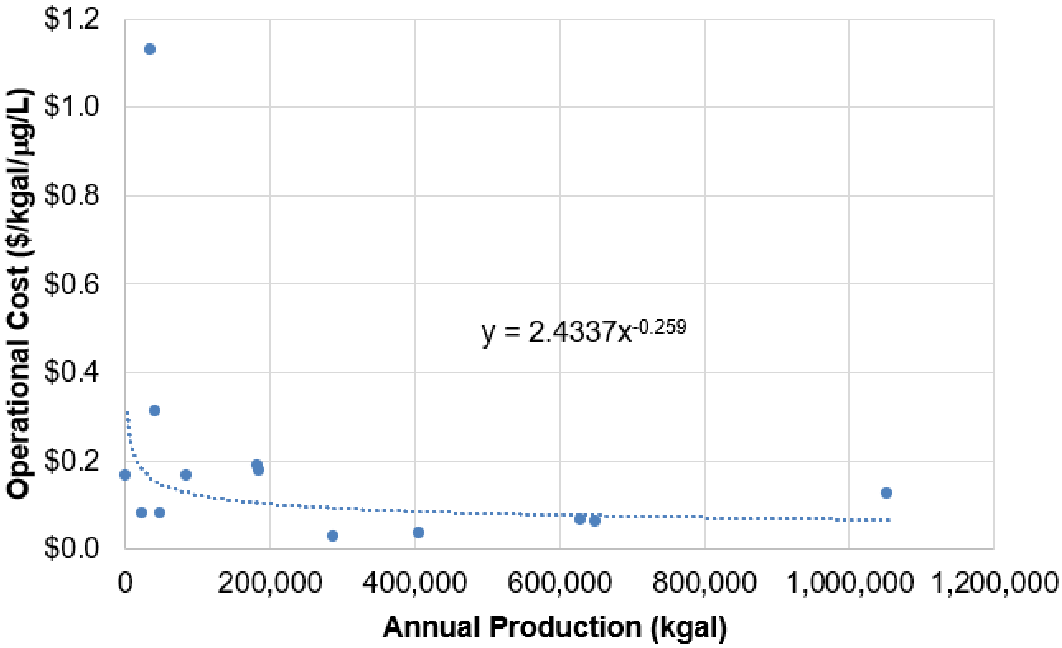
The Cost Assessment Model utilizes a formula utilizing estimated water system annual production and arsenic concentrations to estimate annual adsorption operational cost.

A regression analysis[69] was performed utilizing the arsenic influent/effluent concentrations, annual productions, and normalized O&M costs data from a study[70] used for the 2021 Cost Assessment Model. As shown in the regression graph (Figure 3), the x-axis represents the input annual production in (kgal), while the y-axis represents the output cost in ($/ kgal-water production/ μg/L-arsenic removal). The treatment goal is assumed to achieve 80% of the MCL wherever a water system did not specify effluent concentration. System-reported O&M costs were adjusted to 2023 ENR CCI.[71]

Figure 3 and Equation 14 show the power regression and the regression equation derived, respectively.

[68] Regional multiplier assuming an urban county.
[69] One outlier was excluded from the regression analysis due to high arsenic influent concentration (179 μg/L).
[70] Hilkert Colby, Elizabeth J., Thomas M. Young, Peter G. Green, and Jeannie L. Darby, 2010. Costs of Arsenic Treatment for Potable Water in California and Comparison to U.S. Environmental Protection Agency Affordability Metrics. Journal of the American Water Resources Association (JAWRA) 46(6):1238–1254. DOI: 10.1111/j.1752-1688.2010.00488.x
[71] ENR CCI as of August 2023: 13,472.56

Figure 3: Adsorption Operational Cost Regression



Equation 14: Adsorption Operational Cost

$$y = 2.4337x^{-0.259}$$

where, y = Operational Cost ($/ kgal-water production/ µg/L-arsenic removal)

x = Annual Production (kgal)

State Water Board staff conducted outreach to water systems with the adsorption treatment installed to control the level of arsenic at the source water. The water system data helped validate the Cost Assessment Model's output. It indicates that the Model-predicted operational costs are approximately close to the water system-reported costs as shown in table below. Table 25 summarizes the annual operational costs solicited from water systems and the costs predicted by the Cost Assessment Model.

Table 25: Water System-Provided vs. Model-Predicted Operational Costs

Water System	Annual Production[72]	Arsenic Influent Conc.[73]	Operational Costs	
			System-provided	Model-estimated
System A[74]	245.6 MG	11 µg/L	$76,000 – $90,000	$86,000

[72] Extrapolated based on Drought & Conservation Reporting data (Jan 2023 – May 2023) in the State Water Board's Clearinghouse. Sources with arsenic treatment were identified from mDWW (facilities flow chart) and then system's total annual production was prorated to estimate the water production solely from the sources with arsenic treatment.
[73] 75th percentile of past 9-year data in SDWIS.
[74] Water system size is greater than 500 SC, not meeting the criteria to select adsorption treatment technology. It is utilized for Model-estimated cost validation purposes only.

Water System	Annual Production[72]	Arsenic Influent Conc.[73]	Operational Costs	
			System-provided	Model-estimated
System B[75]	0.049 MG[76]	14.8 µg/L[77]	$12,000	$11,000

MG = million gallons

COAGULATION FILTRATION

Coagulation filtration is another treatment technology the Cost Assessment Model selects for arsenic removal. This technology includes coagulation and precipitation followed by filtration, termed coagulation filtration. The coagulation process consists of the addition of metal-based coagulant, such as ferric chloride to arsenic contaminated water to create iron particles and co-precipitate arsenic. Arsenic must be in oxidized form for effective removal, thus oxidant, typically sodium hypochlorite, is added as a pretreatment process. The filtration processes then remove arsenic particulates. Like adsorption, the process is more efficient at lower pH values.

The Cost Assessment Model is designed to select either **adsorption** or **coagulation filtration** technology for arsenic treatment, depending on Failing system characteristics as further detailed below.

Adsorption

The Cost Assessment Model selects adsorption for Failing systems meeting both criteria listed below.

- Failing systems with 20 to 500 service connections due to operational efficiency. This criterion also aligns with the regulatory threshold for system size for selecting coagulation filtration as the BAT for chemical removal. Current California drinking water regulation,[78] specifies that coagulation filtration is not a BAT for water systems with less than 500 service connections.
- Failing water systems with a raw water arsenic concentration exceeding the MCL but less than 50 µg/L per source.

Coagulation Filtration

The Cost Assessment Model selects coagulation filtration for Failing systems meeting either one of criteria listed below.

- Failing systems with 500 service connections or greater.

[75] Water system size is less than 20 SC, not meeting the criteria to select adsorption treatment technology. It is utilized for validation purposes only.
[76] Annual production estimate collected through the outreach was 0.05 MG.
[77] Arsenic influent concentration collected through the outreach was 10-16 µg/L.
[78] Title 22 CCR § 64447.2 https://govt.westlaw.com/calregs/Document/I79A737D05B6111EC9451000D3A7C4BC3?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)

- Failing systems with raw water arsenic concentrations of 50 µg/L or greater per source.[79]

Table 26 below summarizes the criteria for matching Failing water systems to modeled coagulation filtration technology as the long-term solution within the Cost Assessment Model.

Table 26: Contaminant Treated by Coagulation Filtration in the Cost Model

Contaminant	System Criteria
Arsenic	Failing systems with an MCL exceedance • Service connections ≥ 500; or • Raw water arsenic conc. ≥ 50 µg/L

COAGULATION FILTRATION CAPITAL COST COMPONENTS & ASSUMPTIONS

Coagulation filtration treatment equipment capital costs include filter vessels, chemical feed systems, and a backwash reclaim system. The Cost Assessment Model utilizes an equation to estimate coagulation filtration capital costs. The equation is based on quotes collected in 2015 for flow rate ranges between 500 and 2,500 gpm from two manufacturers. The capital cost estimate is adjusted to current ENR CCI, averaged by flow rate, and then used to develop a linear regression equation to estimate equipment capital costs at a given flow rate.

Table 27 below summarizes the coagulation filtration capital cost components included in the Cost Assessment Model.

Table 27: Summary of Coagulation Filtration Capital Costs

Cost Element	Cost Estimate Method
Components	

Treatment Plant	• Based on 2 quotes from 2 vendors, originally solicited in 2015.
	  ○ Adjusted to current ENR CCI[80] and averaged by flow rate (refer to Table 28 for cost by flow).
	  ○ Developed a regression equation to estimate capital cost at a given flow rate (refer to Equation 16).

Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

[79] This criterion requires meeting the minimum system size threshold to be assigned a centralized treatment, which is 20 service connections or greater.
[80] ENR CCI as of August 2023: 13,472.56

Cost Element	Cost Estimate Method
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%
Permitting / Environmental[81]	2%

Regional multiplier, inflation, and all other cost adjustments listed in Table 27 are applied to the basic capital cost (i.e., equipment & material) as illustrated in the equation below.

Equation 15: Coagulation Filtration Installed Capital Cost

Coagulation Filtration Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32 (regional)[82] + E x 0.1 (electrical) + E x 0.2 (planning & construction) + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

The coagulation filtration equipment cost estimates that are used to develop a linear regression for estimating the cost at a given flow rate is summarized in Table 28.

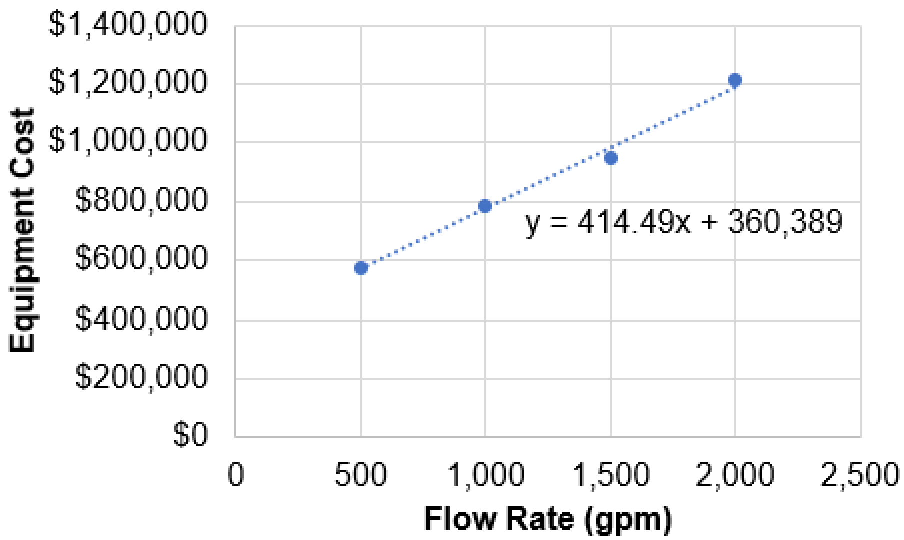
Table 28: Summary of Coagulation Filtration Equipment Cost Estimates by Flow Rate

Flow Rate (gpm)	Equipment Cost Estimate[83]
500	$574,000
1,000	$784,000
1,500	$946,000
2,000	$1,211,000

Figure 4 and Equation 16 illustrate the coagulation filtration equipment cost linear regression and equation.

[81] For CEQA
[82] Regional multiplier assuming an urban county.
[83] Based on vendor-provided quotes in 2015, adjusted to August 2023 ENR CCI as summarized in Table 27.

Figure 4: Arsenic Coagulation Filtration Capital Costs Regression



Equation 16: Coagulation Filtration Equipment Cost

$$y = 414.49x + 360{,}389$$

where, y = Coagulation Filtration Equipment Cost ($)

x = Maximum Daily Demand (gpm)[84]

Table 29 summarizes the Cost Assessment Model's capital cost estimates for coagulation filtration for different flow rates.

Table 29: Summary of Coagulation Filtration Capital Cost by Flow Rate

Flow Rate (gpm)	Modeled Cost Estimates	
	Equipment Cost	Installed Capital Cost[85]
500	$568,000	$1,346,000
1,000	$775,000	$1,837,000
1,500	$982,000	$2,329,000
2,000	$1,189,000	$2,820,000

While the Cost Assessment Model estimates the coagulation filtration capital cost using Equation 16, the following cost components are assumed to be embedded in the capital cost equation.

[84] For the Cost Assessment Model purposes, MDD in gpm is estimated based on the population served and daily water consumption per capita with a peaking factor of 2.25, assuming 16-hour of daily operation (*i.e.*, [population x 150 gallons/day x 2.25] ÷ [16 hours/day x 60 minutes/hour]).

[85] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for coagulation filtration treatment in suburban or rural regions.

Chemical Feed Systems - Storage Tank & Pump
As part of the general treatment process, coagulation filtration requires two chemical feed systems: one for chlorine dosing for pre-oxidation to convert any arsenite (As[III]) to arsenate (As[V]); and another for ferric chloride to be added as a coagulant.

Filter Vessel
The coagulated arsenic flows to filter vessels where it can be filtered out as iron arsenate. Vessel costs vary depending on the filter size and optional features or special designs that may be available on request. In general, filter vessels have backwash capability as a standard feature; however, a backwash reclaim system is not assumed to be part of the standard design. The following section provides more details on the backwash reclaim system component.

Backwash Reclaim System – Wash Water Storage & Recycle Pump
The filters are periodically backwashed with treated water from the distribution system to remove the accumulated debris, which helps maintain the integrity and longevity of the media. The Cost Assessment Model assumes reclaiming of wastewater generated from the backwash cycle. The backwash wastewater is sent to a storage tank for holding and settling. To minimize the volume of sludge stored in the tank, the supernatant[86] is periodically reintroduced to the treatment system, ahead of the filters. A backwash wastewater storage tank and recycle pump can be sized based on the backwash frequency and volume of wastewater produced per cycle. The costs may vary depending on tank size, material, pump capacity, etc.

COAGULATION FILTRATION O&M COST COMPONENTS & ASSUMPTIONS

The O&M cost comprises of three components as summarized in Table 30.

Table 30: Summary of Coagulation Filtration O&M Cost

Cost Element	Cost Estimate Method
Components	
Operational Cost	Utilize Equation 18
Electrical Cost	Utilize Equation 6
Labor Cost	• 20 % of T2 grade operator salary ○ $123,192 x 0.2 = $24,638
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

[86] A relative clear liquid overlying material deposited by settling.

Regional multiplier and inflation adjustments are applied to the basic O&M cost (i.e., sum of operational, electrical, and labor cost) as illustrated in the equation below.

Equation 17: Coagulation Filtration O&M Cost

Coagulation Filtration O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

> Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[87] + (Operational + Electrical + Labor) x 0.031 (inflation)

The Cost Assessment Model utilizes a formula utilizing estimated water system annual production and arsenic concentrations to estimate annual adsorption operational cost.

The Cost Assessment Model utilizes a regression equation based on both estimated annual production and arsenic concentrations to develop coagulation filtration O&M cost estimates.

The regression equation[88] uses normalized O&M cost data from a study[89] used in the 2021 Cost Assessment Model.[90] As shown in the regression graph (Figure 5), x-axis represents the input annual production in (kgal), while y-axis represents the output cost in ($/ kgal-water production/ mg/L-arsenic removal). The treatment goal is assumed to achieve 80% of the MCL wherever water system did not specify effluent concentration. System-reported O&M costs were adjusted to 2023 ENR CCI.[91] Figure 5 and Equation 18 show the power regression and the regression equation derived, respectively.

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87 Regional multiplier assuming an urban county.

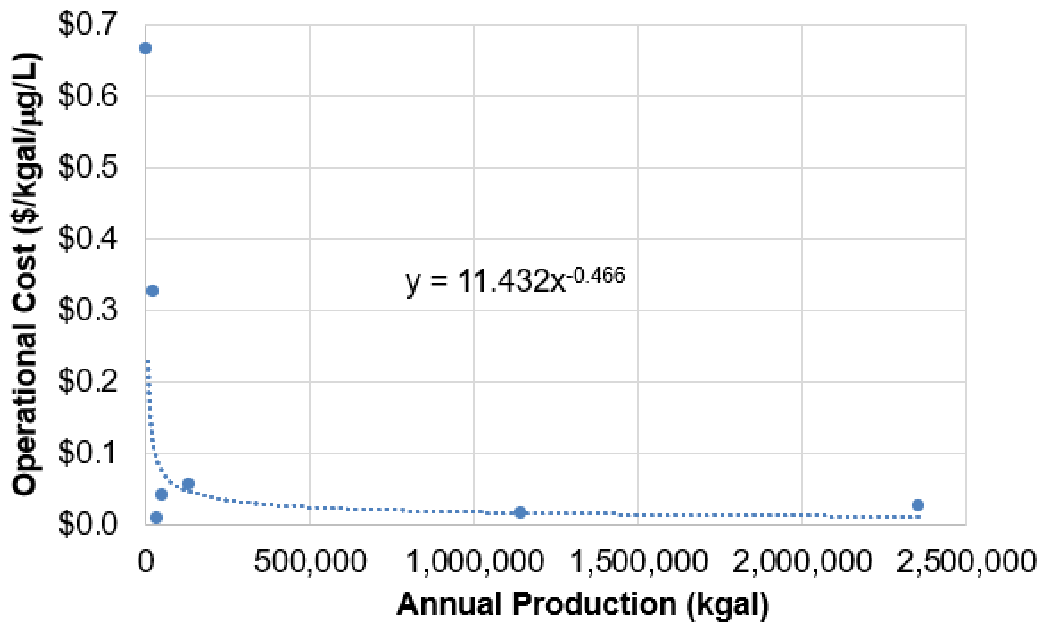
88 In the regression analysis, two outliers were identified and excluded due to high normalized O&M cost ($86 and $27/kgal-production).

89 Hilkert Colby, Elizabeth J., Thomas M. Young, Peter G. Green, and Jeannie L. Darby, 2010. Costs of Arsenic Treatment for Potable Water in California and Comparison to U.S. Environmental Protection Agency Affordability Metrics. Journal of the American Water Resources Association (JAWRA) 46(6):1238–1254. DOI: 10.1111/j.1752-1688.2010.00488.x

90 Attachment C3: Treatment Cost Methodology Details (p. 9) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf

91 ENR CCI as of August 2023: 13,472.56

Figure 5: Coagulation Filtration Operational Costs Regression



Equation 18: Arsenic Coagulation Filtration Operational Cost

$$y = 11.432x^{-0.466}$$

where, y = Operational Cost ($/ kgal-water production/ µg/L-arsenic)

x = Annual Production (kgal)

The following cost components are assumed to be embedded in the operational cost equation. Labor and electricity are applied as separate budgetary items consistent with all other treatment O&M cost estimates.

Media Replacement

While the frequency of the filter media replacement depends on site-specific water quality, available literature pertaining to the State Water Board Funded Projects indicates that replacement typically occurs every 10 years.

Chemicals

As part of the general treatment process, coagulation filtration includes pre-oxidation with chlorine to convert any arsenite to arsenate, which commonly uses sodium hypochlorite. Depending on site-specific water chemistry, it may also require pH adjustment which can be achieved by carbon dioxide. Ferric chloride is the most common iron salt used for a coagulation process for arsenic.

Spent Media & Sludge Disposal

Spent media and the sludge resulting from settling of the solids in the backwash water storage tank can be disposed of using a few different options such as on-site disposal, direct sewer discharge, or off-site disposal.

Analytical Testing
Recurring cost, primarily for compliance monitoring.

FILTRATION

Oxidation followed by filtration is the most common method used for removing iron and manganese in drinking water. The soluble, reduced forms of iron and manganese (Fe^{+2}, Mn^{+2}) are oxidized to (Fe^{+3}, Mn^{+4}), which are then precipitated and trapped in filter media. Filtration is the assumed treatment technology in the Cost Assessment Model for iron/manganese removal as summarized in Table 31 below.

Table 31: Contaminants Treated by Filtration in the Cost Model

Contaminants	System Criteria
• **Iron** • **Manganese**	• Failing systems with an MCL exceedance

FILTRATION CAPITAL COST COMPONENTS & ASSUMPTIONS

The modeled capital costs for filtration include filter vessels, chemical feed and storage, and a backwash reclaim system. The Cost Assessment Model uses an equation to estimate filtration capital costs. The equation uses estimated water system flow rates to calculate capital cost needs. The costs are based on quotes gathered for the 2021 Cost Assessment (adjusted to current ENR CCI)[92] and from new quotes collected in 2023.

Table 32: Summary of Filtration Capital Costs

Cost Element	Cost Estimate Method
Components	
Treatment Plant	Regression equation utilizing the averages of the following cost datasets: • Two cost estimates used in the 2021 Cost Assessment Model; and • An additional cost estimate with quotes gathered from internal (state funded projects) and external sources.
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%

[92] ENR CCI as of August 2023: 13,472.56.

Cost Element	Cost Estimate Method
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%
Permitting / Environmental[93]	2%

Regional multiplier, inflation, and all other cost adjustments listed in Table 32 are applied to the basic capital cost (i.e., equipment & material) as illustrated in the equation below.

Equation 19: Filtration Installed Capital Cost

Filtration Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32 (regional)[94] + E x 0.1 (electrical) + E x 0.2 (planning & construction) + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

Table 33 provides the Cost Assessment Model's capital cost estimates for filtration for different flow rates that are used to develop a linear regression. The regression graph and equation are provided in Figure 6 and Equation 20, respectively.

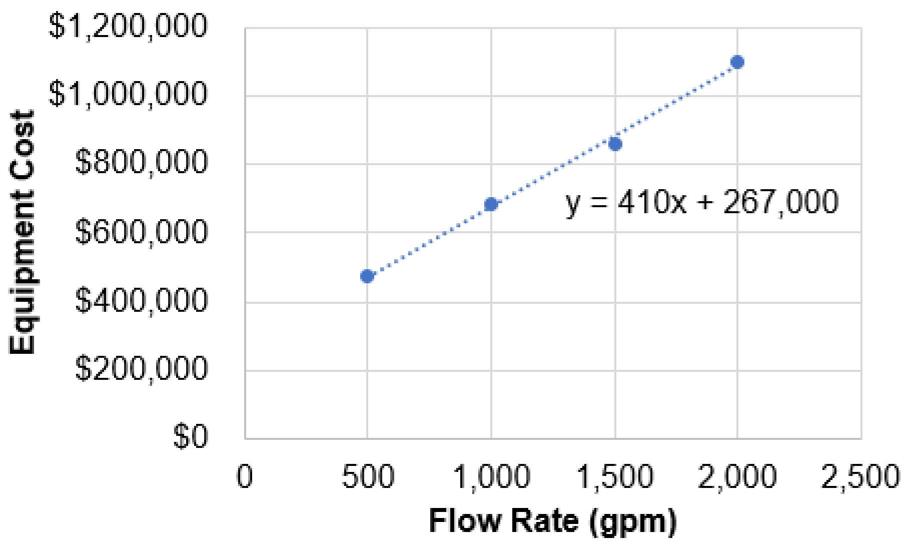
Table 33: Summary of Filtration Equipment Cost Estimates by Flow Rate

Flow Rate (gpm)	Equipment Cost Estimate
500	$476,000
1,000	$683,000
1,500	$858,000
2,000	$1,101,000

93 For CEQA.

94 Regional multiplier assuming an urban county.

Figure 6: Filtration Equipment Costs Regression



Equation 20: Filtration Capital Cost at a Given Flow Rate

$$y = 410x + 267{,}000$$

where, y = Filtration Equipment Cost ($)

x = Maximum Daily Demand (gpm)[95]

Table 34 summarizes the Cost Assessment Model's capital cost estimates for filtration for different flow rates.

Table 34: Summary of Filtration Capital Costs by Flow Rate

Flow Rate (gpm)	Modeled Cost Estimates	
	Equipment Cost	Installed Capital Cost[96]
500	$472,000	$1,119,000
1,000	$677,000	$1,605,000
1,500	$882,000	$2,091,000
2,000	$1,087,000	$2,577,000

[95] For the Cost Assessment Model purposes, MDD in gpm is estimated based on the population served and daily water consumption per capita with a peaking factor of 2.25, assuming 16-hour of daily operation (*i.e.*, [population x 150 gallons/day x 2.25] ÷ [16 hours/day x 60 minutes/hour]).

[96] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for filtration treatment in suburban or rural regions.

The following sections provide additional details on the component costs used to develop this equation.

Filter Vessel

Internal and external research indicates that vessel costs vary depending on the filter size and optional features or special designs that may be available on request. In general, filter vessels are assumed to have backwash capability as a standard feature, but a backwash reclaim system (*i.e.*, wash water storage tank & recycle pump) is not part of the standard design. summarizes the quotes provided by external third-party vendors in 2023.

Table 35: Filter Vessel External Quotes[97]

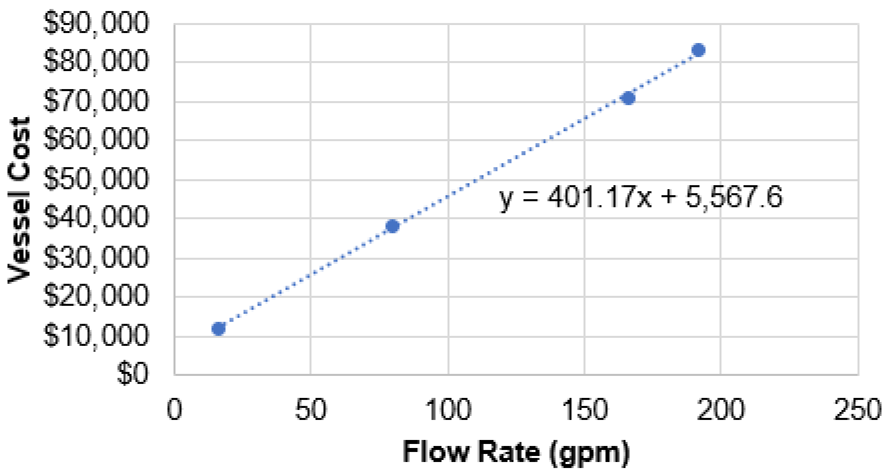
Steel Tank Size (D″ x H″)	Flow Rate (gpm)	Media Qty (ft^3/vessel)	Vessel Cost ($)
24 x 54	16	8	$12,000
54 x 60	80	40	$38,000
78 x 60	166	83	$71,000
84 x 60	192	96	$83,300
Two Units - 84 x 60	384	192	$166,600

The largest unit can run up to 192 gpm and multiple units can be placed working in parallel for greater flow rates. For example, if the flow needs to be doubled, two units can be installed, which will double the cost accordingly. Consultation with a vendor also indicates that configuring with multiple small vessels rather than a single large vessel is beneficial for maintaining an adequate flow rate for backwash[98]. Filter vessel costs extrapolated based on recent external quotes are presented in Figure 7 and Equation 21 below.

[97] Manganese greensand filters. Filter vessels have backwash capability, but no recycling tank and pump embedded. Provided courtesy of Pure Aqua: https://pureaqua.com/

[98] Flow rate for backwash should be higher than normal treatment flow rate.

Figure 7: Filter Vessel Costs Regression



Equation 21: Filter Vessel Cost at a Given Flow Rate

$$y = 401.17x + 5{,}567.6$$

where, y = Filter Vessel Cost ($)

x = Flow Rate (gpm)

Backwash Reclaim System

All filters require periodic backwashing to dispose of accumulated debris and clean the filter media. This is accomplished by reversing the flow using treated water through the unit and then backwashed wastewater goes into an on-site storage tank for holding and settling. The supernatant[99] is periodically recycled to the filtration system. A backwash wastewater storage tank and recycle pump can be sized based on the backwash frequency and volume of backwash water produced per cycle. The costs can be varied depending on tank size, material, pump capacity, etc.

The cost estimates for this component were collected through a review of State Water Board funded projects. The average cost estimate across multiple projects is $126,000 for a backwash reclaim system.

Chemical Feed System for Sodium Hypochlorite

Oxidation processes can occur by feeding a chemical oxidant, most commonly chlorine, using a small chemical storage and feed pump. Chemical feed system costs can be varied depending on storage size, material, pump capacity, etc. The cost estimates for this component were collected through a review of State Water Board funded projects. The average cost estimate across multiple projects is $29,000 for a chemical feed system for sodium hypochlorite.

[99] A relative clear liquid overlying material deposited by settling.

FILTRATION O&M COST COMPONENTS & ASSUMPTIONS

The O&M cost comprises of three components as summarized in Table 36.

Table 36: Summary of Filtration O&M Cost

Cost Element	Cost Estimate Method
Components	
Operational Cost	Utilize Equation 23
Electrical Cost	Utilize Equation 6
Labor Cost	• 10% of T2 grade operator salary ○ $123,192 x 0.1 = $12,319
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

Regional multiplier and inflation adjustments are applied to the basic O&M cost (i.e., sum of operational, electrical, and labor cost) as illustrated in the equation below.

Equation 22: Filtration O&M Cost

Filtration O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[100] + (Operational + Electrical + Labor) x 0.031 (inflation)

The frequency of maintenance for filtration treatment technologies is primarily determined by the concentration of iron and manganese in the raw water and the volume of treated water, thus O&M costs are mainly dependent on the water quality and production volumes. Normally filters have a backwash cycle which helps maintain the integrity and longevity of the media. There are various types of filter media and selection of the proper media also may depend on the water quality. For example, when the combined iron and manganese concentration is in the range of 3 mg/L to 10 mg/L, manganese dioxide-coated greensand media is generally recommended.[101]

[100] Regional multiplier assuming an urban county.
[101] Iron and Manganese in Private Water Systems
https://extension.psu.edu/iron-and-manganese-in-private-water-systems

The Cost Assessment Model's method for estimating filtration O&M costs is the same as the 2021 Cost Assessment Model's[102] method for estimating O&M costs for coagulation filtration. The State Water Board recognizes that this assumption produces conservative filtration O&M cost estimates. The Cost Assessment Model assumes $1.24/kgal-water production for filtration O&M costs.[103]

Equation 23: Filtration Operational Cost

Filtration Operational Cost = $1.24 per kgal-water production

State Water Board staff conducted outreach to water systems with green sand filtration media installed for iron/manganese treatment. Table 37 below summarizes the operational costs collected from water systems and compares them to the output operational cost using the Cost Assessment Model. The water system data was 25% higher than the Cost Assessment Model's estimated costs.

Table 37: Water System-Provided[104] vs. Model-Estimated Operational Costs

Water System	Annual Production	Influent Conc.		Cost	
		Iron	Manganese	System-provided	Model-estimated
System A[105]	2.43 MG	730 µg/L	625 µg/L	$4,000/year[106]	$3,000/year

While the Cost Assessment Model estimates the filtration operational cost as a lump-sum of $1.24/kgal-water production, the following cost components are assumed to be embedded in the operational cost equation. Labor and electricity will be applied as separate budgetary items consistent with all other treatments.

Media Replacement
The frequency of the media replacement depends on site-specific water quality. Feedback from a manufacturer and the water systems with filtration treatment installed for iron/manganese removal indicate that change frequency is wide ranging from 4-5 years to 10-15 years.

Chemical
As part of the general treatment process, filtration for iron/manganese removal includes pre-oxidation to convert any soluble forms of iron/manganese to insoluble forms, which commonly uses sodium hypochlorite.

102 Attachment C3: Treatment Cost Methodology Details (p. 10) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf
103 The 2021 Cost Assessment Model's coagulation filtration O&M cost was $1.07/kgal-water production. It was adjusted to August 2023 ENR CCI (= 13,472.56), which is equivalent to $1.24/kgal-water production.
104 Annual production and contaminants' influent conc. were provided by water system. Labor & electricity are excluded.
105 Media type: Manganese Dioxide-based, Media change frequency: Every 10-years.
106 Lab and field test costs comprised of more than 50% of the total operational cost.

Spent Media & Sludge Disposal
Spent media and the sludge resulting from settling of the solids in the backwash water storage tank can be disposed of using a few different options such as on-site disposal, direct sewer discharge, or off-site disposal.

Analytical Testing
Recurring cost, primarily for compliance monitoring.

REGENERABLE RESIN ANION EXCHANGE

Regenerable resin anion exchange is the process of removing negatively charged ions and exchanging them with similar charged ions on the resin surface, usually chloride. Various contaminants, including nitrate,[107] fluoride, sulfate, and arsenic can all be removed by anion exchange process. Anion resins used to treat water have a finite exchange capacity. When full, they must be regenerated using salt to restore the removal ability. The regeneration frequency varies depending on raw water quality and resin characteristics. The regeneration process creates a wastewater salt brine that must be disposed of. Resin performance degrades over time, which results in the need for resin replacement. Additionally, during anion exchange sulfate concentrations must be monitored to avoid nitrate dumping.[108] This is especially a concern when utilizing non-selective resins.

In the Cost Assessment Model, anion exchange is modeled as a long-term solution for Failing water systems with nitrate water quality-related violations as summarized in Table 38.

Table 38: Contaminants Treated by Regenerable Resin Anion Exchange in the Cost Assessment Model

Contaminant	System Criteria
Nitrate	• Failing systems exceeding MCL for nitrate as nitrogen, with service connections ≥ 20.

ANION EXCHANGE CAPITAL COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model utilizes U.S. EPA's 2023 WBS Model[109] to estimate anion exchange capital costs. Table 39 summarizes the components of the capital cost.

[107] Biological treatment was not considered for nitrate removal in the Cost Assessment Model.
[108] Dumping is the process of nitrate leakage from resins into the treated water. This is caused by a higher affinity of non-selective resins to sulfate. This is due to a continuous load of sulfate into the resin's bed causing nitrate to be "dumped off."
[109] U.S. EPA WBS Anion Exchange Documentation as of March 2023: https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Table 39: Summary of Anion Exchange Capital Cost

Cost Element	Cost Estimate Method
Components	
Treatment Vessel	EPA 2023 WBS Anion Exchange Model Adjusted to current ENR CCI.[110]
Anion Resin[111]	EPA 2023 WBS Anion Exchange Model Adjusted to current ENR CCI.[112]
Piping	EPA 2023 WBS Anion Exchange Model Adjusted to current ENR CCI.[113]
Valves and Fittings	EPA 2023 WBS Anion Exchange Model Adjusted to current ENR CCI.[114]
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Cost Adjustments	
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%
Permitting / Environmental[115]	2%

Table 40 below summarizes the inputs to the U.S. EPA 2023 WBS Anion Exchange Model used to estimate the capital cost for nitrate removal:

Table 40: U.S. EPA 2023 WBS Anion Exchange Model's Inputs & Assumptions

U.S. EPA 2023 WBS Model Input	Assumption
Resin type	• Strong base type II

110 ENR CCI as of August 2023: 13,472.56
111 Two types of resins where modeled: strong base resin, and nitrate selective resin for cases where nitrate exceeds 25 mg/l or sulfate exceeds 250 mg/l
112 ENR CCI as of August 2023: 13,472.56
113 ENR CCI as of August 2023: 13,472.56
114 ENR CCI as of August 2023: 13,472.56
115 For CEQA.

U.S. EPA 2023 WBS Model Input	Assumption
	• Nitrate selective[116]
Flow rate	Standard designs[117]
Empty bed contact time	2-minutes/vessel
Vessel size	Auto sized[118]
No. of vessels	Minimum number of two vessels in series
Throughput	300 BV[119]
Component level	High Cost[120]
System Operation	Fully Automated[121]

The capital cost estimates are calculated for each design flow rate utilizing the inputs listed in the table above. Since the most recent U.S. EPA 2023 WBS Model was published in March 2023, the output cost is adjusted to current ENR CCI values. Table 41 below summarizes the estimates capital cost estimates for anion exchanges produced by the Cost Assessment Model for different flow ranges.

[116] For water sources with an average nitrate concentration exceeding 25mg/l or mean sulfate exceeding 250 mg/l.
[117] Design flow rates are based on ranges of population served and their corresponding design flow categories as detailed in the Anion Exchange documentation: https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models
[118] The vessel size is auto-sized depending on the selected design flow rates. Therefore, bed depth, diameter, and height are automatically adjusted with each selected design flow rate.
[119] U.S. EPA 2023 WBS anion exchange model default bed volume was (420 BV). Based on a recommendation from an external manufacturer to better align bed volumes with the state-wide average levels of sulfate and nitrate, bed volume is changed to 300 BV instead of 420 BV.
[120] “High Cost” component level is selected to reflect the need for durable construction materials such as stainless-steel pressure vessels and stainless-steel piping. A “Low-Medium Cost” system might include fiberglass pressure vessels and PVC piping.
[121] Due to the required frequent regeneration, “system operation” within the U.S. EPA 2023 WBS anion exchange model was changed to “Fully Automated”. Full automation involves monitoring and controlling critical treatment steps, such as chemical addition, routine sampling, chemical metering and backwash pump operation and adjustment, valve operation, etc. Full automation will increase treatment accuracy and decrease labor intervention using built-in automation controls rather than manual process.

Table 41: Summary Comparison of Capital Costs for Anion Exchange

	Strong Base Type II Resin		Nitrate Selective Resin	
Flow Range (gpm)[122]	Equipment Cost	Installed Capital Cost[123]	Equipment Cost	Installed Capital Cost[124]
≤ 21	$250,000	$592,000	$250,000	$592,000
22 – 86	$286,000	$678,000	$286,000	$678,000
87 – 212	$346,000	$821,000	$351,000	$832,000
213 – 514	$490,000	$1,161,000	$426,000	$1,010,000
515 – 1,494	$1,896,000	$4,495,000	$1,931,000	$4,578,000
1,495 – 5,115	$3,770,000	$8,940,000	$3,920,000	$9,294,000
5,116 – 15,704	$7,959,000	$18,871,000	$8,417,000	$19,957,000
15,705 – 52,133	$20,397,000	$48,361,000	$22,254,000	$52,764,000

Equation 24: Installed Capital Anion Exchange Cost

Anion Exchange Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32[125] (regional) + E x 0.1 (electrical) + E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

REGENERABLE RESIN ANION EXCHANGE O&M COST COMPONENTS & ASSUMPTIONS

The anion exchange process generates brine waste following column regeneration. Waste disposal costs tend to account for most ion exchange annual operation costs. The Cost Assessment Model's operational cost estimates for anion exchange are based on Purolite's[126] estimate and design as well as U.S. EPA's 2023 WBS Model. The Cost Assessment Model assumes brine is stored in a holding tank for unspecified off-site disposal. Operational cost is a

[122] Flow ranges are based on U.S. EPA 2023 WBS anion exchange model documentation, where the standard design flows are based on ranges of population served. https://www.epa.gov/system/files/documents/2022-03/ae-documentation-.pdf.pdf

[123] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for anion exchange treatment in suburban or rural regions.

[124] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for anion exchange treatment in suburban or rural regions.

[125] The equation assumes an urban county.

[126] Purolite is a chemical manufacturing company that manufacturers ion exchange resins, catalyst, adsorbent and advanced polymers: https://www.purolite.com

function of modeled throughput,[127] and the throughput is used to estimate the salt and brine operational cost utilizing a regression equation. The O&M cost estimate also includes resin loss and bed replacement estimates costs. Labor and electricity will be included in the O&M cost as separate budgetary items, consistent with all other modeled treatment types. Table 42 below summarizes the O&M cost components for anion exchange treatment.

Table 42: Summary of Anion Exchange O&M Costs

Cost Element	Cost Estimate
Components	
Brine Disposal Cost ($/gallon)	$0.35
Regeneration Salt ($/lb)	$0.25
Resin Loss ($/cf)[128]	$291
Bed Replacement ($/cf)[129]	$291
Electrical Cost	Based on Equation 6
Labor Cost	• 25% of T2 operator grade salary ○ $123,192 x 0.25 = $30,798
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

cf = cubic feet

Regional multiplier and inflation adjustments are applied to the basic O&M cost (i.e., sum of operational, electrical, and labor cost) as illustrated in the equation below.

Equation 25: Anion Exchange O&M Cost

Anion Exchange O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

> Operational Cost = Salt Cost + Disposal Cost + Resin Loss Cost + Bed Replacement Cost

[127] Throughput is represented by the volume of contaminated water being passed through the ion exchange resin before exhaustion is reached.
[128] The U.S. EPA 2023 WBS anion exchange model assumes an annual resin loss rate of 4.5%.
[129] Although the anion exchange resin is regenerated, the resin bed will eventually reach the end of its useful life and require replacement. The U.S. EPA 2023 WBS anion exchange model assumes an annual average bed replacement volume that is 3.8 times higher than resin loss volume.

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[130] + (Operational + Electrical + Labor) x 0.031 (inflation).

The sections below discuss each operational cost for O&M cost component in further detail.

Brine Disposal Cost

The Cost Assessment Model assumes spent brine was disposed off-site. Many disposal options were considered, such as a brine line or evaporation pond. Disposal through a brine line was not considered feasible since most Failing water systems with nitrate issues are not located near an existing brine line. The Cost Assessment Model therefore assumes one-way, non-hazardous brine disposal where a vacuum truck transports the brine to an evaporation pond.

After conducting external research and outreach in 2023 to waste disposal companies and reviewing waste disposal rate sheets for some California counties, a brine disposal cost estimate rate of $0.35/gallon[131] was developed.

Regeneration Salt

The Cost Assessment Model assumes solar (sodium chloride) NACL crystals formed through the solar evaporation process are utilized for anion exchange due to their higher purity compared with other types of salts. Based on market research conducted in 2023, the Cost Assessment Model assumes a regeneration salt cost of $0.25/lb[132] for each regeneration, 3 bed volumes of spent regenerant brine and 2 bed volumes of rinse were directed to the spent brine waste tank for offsite disposal.

Cost Assessment Model's operational cost estimates for both salt consumption and brine disposal are modeled based on resin performance estimated in bed volumes. Mean sulfate concentrations, based on available water quality data for the Failing water system, are used to estimate resin performance.

Resin Loss and Bed Replacement

Resins and their beds (*i.e.,* columns) undergo loss and degradation; and their useful life depends on water quality and pretreatment measures. Resin life can be controlled by adjusting the backwash flow rate and other related parameters.

The resin loss and bed replacement quantities are different, and they are estimated in the Cost Assessment Model by running U.S. EPA's 2023 WBS anion exchange model using the inputs and assumptions as summarized in Table 40 above. The results of the Cost Assessment Model's output for different flow ranges are summarized in Table 43. Since the majority of Failing water systems are small, and their estimated flow rate is below 2,000 gpm, the Cost Assessment Model averages U.S. EPA's 2023 WBS anion exchange model annual resin loss and bed replacement quantities for design flow rates (21 gpm to 1,494 gpm).

[130] Regional multiplier assuming an urban county.
[131] Cost was developed based on gathering assumptions from waste disposal companies including Clean Harbors and considering internal feedback and recommendations.
[132] Morton Solar NaCl salt crystals $10/40 lb

Table 43: U.S. EPA 2023 WBS Anion Exchange Model Resin Loss Results per Standard Flow Range

WBS Standard Design Flow Ranges (gpm)	Resin Loss Replacement (cf/yr)	Complete Bed Replacement (cf/yr)
≤ 21	0.4	1.2
22 – 86	1.1	3.3
87 – 212	3.0	8.0
213 – 514	6.0	19
515 – 1,494	18	70
1,495 – 5,115	62	238
5,116 – 15,704	190	727
15,705 – 52,133	646	2,469

The Cost Assessment Model's estimated replacement unit cost is similar for both resin loss and bed replacement, which is $291/cf. However, the estimated average quantity for each of them is different. Resin loss quantity is assumed to be 5.7 cf/year, while the average estimated bed replacement quantity is assumed to be higher at 20 cf/year. Table 44 summarizes resin and bed replacement total cost calculations.

Table 44: Resin and Bed Replacement Total Cost

Component	Average Quantity	Unit Cost	Total Cost Estimate
Resin Loss	5.7 cf/year	$291/cf	$1,700
Bed Replacement	20 cf/year	$291/cf	$6,000

REGENERABLE RESIN CATION EXCHANGE

Regenerable resin cation exchange is the process of removing unwanted positively charged ions through binding to ion exchange resins. Contaminant cations such as barium, radium, and strontium are removed from feed water by displacing like-charged ions, typically sodium.[133] The regeneration process is carried out using strong acid cation resins. The regeneration process starts by exposing the bed to the brine solution, then slowly rinsing the bed by passing treated water flow through the bed to remove the regenerant ions. Lastly, there is a fast rinse of the bed to flush out any remaining brine.

In the Cost Assessment Model, this treatment is assumed a proven technology to remove Radium-226 and Radium-228 with the design considerations as listed in the Table 45 below.

[133] U.S. WBS-Based Cost Model for Cation Exchange Drinking Water Treatment
https://www.epa.gov/system/files/documents/2022-03/ce-documentation-.pdf.pdf

Table 45: Contaminants Treated by Regenerable Resin Cation Exchange in the Cost Model

Contaminant(s)	System Criteria
• **Radium-226** • **Radium-228**	• Failing systems exceeding MCL for radium • Service connection ≥ 20

CATION EXCHANGE CAPITAL COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model utilizes U.S. EPA's 2023 WBS Cation Exchange Model[134] to develop capital cost estimates for cation exchange. Table 46 below summarizes the components of the capital cost estimate.

Table 46:Summary of Cation Exchange Capital Cost

Cost Elements	Cost Estimate Method
Components	
Treatment Vessel	EPA 2023 WBS Cation Exchange Model Adjusted to current ENR CCI.[135]
Cation Resin	EPA 2023 WBS Cation Exchange Model Adjusted to current ENR CCI.[136]
Piping	EPA 2023 WBS Cation Exchange Model Adjusted to current ENR CCI.[137]
Valves and Fittings	EPA 2023 WBS Cation Exchange Model Adjusted to current ENR CCI.[138]
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%

[134] U.S. EPA 2023 WBS Cation Exchange Model:
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models
[135] ENR CCI as of August 2023: 13,472.56
[136] ENR CCI as of August 2023: 13,472.56
[137] ENR CCI as of August 2023: 13,472.56
[138] ENR CCI as of August 2023: 13,472.56

Cost Elements	Cost Estimate Method
Contingency	25%
Overhead	15%
Permitting / Environmental[139]	2%

The inputs used in U.S. EPA's 2023 WBS Cation Exchange Model to calculate the estimated capital cost are summarized in Table 47. Capital cost estimates are calculated for each design flow rate. The cost estimate is adjusted to current ENR CCI values.

Table 47: Inputs and Assumptions Utilized in the U.S. EPA 2023 WBS Cation Exchange Model

U.S. EPA 2023 WBS Model Input	Assumption
Resin type	Strong acid polystyrenic macroporous resin[140]
Hardness concentration	200 mg/l as $CaCO_3$[141]
Flow rate	Standard designs[142]
Empty bed contact time	2-minutes/vessel
Vessel size	Auto-sized[143]
No. of vessels	Minimum of two vessels in series
Throughput	309 BV[144]
Component level	High Cost[145]
System operation	Fully Automated[146]

[139] For CEQA.
[140] Macroporous resins have better physical stability, and higher resistance to organic fouling and oxidation than Gel-Type resins (AWWA/ASCE 1998). AWWA Water Treatment Plant Design: https://www.awwa.org/Portals/0/files/publications/documents/toc/10009-5ETOC.pdf?_gl=1*1iqail3*_ga*MTY1MTIwMzg3Mi4xNjk0NDczNDI4*_ga_V6LK6LPN9V*MTY5NTE2MzQyMi4zLjAuMTY5NTE2MzQyMy41OS4wLjA.
[141] U.S EPA 2023 WBS Cation Exchange Model default influent hardness concentration
[142] Design flow rates are based on ranges of population served and their corresponding design flow categories as detailed in the Cation Exchange documentation: https://www.epa.gov/system/files/documents/2022-03/ce-documentation-.pdf.pdf
[143] The vessel size in U.S. EPA's Model is auto sized depending on the inputted design flow rates. The U.S. EPA Model also auto-adjusts the bed depth, diameter, and height when the design flow rates are modified.
[144] U.S. EPA 2023 WBS cation exchange model default bed volume. It is estimated based on an assumed default influent hardness concentration of 200 mg/l as $CaCO_3$ and resin type.
[145] "High Cost" component level is selected to reflect the need for durable construction materials such as stainless-steel pressure vessels and stainless-steel piping. A "Low-Medium Cost" system might include fiberglass pressure vessels and PVC piping.
[146] Due to the required frequent regeneration, "system operation" within the U.S. EPA 2023 WBS Anion Exchange Model was changed to "Fully Automated." Full automation involves monitoring and controlling critical treatment steps, such as chemical addition, routine sampling, chemical metering and backwash pump operation and adjustment, valve operation, etc. Full automation will increase treatment accuracy and decrease labor intervention using built-in automation controls rather than manual process.

Table 48 below summarizes the Cost Assessment Model's capital cost estimates for cation exchange for different modeled flow rates.

Table 48: Summary of Installed Capital Cost for Radium Treatment

Flow Range (gpm)[147]	Equipment Cost	Installed Capital Cost[148]
≤ 21	$186,000	$441,000
22 – 86	$224,000	$579,000
87 – 212	$272,000	$645,000
213 – 514	$469,000	$1,112,000
515 – 1,494	$1,600,000	$3,794,000
1,495 – 5,115	$2,834,000	$6,719,000
5,116 – 15,704	$5,764,000	$13,667,000
15,705 – 52,133	$16,694,000	$39,581,000

Equation 26: Cation Exchange Installed Capital Cost

Cation Exchange Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32 [149](regional) + E x 0.1 (electrical)+ E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental).

REGENERABLE RESIN CATION EXCHANGE O&M COST COMPONENTS & ASSUMPTIONS

Cation exchange treatment includes operational requirements similar to anion treatment. The core operational cost for cation exchange is primarily linked to regeneration salt and brine waste disposal costs.

The Cost Assessment Model utilizes U.S. EPA's 2023 WBS Cation Exchange Model to estimate radium treatment operational cost. Labor and electricity are estimated separately, consistent with all other treatments in the Cost Assessment Model. In the modeling design effort, it is assumed that the usable capacity of resin is 27 kilograms $CaCO_3$/cf,[150] with a

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[147] Flow ranges are based on WBS standard design flows based on ranges of population served, as detailed in the Cation Exchange documentation referenced in this White Paper.
[148] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower for cation exchange treatment in rural or suburban regions.
[149] The equation assumes an urban county.
[150] U.S. EPA 2023 WBS Anion Exchange Model default resin capacity.

regenerant dose level of 15 lb/cf of resin. Brine discharge is assumed to be sent to a holding tank to equalize the flow before discharging to a wastewater treatment facility.[151] Table 49 summarizes unit cost for operational cost components.

Table 49: Summary of Cation Exchange O&M Cost Components

Cost Elements	Cost Estimate
Components	
Regeneration Salt ($/lb)	$0.10
Resin Loss ($/cf)	$231.49
Bed Replacement ($/cf)	$231.49
Spent Resin Disposal ($/ton)	$112.16
Electrical Cost	Based on Equation 6
Labor Cost	• 25 % of T2 operator grade salary ○ $123,192 x 0.25 = $30,798
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

The Cost Assessment Model utilizes all operational cost from U.S. EPA's 2023 WBS cation exchange model with the inputs and assumptions summarized in Table 49 to develop a regression equation. U.S. EPA's 2023 WBS estimated cation exchange operational costs by flow ranges is summarized in Table 50.

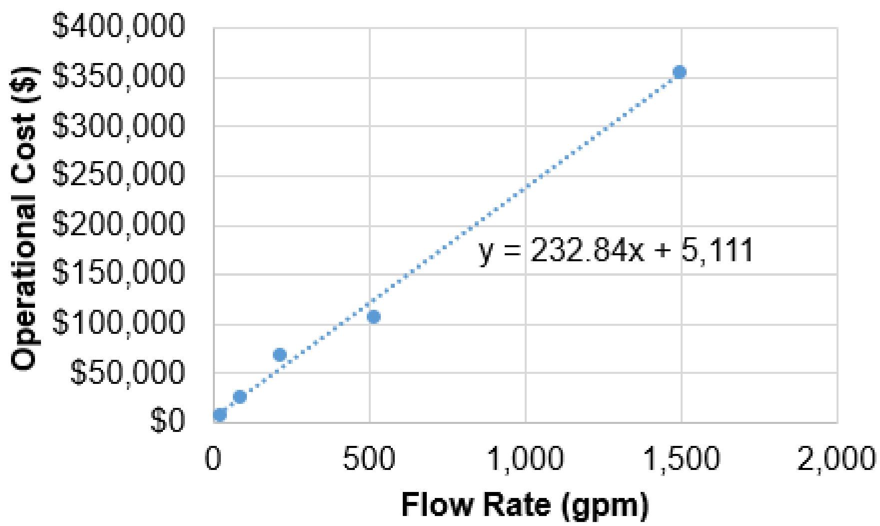
Table 50: Cation Exchange Operational Cost

WBS Standard Design Flow Ranges (gpm)	Estimated Operational Cost ($)
≤ 21	$8,000
22 – 86	$26,000
87 – 212	$69,000
213 – 514	$108,000
515 – 1,494	$357,000
1,495 – 5,115	$1,374,000
5,116 – 15,704	$4,730,000
15,705 – 52,133	$15,879,000

[151] For the purpose of the Cost Assessment Model, the characteristics of spent resin and brine are assumed to be non-hazardous.

The State Water Board utilized the data summarized in Table 50 to develop a linear regression equation to estimate operational costs for individual water systems based on their flow rates (gpm). Since most Failing systems are small, and their estimated flow rate is typically below 2,000 gpm, the State Water Board only included the U.S. EPA's 2023 WBS cost estimates for design flow rates up to 1,494 (gpm) in developing the linear regression equation. Excluding larger flows from the equation is important because they may cause the Cost Assessment Model to overestimate predicted operational cost values. The figure below shows the results of the regression analysis along with the regression equation.

Figure 8: Cation Exchange Operational Cost Regression



Equation 27: Operational Cost at a Design Given Flow Rate

$y = 232.84x + 5{,}111$

where, y = Operational cost ($)

x = Average Daily Demand (gpm)

Equation 28: Cation Exchange O&M Cost

Cation Exchange O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[152] + (Operational + Electrical + Labor) x 0.031 (inflation).

[152] Regional multiplier assuming an urban county.

SINGLE-USE ION EXCHANGE

Ion exchange is one of the best available technologies[153] to treat uranium and perchlorate in drinking water. Although single-use resin disposal can be expensive, regenerative resin carries the risk of leaching radioactive or hazardous contaminants back into the treated water if not handled appropriately. In the Cost Assessment Model, this treatment is modeled as the long-term solution for water systems with uranium, perchlorates, and gross alpha water quality-related violations (Table 51).

Table 51: Contaminants Treated by Single-Use Ion Exchange in the Cost Model

Contaminants	System Criteria
• **Uranium** • **Gross Alpha** • **Perchlorates**	• Failing systems with an MCL exceedance; and • Service connections ≥ 20.

Single-use ion exchange is a passive treatment system, much like GAC, where water is passed through pressure vessels and media. Ion exchange resin is replaced when it becomes exhausted with respect to its target contaminant.

SINGLE-USE ION EXCHANGE CAPITAL COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model's capital cost estimates for single-use ion exchange were developed based on vendor quotes.[154] These vendor quotes were provided for a range of flow rates corresponding to different vessel sizes. The assumed configuration included lead-lag vessels with a maximum hydraulic loading rate of 8 gpm/ft.^{2} Additionally, it was assumed that each vessel would have a resin depth of 36 inches, with a corresponding cost of $300/cf. Table 52 below summarizes the components of the capital cost estimate.

Table 52: Summary of Single-Use Ion Exchange Capital Cost

Cost Elements	Cost Estimate Method
Components	
Treatment Vessels	Corona Environmental modeled vessel costs based on vendor quotes Adjusted to current ENR CCI.[155]
Resin Cost	$300/cf[156]
Cost Adjustments	

153 Title 22 California Code of Regulations, Chapter 15, Article 12, §64447.3. Best Available Technologies (BAT) for Radionuclides and §64447.2. Best Available Technologies (BAT) for Inorganic chemicals.
154 Treatment Cost Methodology Details, Attachment C3: Treatment Cost Methodology Details (p.6) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf
155 ENR CCI as of August 2023: 13,472.56
156 The State Water Board adopted the resin capital cost developed by Corona Environmental, utilizing the EPA's Perchlorate-Selective WBS model, which was subsequently adjusted to reflect the current ENR CCI as of August 2023 ($13,472.56).

Cost Elements	Cost Estimate Method
Components	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%
Overhead	15%
Permitting / Environmental[157]	2%

Table 53 below provides a summary of installed capital cost for single-use ion exchange treatment.

Table 53: Summary of Installed Capital Cost for Single-Use Ion Exchange Treatment

Flow Rate Range (gpm)[158]	Equipment Cost	Installed Capital Cost[159]
1 - 101	$192,000	$455,232
102 - 225	$302,000	$716,042
226 - 401	$418,000	$991,078
402 - 627	$560,000	$1,327,760
628 - 1,256	$1,120,000	$2,655,520

Equation 29: Single-Use Ion Exchange Installed Capital Cost

Single-Use Ion Exchange Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

[157] For CEQA.
[158] Flow ranges are based on six vendor quotes for different treatment rate ranges developed by Corona Environmental and utilized in the 2021 Cost Assessment Model.
[159] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower in suburban or rural regions.

where,

> Total Cost Adjustments = A = E x 0.031 (inflation) + E x 0.32[160] (regional) + E x 0.1 (electrical) + E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

SINGLE-USE ION EXCHANGE O&M COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model's single-use ion exchange operational cost components are estimated for the replacement and disposal of spent resin for uranium and perchlorate. These operational costs estimates are based on quotes gathered from vendors in 2023. Labor and electricity will be applied as separate budgetary items consistent with all other modeled treatments.

Table 54: Summary of Single-Use Ion Exchange Operational Costs

Cost Elements	Cost Estimate Method
Components	
Uranium-Selective Resin Replacement and Disposal Cost	$1/kgal
Perchlorate-Selective Resin Replacement and Disposal Cost	$400/cf
Electrical Cost	Based on Equation 6
Labor Cost	• 20% of T2 operator grade salary ○ $123,192 x 0.20 = $24,638
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

Equation 30: Single-Use Ion Exchange O&M Cost

Single-Use Ion Exchange O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

<u>*where,*</u>

> Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[161] + (Operational + Electrical + Labor) x 0.031 (inflation).

[160] The equation assumes an urban county.
[161] Regional multiplier assuming an urban county.

Uranium-Selective Resin Replacement and Disposal Cost

The Cost Assessment Model utilizes the following BV estimation for uranium-selective resin replacement and disposal costs.

Equation 31: Estimating Number of Bed Volumes[162]

Number of Bed Volumes (BV) = Treated Flow (cf/yr) ÷ Resin Volume (cf)

In Equation 31, the treated flow[163] is assumed to be 688 gpm, which can be converted to 48,335,578 cf/yr; and the resin volume[164] is considered to be 433/cf. Equation 31 estimates approximately 120,000 BV. This BV is used to estimate the cost per kilo gallons (kgal) of water for resin replacement and disposal.

In 2023, State Water Board staff contacted California vendors to solicit updated uranium resin replacement and disposal cost estimates for the proposed updated Cost Assessment Model. The State Water Board, in partnership with Purolite[165] developed an updated cost estimate of $1/kgal[166] for uranium-selective resin replacement and disposal. Equation 32 below illustrates the formula to calculate the estimated cost of uranium-selective resin replacement and disposal. It is assumed that the uranium-selective resin needs to be replaced and disposed of after three years.

Equation 32: Estimating Replacement and Disposal Cost of Uranium-Selective Resin ($/kgal)

Replacement and Disposal Cost of Uranium-Selective Resin ($/kgal) = Resin Cost ($/cf)/ (Volume of Water Produced[167] (gal/cf/1,000)

Figure 9 below illustrates the regression equation based on the average daily demand (in gpm) and its corresponding cost for uranium-selective resin replacement and disposal cost.

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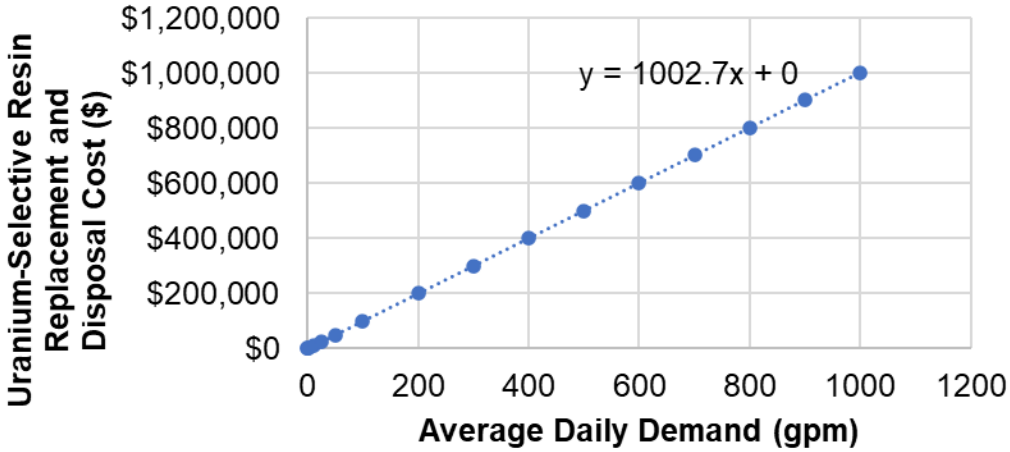
[162] Equation adopted from [Lenntech](https://www.lenntech.com/systems/exchange/vocabulary/ion_exchanger_vocabulary.htm#ixzz7xqo0JFxd).
https://www.lenntech.com/systems/exchange/vocabulary/ion_exchanger_vocabulary.htm#ixzz7xqo0JFxd
[163] Derived from 2021 Cost Assessment Model assumptions.
[164] Resin volume was estimated based on the vessel volume and the number of vessels required with a height of 4 ft. ($i.e., \pi\ x\ radius\ of\ vessel^2\ x\ height\ of\ vessel\ x\ number\ of\ vessels$). The assumed height of vessel was adopted from the 2021 Cost Assessment Model.
[165] [Ion Exchange Resin Manufacturer | Purolite](https://www.purolite.com/index)
https://www.purolite.com/index
[166] Purolite recommended using the PGW6002EBF (uranium-selective) resin because it is designed to be buffered, has a high operating capacity, and serves as a strong base anion (SBA) resin to prevent nitrate and arsenic spiking during startup. This resin costs around $300/cf. Purolite also recommended labor, disposal, and transportation costs at a Technologically Enhanced Naturally Occurring Radioactive Material (TENORM waste) accepting facility, estimated at approximately $600/cf. The combined cost of the resin and waste disposal results in a total cost of $900/cf. This cost was further converted into $/kgal using 120,000 bed volumes.
[167] In 2021 Cost Assessment Model, Corona Environmental calculated the volume of water produced (gal/cu.ft) by multiplying the number of bed volume (120,000) by 7.48 (gallons of water produced/cu.ft) for the unit conversion. The Cost Assessment Model continues to use the same formula.

Figure 9: Uranium-Selective Resin Replacement and Disposal Cost Regression



Equation 33: Uranium-Selective Resin Replacement and Disposal Cost

$y = 1{,}002.7x + 0$

where, y = Uranium-selective resin replacement and disposal cost ($)
x = Annual production (in MG)

Perchlorate-Selective Resin Replacement and Disposal Cost

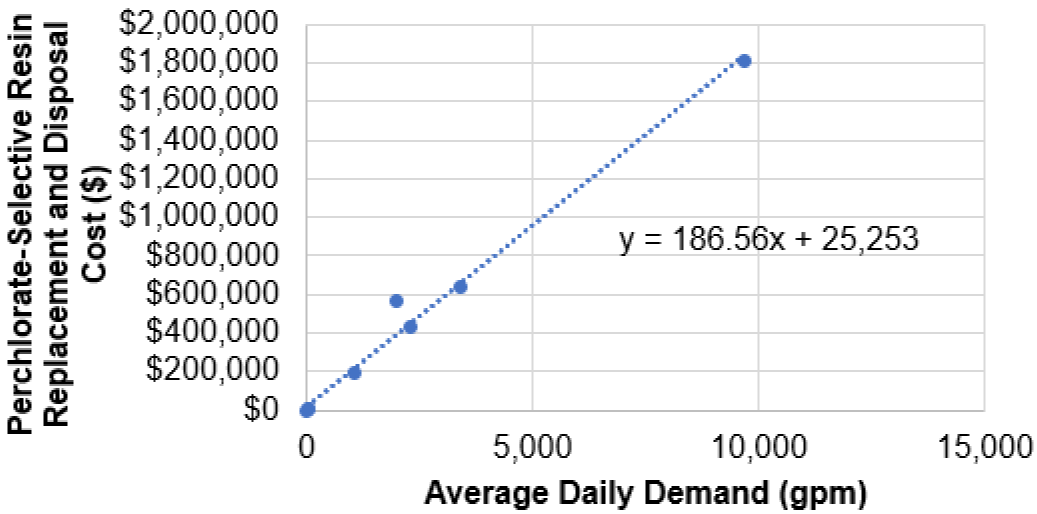
The Cost Assessment Model utilizes a regression equation to estimate perchlorate-selective resin replacement and disposal costs. The formula was developed in partnership with Purolite, a California vendor, in 2023.[168] Purolite recommended utilizing perchlorate-selective resin replacement and disposal costs at approximately $400/cf within the Cost Assessment Model.[169] Purolite also provided cost estimates for the water systems failing for perchlorates, based on $400/cf quote. It is assumed that the perchlorate-selective resin needs to be replaced and disposed of annually.

Figure 10 illustrates the regression equation based on the average daily demand (in gpm) and its corresponding cost for perchlorate-selective resin replacement and disposal cost.

[168] Ion Exchange Resin Manufacturer | Purolite
https://www.purolite.com/index

[169] Purolite estimated cost using perchlorate-related water quality data provided by the State Water Board (No consideration of other competing contaminants – comparatively unconservative approach) 150,000 BV was used for most of the scenarios.

Figure 10: Perchlorate-Selective Resin Replacement and Disposal Cost Regression



Equation 34: Perchlorate-Selective Resin Replacement and Disposal Cost

y = 186.56x + 25,253

where, y = Perchlorate-selective resin replacement and disposal cost ($)
x = Annual production (in MG)

ACTIVATED ALUMINA

Activated alumina is the best available technology[170] for removing fluoride from drinking water. It eliminates contaminants through adsorption, wherein the contaminated water passes through a bed of granular activated alumina. In the Cost Assessment Model,[171] the activated alumina regeneration process was typically assumed to occur in three stages:

- Lowering the pH with sulfuric acid to approximately 5.5 to charge the functional sites of the media.
- Following pH depression, the water passes through pressure vessels loaded with activated alumina media to remove fluoride.
- Subsequently, the pH is typically readjusted, usually with caustic soda.

In the Cost Assessment Model, this treatment is modeled as the long-term solution for water systems with fluoride water quality-related violations (Table 55).

[170] Title 22 California Code of Regulations, Chapter 15, Article 12, Table 64447.2-A, Best Available Technologies, Inorganic Chemicals
https://govt.westlaw.com/calregs/Document/I79A737D05B6111EC9451000D3A7C4BC3?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)
[171] Attachment C3: Treatment Cost Methodology Details (p. 10)
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdff

Table 55: Contaminants Treated by Activated Alumina in the Cost Assessment Model

Contaminant	System Criteria
Fluoride	• Failing systems with an MCL exceedance; and • Service connections ≥ 20.

ACTIVATED ALUMINA CAPITAL COST COMPONENTS & ASSUMPTIONS

In the Cost Assessment Model, the activated alumina capital cost estimation methodology is adopted from the Model's capital cost assumptions for GAC adsorption.[172] The Cost Assessment Model's estimated cost for pressure vessels was based on multiple vendor quotes collected from 2015 to 2018. The Cost Assessment Model adjusted those estimates using current ENR CCI, which are then averaged by vessel size.

In addition to adopting the underlying GAC adsorption capital costs, the Cost Assessment Model added additional components for estimated activated alumina treatment capital costs: two chemical feeds and storage systems (for sulfuric acid and caustic soda), enhanced instrumentation (pH and flow meters), and a Programmable Logic Controller (PLC). Table 46 below summarizes the components of the capital cost.

Table 56:Summary of Activate Alumina Capital Cost

Cost Elements	Cost Estimate Method
Components	
Treatment Vessels	Corona Environmental developed cost based on vendor quotes Adjusted to current ENR CCI.[173]
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%

[172] Attachment C3: Treatment Cost Methodology Details (p. 2)
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf
[173] ENR CCI as of August 2023: 13,472.56

Cost Elements	Cost Estimate Method
Overhead	15%
Permitting / Environmental[174]	2%

Table 57 summarizes the installed capital costs estimated by the Cost Assessment Model for different flow rate ranges.

Table 57: Summary of Activated Alumina Installed Capital Cost

Flow Rate Range (gpm)	Equipment & Material Cost	Installed Capital Cost[175]
1 - 250	$673,700	$1,597,343
251 - 425	$808,440	$1,916,811
426 - 675	$901,000	$2,136,271
676 - 900	$1,097,840	$2,602,979

Equation 35: Activated Alumina Installed Capital Cost

Activated Alumina Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32[176] (regional) + E x 0.1 (electrical) + E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

ACTIVATED ALUMINA O&M COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model utilizes U.S. EPA's WBS Adsorptive Media Model to develop a linear regression equation to estimate activated alumina O&M costs. The cost for pH adjustment is modeled assuming an initial pH of 7.9 and alkalinity of 160 mg/L as $CaCO_3$. The pH is adjusted to 5.5 with sulfuric acid and then readjusted back to 7.9 using caustic soda after treatment. U.S. EPA's 2023 WBS Model[177] estimates the cost of media regeneration and the

[174] For CEQA.
[175] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower in suburban or rural regions.
[176] The equation assumes an urban county.
[177] U.S. EPA's 2023 WBS Model for Adsorptive Media
https://www.epa.gov/system/files/other-files/2023-04/WBS_adsorb_031323.xlsm

costs of basic and acidic chemicals for pH adjustment throughout the adsorption process. Table 58 summarizes the modeled assumptions.

Table 58: Summary of Activated Alumina Operational Assumptions

Cost Elements	Cost estimate Method
Components	
Alkalinity (mg/L as $CaCO_3$)	25[178]
Assumed Initial pH	7.9
Number of BV	1,150[179]
Caustic Soda 50%	$0.32/lb[180]
Sulfuric Acid 93%	$0.93/lb[181]
Regenerative Activated Alumina	$161.37/cf[182]
Electrical Cost	Based on Equation 6
Labor Cost	• 20 % of T2 operator grade salary ○ $123,192 x 0.20 = $24,638
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

Equation 36: Activated Alumina O&M Cost

Activated Alumina O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

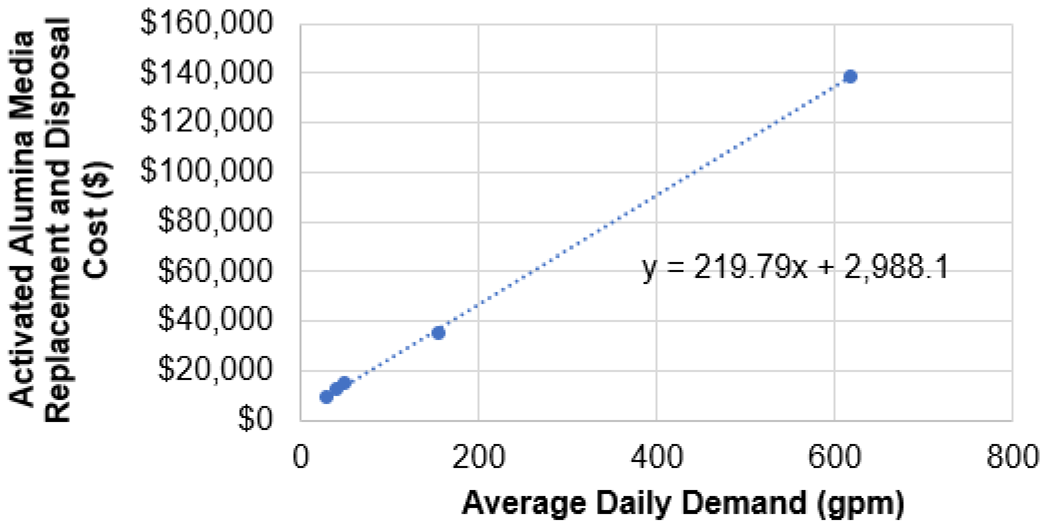
where,

[178] As of August 17, 2023, the statewide average alkalinity of water systems failing for fluoride was calculated. Water systems with multiple sources and available alkalinity data had their values averaged across all sources. Water systems that reported zero alkalinity, either due to a lack of data or assumptions of concentrations not reaching reporting levels, were excluded from the calculation.
[179] According to U.S. EPA's 2023 WBS Model, BVs vary based on water quality and system configuration. U.S. EPA's WBS guidelines: AWWA (1999) reports 1,000 to 1,300 BV when influent fluoride concentration is 3.0 to 6.0 mg/L. Hence, average BV of 1,150 is assumed.
[180] Cost data based on U.S. EPA's 2023 WBS Adsorptive Media Model https://www.epa.gov/system/files/other-files/2023-04/WBS_adsorb_031323.xlsm
[181] Cost data based on U.S. EPA's 2023 WBS Adsorptive Media Model https://www.epa.gov/system/files/other-files/2023-04/WBS_adsorb_031323.xlsm
[182] Cost data based on U.S EPA's 2023 WBS Adsorptive Media Model https://www.epa.gov/system/files/other-files/2023-04/WBS_adsorb_031323.xlsm

Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[183] + (Operational + Electrical + Labor) x 0.031 (inflation)

The linear regression equation uses U.S. EPA's 2023 WBS Model's cost outputs to estimate O&M costs for estimated average daily demand (in gpm). Labor and electricity are applied as separate budgetary items consistent with all other treatments.

Figure 11: Activated Alumina Operational Cost Regression



Equation 37: Activated Alumina Media Replacement and Disposal Cost

$$y = 219.79x + 2{,}988.1$$

where, y = Activated alumina replacement and disposal cost ($)
x = Annual production (in MG)

4-LOG VIRUS TREATMENT

The Ground Water Rule (GWR)[184] may require 4-log virus treatment for groundwater sources that are susceptible to fecal contamination. Virus treatment may include virus removal and/or inactivation. A 4-log virus treatment is analogous to 9,999 out of 10,000 or 99.99% inactivation/removal. Virus treatment is typically accomplished via chlorine, ozone, ultraviolet radiation (UV), chlorine dioxide, or chloramines. However, chlorine and ozone are most common for small water systems.

The Cost Assessment Model selects 4-log virus treatment as the long-term solution for water systems failing to comply with the GWR (Table 59). The Cost Assessment Model assumes 4-log virus treatment is achieved through chlorination within a water main for all the flow rate

[183] Regional multiplier assuming an urban county.
[184] U.S. EPA's Ground Water Rule
https://www.epa.gov/dwreginfo/ground-water-rule

ranges and tank(s) for larger flow rate ranges. Ozone, UV, chlorine dioxide, and chloramines were not considered in the Cost Assessment Model due to their associated higher capital expenses and operational complexity.

Table 59: Contaminants Treated by 4-log Virus Treatment in the Cost Assessment Model

Contaminant	System Criteria
Fecal contaminants (microorganisms)[185] • *E. coli*	• Failing systems for GWR violation. • Groundwater sources.

4-LOG VIRUS TREATMENT CAPITAL COST COMPONENTS & ASSUMPTIONS

In the Cost Assessment Model, the modeled capital costs for 4-log virus treatment are based on U.S. EPA's Disinfection Profiling and Benchmarking Technical Guidance Manual.[186] The Cost Assessment Model includes the following assumptions to estimate 4-log virus treatment capital costs:

- A new water main is needed for all flow rate ranges (1 – 2,100 gpm) for disinfection.
- One new tank is needed for water systems with an estimated flow rate range between 700 to 1,400 gpm, and two new tanks for water systems with estimate flow rate ranges greater than 1,400 gpm to achieve appropriate chlorine contact time.
- Tanks were not considered for flow rates less than 700 gpm.

Table 60 below lists all the assumptions included in the 4-log virus treatment capital cost estimate.

Table 60: Assumptions to Estimate 4-log Virus Treatment Capital Costs

Component	Assumption
Chlorine dosage	1.5 mg/L
Water temperature	15°C
pH of water	8
Baffling factor for the water main pipeline	0.9
Diameter of water main pipeline	12 inches
Baffling factor for the tank(s)	0.3

The Cost Assessment Model's capital costs were derived from vendor-supplied quotes for tanks and pipes. The original quotes, from 2018 to 2020, and are adjusted to current dollars

185 U.S EPA's National Primary Drinking Water Regulations
https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations
186 U.S. EPA, Disinfection Profiling and Benchmarking Technical Guidance Manual. June 2020
https://www.epa.gov/system/files/documents/2022-02/disprof_bench_3rules_final_508.pdf

using ENR CCI. Table 61 below summarizes the capital cost components for 4-log virus treatment.

Table 61: Summary of 4-log Virus Treatment Capital Cost Components

Cost Elements	Cost Estimate Method
Components	
Tank	Included only for water systems with estimated flows of 700 – 2,100 gpm, a tank cost is estimated at $20/gallon.
Water Main	$220/lf
SCADA	$18,000
Chlorine Analyzer	$4,000
pH Analyzer	$1,081
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%

Table 62 below provides a summary of the Cost Assessment Model's estimated installed capital cost for 4-log virus treatment for different flow rate ranges.

Table 62: Summary of Installed Capital Cost Estimates for 4-log Virus Treatment

Flow Rate Range (gpm)[187]	Equipment & Material Cost	Installed Capital Cost[188]
1 – 175	$60,000	$142,260
176 – 300	$86,000	$203,906
301 – 700	$239,000	$566,669
701 – 1,400	$477,000	$1,130,967
1,401 – 2,100	$705,000	$1,671,555

[187] Flow ranges are based on an assumed treatment rate range developed by Corona Environmental and utilized in the 2021 Cost Assessment Model.
[188] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower in suburban or rural regions.

Equation 38: 4-log Virus Treatment Installed Capital Cost

4-log Virus Treatment Installed Capital Cost = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32[189] (regional) + E x 0.1 (electrical) + E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

Water Main

The Cost Assessment Model assumes that water systems can achieve either full or partial 4-log virus treatment in a water main. The Cost Assessment Model assumes a new water main is needed for each water system included in the analysis for all estimated flow ranges due to a lack of available asset-related data for Failing water systems. Table 63 below lists all assumed water main lengths based on the flow rates ranges.

Table 63: Assumed Length of Water Main Depending Upon Flow Rate Ranges

Flow Rate Ranges (gpm)	Assumed Water Main Length (lf)
0 - 15	12
16 - 50	40
51 – 175	140
176 – 300	240
301 – 700	50
701 – 1,400	50
1,400 – 2,100	50

The Cost Assessment Model assumes the modeled water mains are 12-inch polyvinyl chloride (PVC) for all estimated flow rates. The Cost Assessment Model utilizes guidance in U.S. EPA's Disinfection Profiling and Benchmarking Technical Guidance Manual to develop estimated water main lengths based on estimated flow rates for each water system included in the analysis (Equation 39). The Cost Assessment Model's assumptions are summarized in the Appendix section, *4-log Virus Treatment Capital Cost Components & Assumptions*, above.

[189] The equation assumes an urban county.

The Cost Assessment's water main cost assumption is $220 per linear foot. This cost estimate was developed in 2023 utilizing internal and external water main quotes.[190] Underlying water main cost estimate assumptions are detailed below:

- Material cost for 12" PVC C900[191] = $55/lf
- Installation cost vary with location accessibility, material, and other installation conditions and typically ranges from $75 to $255/lf[192]
- For the purpose of the cost model estimate, assume average installation cost = $165/lf

Equation 39: Installed Water Main Cost Assumption

Cost/Lf = Material ($55) + Installation ($165) = $220/lf

Tank

The Cost Assessment Model includes the estimated cost of a new tank or tanks with an inlet, outlet, and a baffling mechanism for flow rates greater than 700 gpm, in addition to a water main, to achieve needed chlorine contact time. Water systems with estimated flow rate ranges between 700 to 1,400 gpm are modeled for one new tank and water systems with estimated flow rate ranges between 1,400 to 2,100 gpm are modeled for two new tanks. Water systems with less than 700 gpm estimated flow rates do not have a new tank modeled for them as it is assumed that disinfection will occur completely in the water main for these water systems.

The Cost Assessment Model's tank cost assumption is $20/gallon.[193] This cost estimate was developed in 2023 using two external vendor quotes with assumed flow rates between 700 – 2,100 gpm.

Small-Scale Supervisory Control and Data Acquisition (SCADA) for Chlorination

Use of SCADA is recommended for continuous monitoring of chlorination systems. This is to ensure compliance with 4-log virus treatment through maintaining the required disinfection contact time. The cost of a small-scale SCADA system can vary significantly due to the size of the water system, treatment technology, and complexity of the SCADA system.

The Cost Assessment Model utilizes a small-scale SCADA vendor provided quote from 2023 that is chlorination specific.[194] This device's capital cost is assumed to be $18,000. The SCADA

[190] $250/lf (2022) State Water Board funded Tulare City consolidation project; $198/lf (2022) from provided the by City of Independence's Construction Project Manager; and $220/lf (2023) from Ferguson Water Works, assuming average installation cost.
[191] C900 PVC: C900 is the American Water Works Association (AWWA) standard for cast-iron-pipe-equivalent outside diameter PVC pressure pipe and fabricated fittings covering nominal pipe sizes from 4 inches through 12 inches. C900 pipes and fittings must comply with the Safe Drinking Water Act requirements, meaning for potable water transmission and distribution. The C900 standard does not include injection-molded PVC fittings.
[192] Ferguson Water Works pipeline installation range.
[193] $20/gallon was derived from reviewing two external vendor quotes: $36/gallon (2023) from Highland Tanks for a fully furnished tank; and $18/gallon (2023) from Clear Water Store, which includes all the inlet, outlet, and baffling mechanisms.
[194] Xio - Installation and equipment ($14,000) and software & cloud protection plan (per month) $300 - $400 – Chlorination specific.

system cost covers installation and equipment ($14,000) as well as a one-year software and cloud protection plan ($4,000).

Chlorine Analyzer

A chlorine analyzer is necessary to accurately monitor free chorine, provide real-time results, and ensure regulatory compliance. Chlorine analyzer costs may vary depending on a water system's geographical location as well as the device's display and data logging features. The Cost Assessment Model assumes $4,000 for a chlorine analyzer. This cost estimate was developed in 2023 by average quotes collected through internal and external research.[195]

pH Analyzer

If the pH is too high or too low, the efficiency of chlorine as a disinfectant can be compromised. Therefore, a pH analyzer is necessary to accurately monitor the pH value of water for its acidity or alkalinity. The Cost Assessment Model's cost estimate for a pH analyzer is $1,081. This cost estimate was developed in 2023 by averaging two external quotes.[196]

4-LOG VIRUS TREATMENT O&M COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model estimates 4-log O&M costs utilizes components costs for chlorine analyzer reagent, 12.5% liquid sodium hypochlorite, labor, and electricity. Labor and electricity are applied as separate budgetary items consistent with all other treatment technologies. Table 64 summarizes all 4-log virus treatment estimated operational cost components.

Table 64: Summary of 4-log Virus Treatment Operational Costs

Cost Elements	Cost Estimate Method
Components	
Chlorine Analyzer Reagent	$1,008[197]
12.5% Liquid Sodium Hypochlorite (NaOCl)	$7.80/gallon
Electrical Cost	Based on Equation 6
Labor Cost	• 10 % of T2 operator grade salary ○ $123,192 x 0.10 = $12,319
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%

[195] $4,000 chlorine cost estimate derived from the following quotes: $4,000 (2019) from State Water Board funded project: Linda County Water District Well 17 Water Treatment Plant and Storage Tank Project; $3,000 - $5,000 (2023) from the vendor - Hach (http://www.hach.com); and $3,803 (2023) from the vendor JPR Systems (Yokogawa) (http://www.jprsystems.com)
[196] $1,081 pH analyzer cost estimate derived from the following quotes: $790 (2023) from vendor Hach (http://www.hach.com); and $1,372 from vendor Thermo Fisher (https://www.thermofisher.com)
[197] Represents annual cost of chlorine analyzer reagent for 4-log virus treatment.

Equation 40: 4-log Virus Treatment O&M Cost

4-log Virus Treatment O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

> Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[198] + (Operational + Electrical + Labor) x 0.031 (inflation)

Chlorine Analyzer Reagents

A chlorine analyzer reagent includes a N,N-diethyl-p-phenylenediamine (DPD) indicator, free chlorine indicator, and buffer solutions. These chemicals are usually sold in sets. The reagents react with the chlorine in a water sample, resulting in a color change. The intensity of color change is directly related to the amount of chlorine in the water sample. These reagents are used with certain types of analyzers available in the market.

The cost of chlorine analyzer reagent can vary depending on the vendor, location, and many other factors. The Cost Assessment Model assumes a flat monthly cost of $84 for chlorine analyzer reagent. This cost estimate was developed in 2023 utilizing two vendor-provided quotes.[199]

12.5% Liquid Sodium Hypochlorite (NaOCl)

12.5% NaOCl, a powerful and widely used chemical to disinfect drinking water. It effectively inactivates harmful pathogens and viruses in water. The estimated costs associated with purchasing 12.5% NaOCl in the Cost Assessment Model is $7.80 per gallon. This cost estimate is based on a vendor quote from 2023.[200] The annual cost of 12.5% NaOCl needed to disinfect water is estimated[201] using the equation below.

---

[198] Regional multiplier assuming an urban county.

[199] $84 chlorine analyzer reagent cost estimate derived from averaging two vendor provided quotes: $67.25 (2023) from HACH J.A.W. Total Chlorine Reagent Kit (P/N 09552H), 30-day supply of TOTAL Chlorine Reagent (J.A.W. = "Just Add Water") for the HACH Chlorine Analyzers (https://www.hach.com); and $101.90 from Thermo Fischer Scientific**,** Lovibond™ Process Chlorine Analyzer Reagents: Free Chlorine, Includes: Free Chlorine Indicator Solution (473mL), Free Chlorine Buffer Solution (473mL), DPD Indicator Powder (24g) (https://www.thermofisher.com)

[200] Lab Alley
https://www.laballey.com/

[201] Adopted from the units and conversion factors document for chlorination and chemical dosage calculations documentation provided by the State Water Board in 2016.
https://www.waterboards.ca.gov/drinking_water/certlic/occupations/documents/opcert/2016/treat_exam_conversion.pdf

Equation 41: Chlorine Dosage, mg/l

Total Chlorine Dosage (mg/l)[202] = Chlorine Demand, mg/l + Residual, mg/l

Equation 42: Estimated Annual Cost of 12.5% NaOCl ($/yr):

Annual cost of 12.5% NaOCl ($/yr) = (12.5% NaOCl, $/gal) x MGD x 365 days/yr (ppm or mg/L of chlorine[203]) x 8.34 lbs/gal) ÷ (12.5% x 8.34 lbs/gal)

SURFACE WATER TREATMENT PACKAGE PLANT

According to the U.S. EPA,[204] the main objective of the Surface Water Treatment Rules (SWTRs) is to minimize the occurrence of illness stemming from pathogens found in drinking water. Among the disease-causing pathogens are *Legionella*, *Giardia Lamblia,* and *Cryptosporidium*. Under the SWTRs, water systems are often required to filter and/or disinfect water obtained from surface sources and groundwater under the direct influence of surface water (GWUDI).

A surface water treatment package plant includes both filtration and disinfection.[205] The package plant can minimize space needs and streamline treatment process, making operation easier and enabling remote control with SCADA, if needed.

Table 65: Contaminants Treated by a Surface Water Treatment Package Plant in the Cost Assessment Model

Contaminants	System Criteria
• **Turbidity** • **Aluminum**[206] • **Fecal contaminants (microorganisms)**[207] 　○ ***E. coli***	• Failing systems with a SWTR violation. • Surface water sources.

202 Where, Chlorine Demand = 1 mg/L; Residual = 0.5 mg/L. Hence, Total Chlorine Dosage = 1.5 mg/L
203 Chlorine dosage of 1.5 mg/l.
204 U.S. EPA, Surface Water Treatment Rules
https://www.epa.gov/dwreginfo/surface-water-treatment-rules
205 For purposes of the Cost Assessment Model, the modeled surface water treatment package plant is assumed to include 4-log virus treatment. The State Water Board recognizes that the treatment objective of 4-log virus treatment may be partially met through filtration. However, for simplicity, the Cost Assessment Model assumes full 4-log virus treatment is accomplished within the surface water treatment package plant by disinfection.
206 Surface water treatment is not considered the best available technology for treating Aluminum. Aluminum is added as a flocculant in drinking water treatment, which can leach out in the treated water. According to California Code of Regulations, Chapter 15, Article, 12, Table 64447.2-A, Best Available Technologies (BAT) Inorganic Chemicals, it is suggested to optimize treatment and reduce aluminum added for flocculation. In the 2021 Cost Assessment Model, it was assumed that the Aluminum would be removed during the filtration stage of the surface water treatment package plant. The State Water Board recommends modeling surface water treatment to address water quality violations associated with Aluminum.
207 The microorganisms include *Cryptosporidium*, *Giardia Lamblia*, Heterotrophic Plate Count (HPC), *Legionella*, total coliforms (including fecal coliform and *E.coli*), and viruses based on U.S. EPA's National Primary Drinking Water Regulations.
https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

SURFACE WATER TREATMENT CAPITAL COST COMPONENTS & ASSUMPTIONS

In the Cost Assessment Model, capital costs for both conventional and membrane package systems are estimated using vendor quotes. Capital costs are averaged and grouped by treatment flow rates. In addition to surface water treatment capital costs, the Cost Assessment Model also includes the capital cost components for 4-log virus treatment within the total capital cost estimate to achieve disinfection credit. Table 66 below summarizes the Cost Assessment Model's estimated installed capital cost components for surface water treatment.

Table 66: Summary of Surface Water Treatment Capital Costs

Cost Elements	Cost Estimate Method
Components	
Filtration	Costs for membrane and conventional treatment package systems are grouped together for averaging.[208] Cost is adjusted to current ENR CCI values.
Handheld Turbidimeter	$2,363/unit
Small-Scale SCADA	$18,000/unit
Chlorine Analyzer for 4-log Virus Treatment Capital Cost	$4,000/unit
Tank for 4-log Virus Treatment Capital Cost	$20/gallon
Water Main Pipeline for 4-log Virus Treatment Capital Cost	$220/lf
pH Analyzer for 4-log virus inactivation	$1,081
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%) • Urban Counties (+32%)
Inflation	3.1%
Electrical	10%
Planning & Construction	20%
Engineering Services	20%
Legal & Admin.	10%
Contingency	25%

[208] https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf

Table 67 below provides a summary of the Cost Assessment Model's estimated installed capital cost for surface water treatment for different flow rate ranges.

Table 67: Summary of Installed Capital Cost for Surface Water Treatment Package Plant

Flow Rate Range (gpm)[209]	Equipment Cost	Installed Capital Cost[210]
1 - 175	$328,000	$777,688
175 - 300	$460,000	$1,090,660
300 - 700	$795,000	$1,884,945
700 – 1,400	$1,217,000	$2,885,507
1,400 – 2,100	$1,847,000	$4,379,237

Equation 43: Surface Water Treatment Package Plant Installed Capital Cost

Surface Water Treatment Package Plant = Equipment & Material Cost (E) + Total Cost Adjustments

where,

> Total Cost Adjustments = E x 0.031 (inflation) + E x 0.32[211] (regional) + E x 0.1 (electrical) + E x 0.2 (planning & construction + E x 0.2 (engineering services) + E x 0.1 (legal and administrative) + E x 0.25 (contingency) + E x 0.15 (overhead) + E x 0.02 (permitting/environmental)

The following sections provide detailed overview of the State Water Board's capital cost component estimates for the surface water treatment package plant.

Filtration

Filtration is the most commonly used treatment process to remove turbidity, organic matter, and harmful bacteria from water. In the Cost Assessment Model,[212] filter cost estimates across different flow rates were collected for many types of filters from multiple vendors. The cost is adjusted to current ENR CCI values. Table 68 summarizes all the capital cost estimates for the filters, excluding the engineering multiplier applied in the 2021 Cost Assessment Model.

[209] Flow ranges are based on an assumed treatment rate range developed by Corona Environmental and utilized I the 2021 Cost Assessment Model

[210] The installed capital cost estimate in this table were developed for an urban region. The cost estimates are lower in suburban or rural regions.

[211] The equation assumes an urban county.

[212] Attachment C3: Treatment Cost Methodology Details (p. 10) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/c3.pdf

Table 68: Summary of Estimated Filtration Costs

Flow Rate Range (gpm)[213]	Cost Estimate
1 - 175	$266,000
175 - 300	$372,000
300 - 700	$553,000
700 – 1,400	$738,000
1,400 – 2,100	$1,139,000

Handheld Turbidimeter

Turbidity, or the relative clarity of water, can interfere with the effectiveness of surface water treatment. Monitoring turbidity, such as via a handheld turbidimeter, is a necessary indicator of adequate surface water treatment. The Cost Assessment Model assumes $2,363 for a handheld turbidity meter. This cost estimate was developed in 2023 utilizing the average of two vendor-provided quotes.[214]

Water Main

The Cost Assessment Model assumes that water systems can achieve either full or partial 4-log virus treatment in a water main. The Cost Assessment Model assumes a new water main is needed for each water system included in the analysis for all estimated flow ranges due to a lack of available asset-related data for Failing water systems.

The Cost Assessment Model assumes the modeled water mains are 12-inch polyvinyl chloride (PVC) for all estimated flow rates. The Cost Assessment Model utilizes guidance in U.S. EPA's Disinfection Profiling and Benchmarking Technical Guidance Manual to develop estimated water main lengths based on estimated flow rates for each water system included in the analysis Equation 44. The Cost Assessment Model's assumptions are summarized in the Appendix section, *4-log Virus Treatment Capital Cost Components & Assumptions*, above.

The Cost Assessment's water main cost assumption is $220 per linear foot. This cost estimate was developed in 2023 utilizing internal and external water main quotes.[215] Underlying water main cost estimate assumptions are detailed below:

- Material cost for 12" PVC C900[216] = $55/lf

[213] Flow ranges are based on an assumed treatment rate range developed by Corona Environmental and utilized I the 2021 Cost Assessment Model.
[214] $2,363 handheld turbidimeter cost estimate derived from averaging two quotes: $1,926 (2023) from Hach 2100Q Portable Turbidimeters (https://www.hach.com); and $2,800 (2023) from a U.S based vendor. The vendor has requested confidentiality; therefore, the vendor's name cannot be provided.
[215] $250/lf (2022) State Water Board funded Tulare City consolidation project; $198/lf (2022) from provided the by City of Independence's Construction Project Manager; and $220/lf (2023) from Ferguson Water Works, assuming average installation cost.
[216] C900 PVC: C900 is the American Water Works Association (AWWA) standard for cast-iron-pipe-equivalent outside diameter PVC pressure pipe and fabricated fittings covering nominal pipe sizes from 4 inches through 12

- Installation cost vary with location accessibility, material, and other installation conditions and typically ranges from $75 to $255/lf[217]
- For the purpose of the cost model estimate, assume average installation cost = $165/lf

Equation 44: Installed Water Main Cost Assumption

Cost/Lf = Material ($55) + Installation ($165) = $220/lf

Tank

The Cost Assessment Model includes the estimated cost of a new tank or tanks with an inlet, outlet, and a baffling mechanism for flow rates greater than 700 gpm, in addition to a water main, to achieve needed chlorine contact time. Water systems with estimated flow rate ranges between 700 to 1,400 gpm are modeled for one new tank and water systems with estimated flow rate ranges between 1,400 to 2,100 gpm are modeled for two new tanks. Water systems with less than 700 gpm estimated flow rates do not have a new tank modeled for them as it is assumed that disinfection will occur completely in the water main for these water systems.

The Cost Assessment Model's tank cost assumption is $20/gallon.[218] This cost estimate was developed using two external vendor quotes with assumed flow rates between 700 – 2,100 gpm.

Small-Scale Supervisory Control and Data Acquisition (SCADA) for Chlorination

Use of SCADA is recommended for continuous monitoring of chlorination systems. This is to ensure compliance with 4-log virus treatment through maintaining the required disinfection contact time. The cost of a small-scale SCADA system can vary significantly due to the size of the water system, treatment technology, and complexity of the SCADA system.

The Cost Assessment Model utilizes a small-scale SCADA vendor provided quote from 2023 that is chlorination specific.[219] This device's capital cost is assumed to be $18,000. The SCADA system cost covers installation and equipment ($14,000) as well as a one-year software and cloud protection plan ($4,000).

Chlorine Analyzer

A chlorine analyzer is necessary to accurately monitor free chorine, provide real-time results, and ensure regulatory compliance. Chlorine analyzer costs may vary depending on a water system's geographical location as well as the device's display and data logging features. The

inches. C900 pipes and fittings must comply with the Safe Drinking Water Act requirements, meaning for potable water transmission and distribution. The C900 standard does not include injection-molded PVC fittings.

[217] Ferguson Water Works pipeline installation range.

[218] $20/gallon was derived from reviewing two external vendor quotes: $36/gallon (2023) from Highland Tanks for a fully furnished tank; and $18/gallon (2023) from Clear Water Store, which includes all the inlet, outlet, and baffling mechanisms.

[219] Xio - Installation and equipment ($14,000) and software & cloud protection plan (per month) $300 - $400 – Chlorination specific.

Cost Assessment Model assumes $4,000 for a chlorine analyzer. This cost estimate was developed in 2023 by average quotes collected through internal and external research.[220]

pH Analyzer

If the pH is too high or too low, the efficiency of chlorine as a disinfectant can be compromised. Therefore, a pH analyzer is necessary to accurately monitor the pH value of water for its acidity or alkalinity. The Cost Assessment Model's cost estimate for a pH analyzer is $1,081. This cost estimate was developed in 2023 by averaging two external quotes.[221]

SURFACE WATER TREATMENT PACKAGE PLANT O&M COST COMPONENTS & ASSUMPTIONS

The Cost Assessment Model includes the O&M cost components for surface water treatment as summarized in Table 69. Labor and electricity are applied as separate budgetary items consistent with all other treatments.

Table 69: Summary of Surface Water Treatment Package Plant Operational Costs

Cost Elements	Cost Estimate Method
Components	
Coagulant	$2.75/lb
Filter Aid - Nonionic Polymer	$2/lb
Filter Media Replacement	$220[222]
Pre/post Treatment pH Adjustment	Sodium hydroxide (caustic): $2.75/lb
Turbidity Standards Calibration Kit	$284[223]
Chlorine Analyzer Reagent for 4-log Virus Treatment	$1,008[224]
12.5% Liquid Sodium Hypochlorite (NaOCl) for 4-log Virus Treatment	$7.80/gallon
Electrical Cost	Based on Equation 6
Labor Cost	• 25 % of T3 operator grade salary ○ $127,992x 0.25 = $31,998
Cost Adjustments	
Regional Multiplier	• Rural Counties (0%) • Suburban Counties (+30%)

220 $4,000 chlorine cost estimate derived from the following quotes: $4,000 (2019) from State Water Board funded project: Linda County Water District Well 17 Water Treatment Plant and Storage Tank Project; $3,000 - $5,000 (2023) from the vendor - Hach (http://www.hach.com); and $3,803 (2023) from the vendor JPR Systems (Yokogawa) (http://www.jprsystems.com)
221 $1,081 pH analyzer cost estimate derived from the following quotes: $790 (2023) from vendor Hach (http://www.hach.com); and $1,372 from vendor Thermo Fisher Scientific (https://www.thermofisher.com)
222 Represents annual cost of filter media.
223 Represents annual cost of turbidity standards calibration kit.
224 Represents annual cost of chlorine analyzer reagent for 4-log virus treatment.

Cost Elements	Cost Estimate Method
	• Urban Counties (+32%)
Inflation	3.1%

Chemical demand is calculated in $/lb. To calculate the estimated volumetric need for treatment chemicals, the following formula[225] is used in the Cost Assessment Model:

Equation 45: Calculation for Chemical Demand

lb/day = (MGD x (ppm or mg/L) x 8.34 lbs/gal) ÷ % purity (if applicable)

Equation 46: Surface Water Treatment Package Plant O&M Cost

Surface Water Treatment Package Plant O&M Cost = Operational Cost + Electrical Cost + Labor Cost + Total Cost Adjustments

where,

> Total Cost Adjustments = (Operational + Electrical + Labor) x 0.32 (regional)[226] + (Operational + Electrical + Labor) x 0.031 (inflation)

Coagulant - Ferric Chloride

According to the U.S. EPA 1991 Surface Water Treatment Guidance,[227] a coagulant must be used at all times while the treatment plant is in operation. This is because dependable removal of *Giardia cysts* cannot be guaranteed if water is filtered without coagulation. Coagulants are used to clump suspended solid particles in the water. Typically, coagulation includes iron or aluminum salts which have a positive charge such as polyaluminum chloride. The Cost Assessment Model assumes $2.35 per pound for coagulant. This cost estimate was developed in 2023 and is based on two vendor-provided quotes.[228] Equation 47 below provides the formula to calculate estimated annual coagulant cost.

Equation 47: Annual Coagulant Demand Cost Calculation

$ / year = (MGD x (ppm or mg/L[229]) x 8.34 lbs/gal) x 365 days/year x $2.35 /lb

[225] Adopted from the units and conversion factors document for chlorination and chemical dosage calculations documentation provided by the State Water Board in 2016.
https://www.waterboards.ca.gov/drinking_water/certlic/occupations/documents/opcert/2016/treat_exam_conversion.pdf
[226] Regional multiplier assuming an urban county.
[227] U.S. EPA 1991 Surface Water Treatment Guidance
https://www.epa.gov/sites/default/files/2015-10/documents/guidance_manual_for_compliance_with_the_filtration_and_disinfection_requirements.pdf
[228] $2.35/lb coagulant cost estimate is based on: $1.70/lb (2023) from Univar Solutions (https://www.chemcentral.com/water-treatment/delpac-2000-technical-grade-nsf-55-gallon-drum-16145815.html); and $2.00 - $4.00/lb from a U.S based vendor. The vendor has requested confidentiality; therefore, the vendor's name cannot be provided.
[229] Coagulant demand depends upon the source water quality, which can fluctuate due to weather conditions. For purposes of the Cost Assessment, it is assumed that coagulant demand is 10 mg/l.

Filter Aid - Nonionic Polymer

Filter aids are used to remove suspended solids to some extent from the water which tend to clog the filter medium during the filtration process. They improve efficiency of the filter and prevent clogging. The Cost Assessment Model assumes $2.00 per pound for filter aid. This cost estimate was developed in 2023 and is based on a vendor-provided quote for a California water system in 2020.[230] Equation 48 below provides the formula to calculate annual filter aid cost.

Equation 48: Annual Filter Aid Demand Cost Calculation

$ / year = (MGD x (ppm or mg/L[231]) x 8.34 lbs/gal) x 365 days/year x $2.00/lb

Filter Replacement

Contaminants can build up on filters over time, clogging the pores. Sometimes, these contaminants can leach back into treated water and contaminate it. Filter replacement is necessary to maintain filtration efficiency.

Table 70 summarizes the U.S. EPA's 2023 WBS Model cost data for filtration replacement cost by varying million gallons per day (MGD) demand. Due to the low variation in the unit cost across flow ranges within the U.S. EPA's Model, the Cost Assessment Model utilizes an annual average unit cost of $220, for all flow ranges, for filter replacement.

Table 70: U.S. EPA 2023 WBS Model Filter Replacement Cost[232]

Size Needed (MGD)	Size Selected (MGD)	Avg. Unit Cost
0	0.05	$154
0.051	0.144	$154
0.145	0.2	$171
0.201	0.5	$266
0.501	1	$266
1.001	2	$266
2.001	5	$266

Pre/post Treatment pH Adjustment

pH is an indicator of the acidity or alkalinity of water. Throughout various stages of water treatment, specific pH levels are needed to ensure that treatment chemicals react effectively with contaminants. As a result, pre- and post- pH adjustment may be necessary. Sulfuric acid

[230] Contra Costa Water District, Quotes based on bid document from Polydyne Inc
https://www.ccwater.com/DocumentCenter/View/8621/2100-ITB-NONIONIC-POLYMER-BID-RESULTS?bidId=
[231] Filter aid demand depends upon the source water quality, which can fluctuate due to weather conditions. For purposes of the Cost Assessment, it is assumed that filter aid demand is 1 mg/l.
[232] These estimates were sourced from the U.S. EPA's WBS Reverse Osmosis and Nanofiltration (RO/NF) Model.
https://www.epa.gov/system/files/other-files/2022-03/reverse-osmosis-and-nanofiltration-ro-and-nf-.xlsm.xlsm

and sodium hydroxide (caustic) are the most commonly used substances for neutralizing acids or bases.

The Cost Assessment Model assumes Sodium Hydroxide (Caustic) is needed for pre-and post- pH adjustment. A flat estimated cost of $2.75/lb sodium hydroxide (caustic) is assumed. This cost estimate was developed utilizing external vendor cost data from 2023.[233] Equation 49 below provides the formula to calculate annual filter aid cost.

Equation 49: Annual Sodium Hydroxide Cost Calculation

$ / year = (MGD x (ppm or mg/L[234]) x 8.34 lbs/gal) x 365 days/year x $2.00/lb

Turbidity Standards Calibration Kit

Turbidity standards calibration kits are used to calibrate turbidimeters. A typical kit contains four sealed vials of 0.1, 20, 100, and 800 NTU standards. The Cost Assessment Model assumes annual turbidity standards calibration kit cost of $284. This cost estimate was developed in 2023 and is based on a vendor-provided quote.[235]

Chlorine Analyzer Reagents

A chlorine analyzer reagent includes a N,N-diethyl-p-phenylenediamine (DPD) indicator, free chlorine indicator, and buffer solutions. These chemicals are usually sold in sets. The reagents react with the chlorine in a water sample, resulting in a color change. The intensity of color change is directly related to the amount of chlorine in the water sample. These reagents are used with certain types of analyzers available in the market.

The cost of chlorine analyzer reagent can vary depending on the vendor, location, and many other factors. The Cost Assessment Model assumes a flat monthly cost of $84 for chlorine analyzer reagent. This cost estimate was developed in 2023 utilizing two vendor-provided quotes.[236]

12.5% Liquid Sodium Hypochlorite (NaOCl)

12.5% NaOCl, a powerful and widely used chemical to disinfect drinking water. It effectively inactivates harmful pathogens and viruses in water. The estimated annual costs associated

[233] $2.75/lb Sodium Hydroxide cost estimate is based on: $0.32 Small Quantity Chemical, EPA's WBS Model Cost Data (2023) (https://www.epa.gov/system/files/other-files/2022-03/reverse-osmosis-and-nanofiltration-ro-and-nf-.xlsm.xlsm) and 2.5/lb from Univar Solutions (https://www.univarsolutions.com/product-categories/essential-chemicals-ingredients/liquid-caustic-soda?certification=6236&infinity=ict2%7Enet%7Egaw%7Ear%7E537209260014%7Ekw%7Esodium+hydroxide+price%7Emt%7Eb%7Ecmp%7ESearch-+Sodium+Hydroxide+Bulk%7Eag%7ESodium+Hydroxide+Bulk)

[234] Sodium Hydroxide demand for pH adjustment depends upon the source water quality, which can fluctuate due to weather conditions. For purposes of the Cost Assessment, it is assumed that sodium hydroxide demand is 10 mg/l.

[235] Hach, Stablcal® Turbidity Standards Calibration Kit, 2100P Portable Turbidimeter, Sealed Vials https://www.hach.com/p-stablcal-turbidity-standards-calibration-kit-2100p-portable-turbidimeter-sealed-vials/2659405

[236] $84 chlorine analyzer reagent cost estimate derived from averaging two vendor provided quotes: $67.25 (2023) from HACH J.A.W. Total Chlorine Reagent Kit (P/N 09552H), 30-day supply of TOTAL Chlorine Reagent (J.A.W. = "Just Add Water") for the HACH Chlorine Analyzers (https://www.hach.com); and $101.90 from Thermo

with purchasing 12.5% NaOCl in the Cost Assessment Model is $7.80 per gallon. This cost estimate is based on a vendor quote from 2023.[237] The annual cost of 12.5% NaOCl needed to disinfect water is estimated[238] using the equations below.

Equation 50: Chlorine Dosage, mg/l

Total Chlorine Dosage (mg/l)[239] = Chlorine Demand, mg/l + Residual, mg/l

Equation 51: Estimated Annual Cost of 12.5% NaOCl ($/yr):

Annual cost of 12.5% NaOCl ($/yr) = (12.5% NaOCl, $/gal) x MGD x 365 days/yr (ppm or mg/L of chlorine[240]) x 8.34 lbs/gal) ÷ (12.5% x 8.34 lbs/gal)

Fischer Scientific**,** Lovibond™ Process Chlorine Analyzer Reagents: Free Chlorine, Includes: Free Chlorine Indicator Solution (473mL), Free Chlorine Buffer Solution (473mL), DPD Indicator Powder (24g) (https://www.thermofisher.com)

237 Lab Alley
https://www.laballey.com/

238 Adopted from the units and conversion factors document for chlorination and chemical dosage calculations documentation provided by the State Water Board in 2016.
https://www.waterboards.ca.gov/drinking_water/certlic/occupations/documents/opcert/2016/treat_exam_conversion.pdf

239 Where, Chlorine Demand = 1 mg/L; Residual = 0.5 mg/L. Hence, Total Chlorine Dosage = 1.5 mg/L

240 Chlorine dosage of 1.5 mg/l.