CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Draft White Paper Discussion On:

Long Term Solutions Cost Methodology for Public Water Systems and Domestic Wells

Version 2

November 20, 2020

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Executive Summary

The State Water Resources Control Board (State Water Board) is developing a methodology for estimating long-term cost solutions for public water systems, tribal water systems,[1] state small water systems, and domestic wells that are in violation or determined to be At-Risk. The statewide cost estimate for systems in violation and At-Risk will help the State Water Board inform the annual funding needs for the Safe and Affordable Drinking Water Fund and the SAFER Program.

The primary focus of this white paper is to provide an overview of the Long-Term Cost Assessment Model methodology that is under development. It is important to note that the sole purpose of the Cost Assessment Model (Model) is to assist the State Water Board in high-level budget planning needs for the Safe and Affordable Drinking Water Fund and informing other policy matters. This Model will not be used to inform system or community-level decisions around solution selection, implementation, or funding allocations. The State Water Board recognizes that the ultimate solution for each individual water system will involve more detailed investigation and should include the input of the community and other stakeholders.

The State Water Board, in partnership with the University of California, Los Angeles (UCLA) and Corona Environmental Consulting, is seeking to inform stakeholders about the development of the draft Cost Assessment Model and highlight a number of the identified possible solutions the Model will evaluate to estimate the long-term cost of addressing identified water system challenges. Some of the possible long-term solutions include:

- Physical consolidation
- Managerial consolidation
- Blending water sources
- Drilling new wells
- Treatment of groundwater or surface water to address contaminants that exceed water quality standards
- Providing point-of-use or point-of-entry treatment to individual customers in a water system, with less than 200 connections, to address contaminants that exceed water quality standards
- Installation of other needed infrastructure such as: storage tanks, back-up generators, booster pumps and/or supervisory control and data acquisition (SCADA) systems

The State Water Board will continue to host public webinar workshops to provide opportunities for stakeholders to learn about and contribute to the State Water

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[1] The State Water Board will be outreaching to Indian Health Services to collect data on estimates of needs to support tribal communities in California. Cost estimates for meeting needs for Tribal water systems will be developed by the State Water Board if this data is received. If tribal needs data is not available, the State Water Board will develop an approach to approximate potential needs and costs for these systems.

Board's efforts to develop a more robust Cost Assessment Model for public water systems, state small water systems, tribal water systems, and domestic wells. This is the first iteration of the cost-model and the State Water Board expects that the model will be modified and upgraded in the future, particularly as new regulatory changes occur, and new information becomes available.

Introduction

In 2016, the State Water Board adopted a Human Right to Water Resolution making the Human Right to Water[2] (HR2W), as defined in Assembly Bill 685[3], a primary consideration and priority across all of the state and regional boards' programs. The HR2W recognizes that "every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking and sanitary purposes."

In 2019, to advance the goals of the HR2W, California passed Senate Bill 200[4] (SB 200), which enabled the State Water Board to establish the Safe and Affordable Funding for Equity and Resilience (SAFER) Program[5]. SB 200 established a set of tools, funding sources, and regulatory authorities the State Water Board can harness through the SAFER Program to help struggling water systems sustainably and affordably provide safe drinking water to their customers.

Foremost among the tools created under SB 200 is the Safe and Affordable Drinking Water Fund[6]. The Fund provides up to $130 million per year through 2030 to enable the State Water Board to develop and implement sustainable solutions for underperforming drinking water systems. The annual Fund Expenditure Plan prioritizes projects for funding, documents past and planned expenditures, and is "based on data and analysis drawn from the drinking water **Needs Assessment**" (Health and Safety Code §116769).

SB 200 explicitly requires the annual Fund Expenditure Plan include "an estimate of the funding needed for the next fiscal year based on the amount available in the fund, **anticipated funding needs**, other existing funding sources, and other

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[2] Human Right to Water
https://www.waterboards.ca.gov/water_issues/programs/hr2w/

[3] Assembly Bill 685
https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120AB685

[4] Senate Bill 200
https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB200

[5] SAFER Program
https://www.waterboards.ca.gov/safer/

[6] Safe and Affordable Drinking Water Fund
https://www.waterboards.ca.gov/water_issues/programs/grants_loans/sustainable_water_solutions/safer.html

relevant data and information" (Health and Safety Code §116769).

FY 2020-21 Fund Expenditure Plan

The FY 2020-21 Fund Expenditure Plan does not include the Cost Assessment model or results from the efforts detailed in this white paper. The State Water Board intends to incorporate the results of this effort into the next iteration of the Fund Expenditure Plan for FY 2021-22 after the Needs Assessment methodologies have been more fully developed through a stakeholder-driven process.

About the Needs Assessment

The State Water Board's Needs Assessment consists of three core components:

- **Risk Assessment**: Identifying public water systems,[7] tribal water systems,[8] state small water systems,[9] and regions where domestic wells[10] consistently fail or are at-risk of failing to provide adequate[11] safe drinking water.
- **Cost Assessment:** Determining the costs related to the implementation of interim and/or emergency measures and longer-term solutions for

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[7] "Public Water System" means a system for the provision to the public of water for human consumption through pipes or other constructed conveyances that has 15 or more service connections or regularly serves at least 25 individuals daily at least 60 days out of the year. A PWS includes any collection, pretreatment, treatment, storage, and distribution facilities under control of the operator of the system that are used primarily in connection with the system; any collection or pretreatment storage facilities not under the control of the operator that are used primarily in connection with the system; and any water system that treats water on behalf of one or more public water systems for the purpose of rendering it safe for human consumption. (Health & Saf. Code, § 116275, subd. (h).)

[8] "Tribal water systems" means federally recognized California Native American Tribes, and non-federally recognized Native American Tribes on the contact list maintained by the Native American Heritage Commission for the purposes of Chapter 905 of the Statutes of 2004. (Health & Saf. Code, § 116766, subd. (c)(1).) Drinking water systems for federally recognized tribes fall under the regulatory jurisdiction of the United States Environmental Protection Agency (USEPA), while non-federally recognized tribes are currently under the jurisdiction of the State Water Board.

[9] "State small water system" means a system for the provision of piped water to the public for human consumption that serves at least five, but not more than 14, service connections and does not regularly serve drinking water to more than an average of 25 individuals daily for more than 60 days out of the year. (Health & Saf. Code, § 116275, subd. (n).)

[10] "Domestic well" means a groundwater well used to supply water for the domestic needs of an individual residence or a water system that is not a public water system and that has no more than four service connections. (Health & Saf. Code, § 116681, subd. (g).)

[11] "Adequate supply" means sufficient water to meet residents' health and safety needs at all times. (Health & Saf. Code, § 116681, subd. (a).)

systems in violation and at-risk systems. Solutions may include, but are not limited to, water partnerships, physical and managerial consolidations, administrators, treatment facility additions or upgrades, distribution system repairs or replacement, and/or point of use/point of entry treatment. The cost assessment also includes the identification of available funding sources and the funding gaps that may exist to support interim and long-term solutions.

- **Affordability Assessment:** Identifying community water systems that serve disadvantaged communities[12] that must charge their customers' fees that exceed the affordability threshold established by the State Water Board in order to provide adequate safe drinking water.

Figure 1. Needs Assessment Components

The State Water Board's Needs Analysis Unit in the Division of Drinking Water (DDW) is leading the implementation of the Needs Assessment in coordination with the Division of Water Quality (DWQ) and Division of Financial Assistance (DFA). The University of California, Los Angeles (UCLA) was contracted (agreement term: 09.01.2019 through 03.31.2021) to support the initial development of Needs Assessment methodologies for the Risk Assessment and Cost Assessment. Although it is important to note, the contract with UCLA was written and scoped prior to passage of SB 200 and was originally designed to conduct a one-time Needs Assessment. Three State Water Board workshops hosted in early 2019

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[12] "Disadvantaged community" or "DAC" means the entire service area of a community water system, or a community therein, in which the median household income is less than 80 percent of the statewide annual median household income level. (Health & Saf. Code, § 116275, subd. (aa).) See separate definition of 'GGRF Disadvantaged Community'.

informed the original scope of the UCLA contract.[13] [14]

Overall, the Needs Assessment contract with UCLA consists of two core Elements:

- **Identification of Public Water Systems in Violation or At-Risk**: focuses primarily on developing and evaluating risk indicators for community water systems up to 3,300 connections and non-transient non-community water systems, due to the large number of historical violations associated with these smaller systems.

- **Cost Analysis for Interim and Long-Term Solutions**: developing a model to estimate the costs related to both necessary interim and/or emergency measures and longer-term solutions to bring systems into compliance and address the challenges faced by at-risk water systems. This Element also includes the identification of available funding sources and the funding gaps that may exist to support interim and long-term solutions.

These two UCLA Contract Elements of the Needs Assessment are providing the SAFER Program with foundational methodologies for evaluating drinking water risk for public water systems and domestic well users and estimating the cost to ameliorate these challenges. Moving forward, the Needs Analysis Unit will be updating the Needs Assessment regularly to support the implementation of the SAFER Program. The results of the Needs Assessment will be used to help prioritize public water systems, tribal water systems, state small water systems, and domestic wells for funding in the Safe and Affordable Drinking Water Fund Expenditure Plan; direct State Water Board technical assistance; and to develop strategies for implementing interim and long-term solutions.

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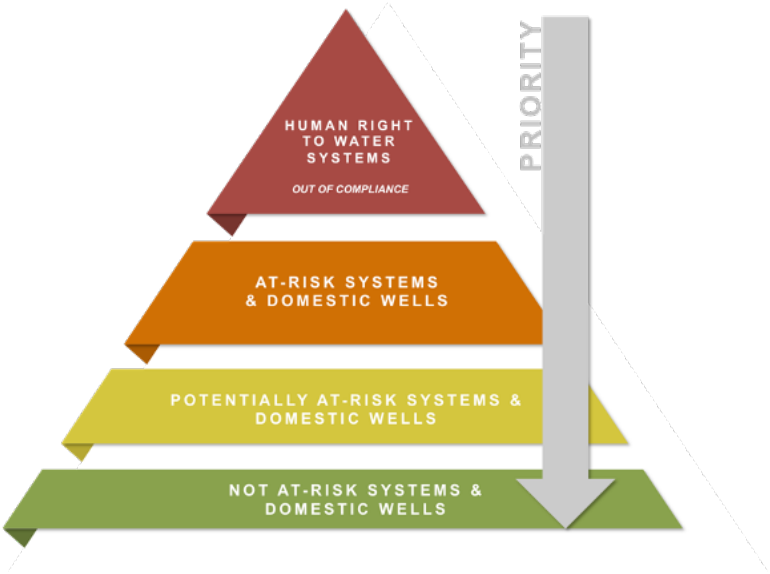
[13] Key Participants: Rural Community Assistance Corporation; CA Rural Water Association; UC Davis, UCLA; UC Berkeley; Pacific Institute; Office of Environmental Health Hazard Assessment; and many more

[14] Drinking Water Quality Needs Assessment
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/needs.html

Figure 2. SAFER Prioritization of Risk Assessment Results



Long-Term Cost Assessment

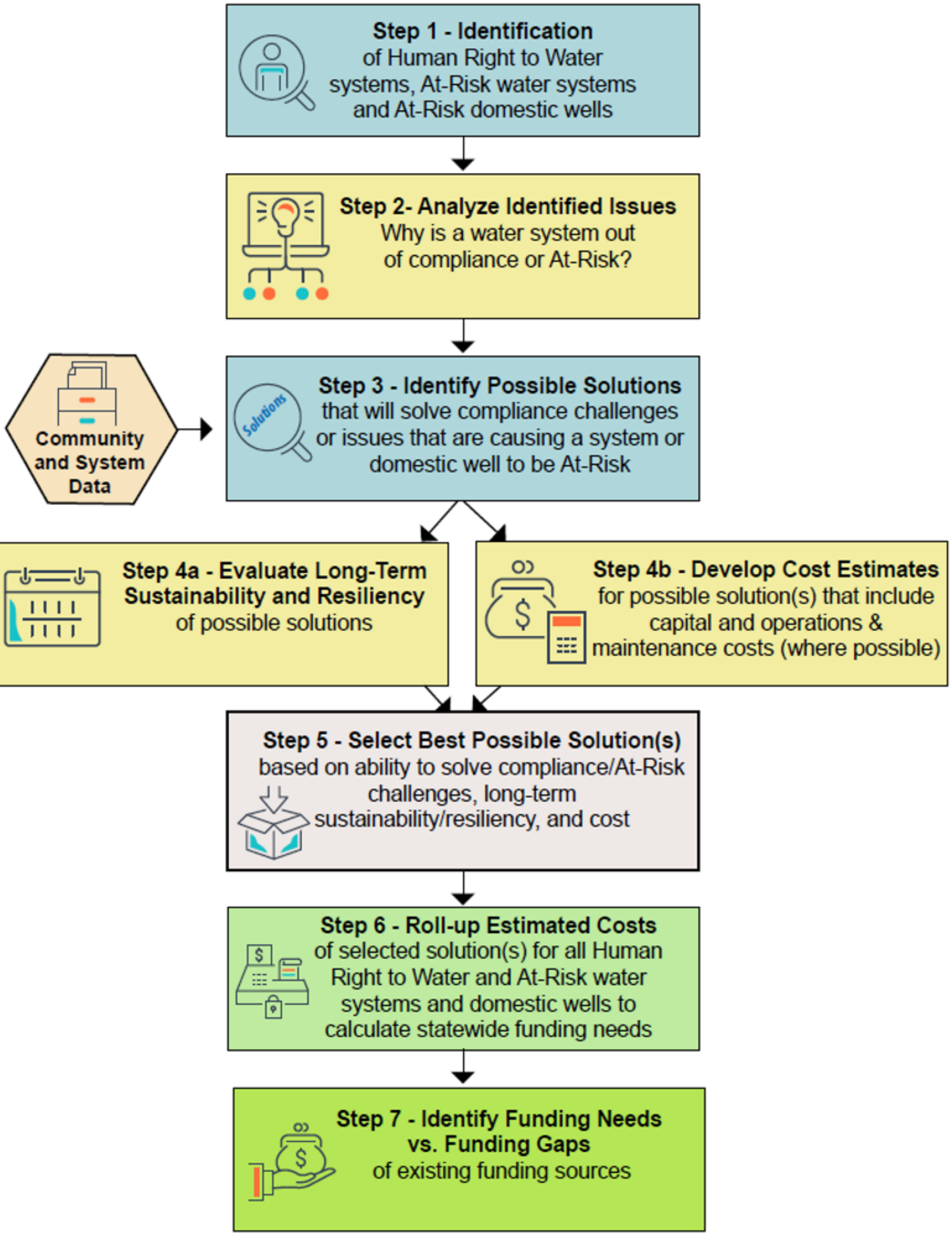
UCLA partnered with Corona Environmental Consulting, LLC (Corona) to develop the Long-Term Cost Assessment Model for the State Water Board. The goals of the Long-Term Cost Assessment are: 1) to estimate the potential cost of implementing solutions for systems in violation (HR2W Systems) and At-Risk water systems and domestic wells; and 2) inform future Fund Expenditure Plans by identifying potential funding gaps that may exist to support these long-term solutions.

The primary focus of this white paper is to provide an overview of the Long-Term Cost Assessment Model methodology that is being developed, highlighting the potential solutions being considered for incorporation into the model and the cost figures being developed for those possible solutions.

Process

The Cost Assessment Model under development utilizes the following process summarized in Figure 1 to identify potential solutions and estimate the long-term costs for implementing those solutions for systems in violation (HR2W Systems) and At-Risk. Figure 3. provides an overview of these core components of the model:

Figure 3. Cost Assessment Model Process



Step 1: Identification of Water Systems and Domestic Wells

The purpose of the Cost Assessment Model is to estimate the potential cost of implementing solutions for systems in violation (HR2W Systems) and At-Risk water systems and domestic wells. Therefore, the first critical dataset the model requires is the list of HR2W systems and At-Risk water systems and domestic wells.

- **HR2W Systems**: The identification of HR2W systems is conducted on a regular basis by the State Water Board utilizing enforcement and compliance data. The list of current HR2W systems is maintained on the State Water Board website: https://www.arcgis.com/apps/MapJournal/index.html?appid=143794cd74e344a29eb8b96190f4658b

- **At-Risk Public Water Systems**: The State Water Board and UCLA are developing a methodology for determining At-Risk public water systems. The Risk Assessment methodology will be finalized by January 2021 and the initial list of At-Risk public water systems will be identified and incorporated into the Cost Assessment Model. Learn more about the development of the Risk Assessment methodology in the draft white paper "Evaluation of Potential Indicators & Recommendations for Risk Assessment 2.0 for Public Water Systems": https://www.waterboards.ca.gov/drinking_water/programs/safer_drinking_water/docs/e_p_i_recommendations_risk_assessment_2_public_water_systems.pdf

- **At-Risk State Small Water Systems and Domestic Wells**: The State Water Board's DWQ's Groundwater Ambient Monitoring and Assessment Program (GAMA) Unit is leading the effort to develop the Risk Assessment methodology for state small water systems and domestic wells that is focused on groundwater quality. This effort will be accomplished through the mapping of aquifers that are used as a source of drinking water that are at high risk of containing contaminants that exceed primary drinking water standards.

  DWQ's GAMA Unit has published a Draft White Paper[15] for public feedback and Needs Assessment Domestic Well Water Quality Tool,[16] detailing the development of the Risk Assessment methodology for state small water

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[15] Draft GAMA Needs Assessment White Paper 021420 https://gispublic.waterboards.ca.gov/portal/home/item.html?id=0e7fe8d490ef45fb826ab3ad86db5409

[16] Needs Assessment Domestic Well Water Quality Tool https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=292dd4434c9c4c1ab8291b94a91cee85

systems and domestic wells.

- **At-Risk Tribal Water Systems**: The State Water Board's Needs Analysis Unit and Office of Public Participation are working to collect data and develop a Risk Assessment methodology for Federal tribal water systems located in California. State tribal water systems are under the regulatory jurisdiction of the State Water Board and are therefore incorporated similarly to other public water systems.

The Cost Assessment Model also utilizes location data of public water systems, state small water systems, and domestic wells that are not on the HR2W list or deemed At-Risk in order to identify possible physical consolidation and regional solutions. Detailed information on the datasets used to gather locational information on water systems and domestic wells, including water quality, is provided in Appendix A.

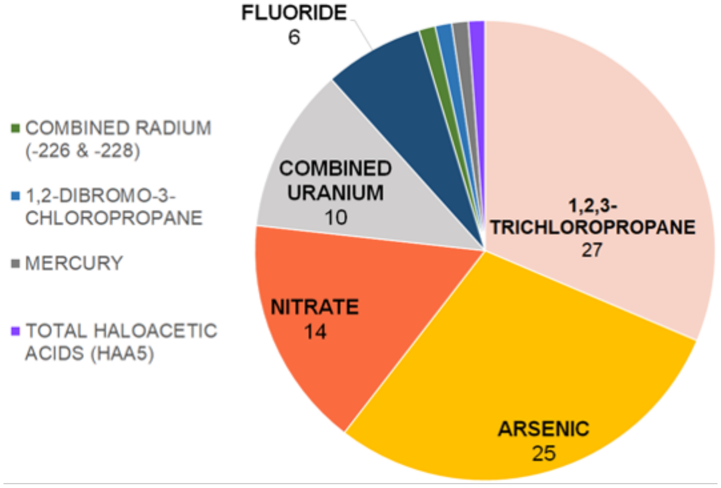
Step 2: Analyze Identified Issues

In order to estimate the cost of providing solutions to HR2W systems and At-Risk systems, the Model needs to incorporate and analyze the challenges and issues these systems are struggling with in order to provide sustained safe and accessible drinking water. Ultimately, the State Water Board's Risk Assessment will be utilized to identify these challenges or issues for the Model. The Risk Assessment will analyze a variety of risk indicators that fall into the following four categories. Water system performance for each of these risk indicators will provide the Model a baseline amount of data to begin analyzing possible modeled solutions.

- Water Quality
- Accessibility
- Affordability
- Technical, Managerial, and Financial (TMF) Capacity

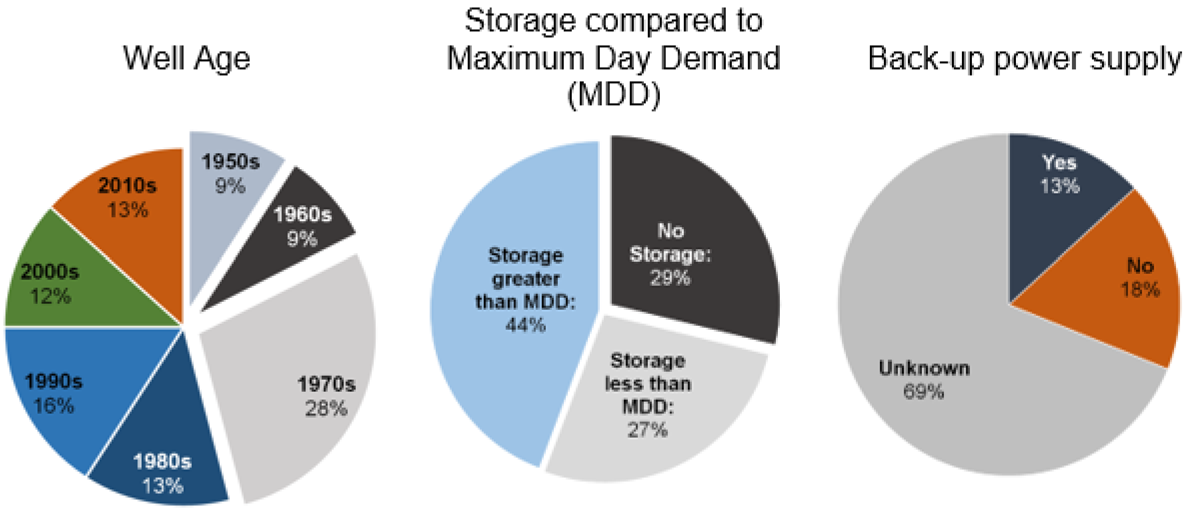
The Risk Assessment methodology is being developed in parallel to the Cost Assessment Model. Due to the timing of this project, Corona conducted a case study of the HR2W systems in Kern County to identify and refine the possible challenges the Cost Assessment Model may need to address. Kern County was selected for initial analysis because it has 61 of the state's 311 HR2W listed systems. Figure 4 summarizes the different water quality violations in Kern County.

Figure 4. Kern County HR2W Systems Water Quality Violations



To examine these challenges in a more quantitative way, the sanitary surveys[17] for 60 of the HR2W systems in Kern County were analyzed to look at source age, source capacity, and storage capacity. Figure 5 summarizes the proportion of systems that may have additional infrastructure needs based on this review.

Figure 5. Additional Issues Identified



The Kern County case study identified several challenges that are anticipated to be applicable across the state and utilized this information to develop more nuanced assumptions in the Model. These findings are summarized below and further

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[17] The most recent Sanitary Surveys for Kern County Human Right to Water systems were provided by the State Water Board in PDF format.

discussed in Appendix B.

- In Kern County, 75% of the water systems served fewer than 200 connections. Small water systems having fewer technical, managerial and financial resources to leverage may need additional technical assistance or managerial support to achieve interim and long-term compliance.
- Approximately 48% of the water systems reviewed in the Kern County case study had only one well and thus lacked the water supply redundancy to meet current standards. These water systems frequently also had inadequate storage and no backup power. Therefore, water systems that are not consolidated may need additional water infrastructure redundancy to remain out of the At-Risk or Potentially At-Risk category.
- Only 25% of the wells were constructed within the past twenty years, indicating that at least some of the water system infrastructure is likely beyond its useful life. Aging infrastructure effects many of the water systems in Kern County. This is expected to impact the cost of consolidation/regionalization projects if receiving entities are hesitant to combine with water systems having poor existing infrastructure and/or increase the need for funding for infrastructure replacement.

The study also identified a high prevalence of 1,2,3-Trichloropropane (1,2,3-TCP) violations. It is theorized that the high number of 1,2,3-TCP violations are in part a result of the relatively recent implementation of the maximum contaminant level, effective in December 2017. It is also observed that there is significant co-occurring contamination across Kern County with nitrate and that the presence of multiple contaminants will significantly increase treatment costs and complexity.

At this time, water quality information is lacking for State Small Water Systems and domestic wells. Future iterations of this analysis would benefit from more specific information about these water sources and associated infrastructure. Regional water quality maps for selected constituents have been developed statewide by the State Water Board's Groundwater Ambient Monitoring and Assessment (GAMA) program.[18] Any domestic wells in areas of the state that are expected to have the water quality issues mapped in the GAMA project are assumed to have a water quality issue.

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[18] State Water Resources Control Board. 2020. Needs Analysis Groundwater Ambient Monitoring and Assessment (GAMA) Tool, GAMA Program.
https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=292dd4434c9c4c1ab8291b94a91cee85

Step 3: Identifying Possible Solutions

Identified Issues Mapping to Possible Solutions

For each category of issue identified, a range of potential solutions can be considered for the Model. Table 1 summarizes the issues and potential modeled solutions for the HR2W and At-Risk Public Water Systems, and Table 2 identifies the issues and potential solutions for State Small Water Systems and Domestic Wells. As more information becomes available for State Small Water Systems, other potential modeled solutions can be added.

Table 1. Identified Issues and Potential Solutions for HR2W and At-Risk Public Water Systems

Identified Issues	Potential Modeled Solutions	
Water Quality	• Physical consolidation • Managerial consolidation • Blending water sourced	• Treatment • Point of use or point of entry (less than 200 connections) • Drilling new wells
Single Source	Physical consolidation, drilling new wells	
Source Over 40-Years Old	Physical consolidation, drilling new wells	
Storage does not meet Maximum Day Demand	Other needed infrastructure such as storage tanks, booster pumps, back-up generators, main replacement, SCADA systems, and/or meters	
No Back-up Generator		
Mains Over 40-Years Old		
No Meters		
Accessibility Risk Indicators	Managerial consolidation, physical consolidation, or extension of service, drilling a new well	
Affordability Risk Indicators	To be considered in solution and funding source selection in the future. A possible solution for DAC and	

Identified Issues	Potential Modeled Solutions
	SDAC systems could be operations and maintenance projects. Additional alternatives are in development.
Technical, Managerial, and Financial (TMF) Risk Indicators	Physical consolidations, managerial consolidation, and Technical Assistance

The potential solutions for systems At-Risk due to Accessibility, Affordability, and TMF are still under development.

Table 2. Identified Issues and Potential Solutions for State Small Water Systems and Domestic Wells

Identified Issues	Potential Modeled Solutions

Water Quality for **At-Risk** State Small Water Systems and Domestic Wells	• Incorporation in regional projects:
	  • Physical consolidation
	  • Managerial consolidation
	• Point of use/point of entry treatment
	• Bottled Water where point of use or point of entry is not a technically viable solution (e.g. high nitrate concentrations)

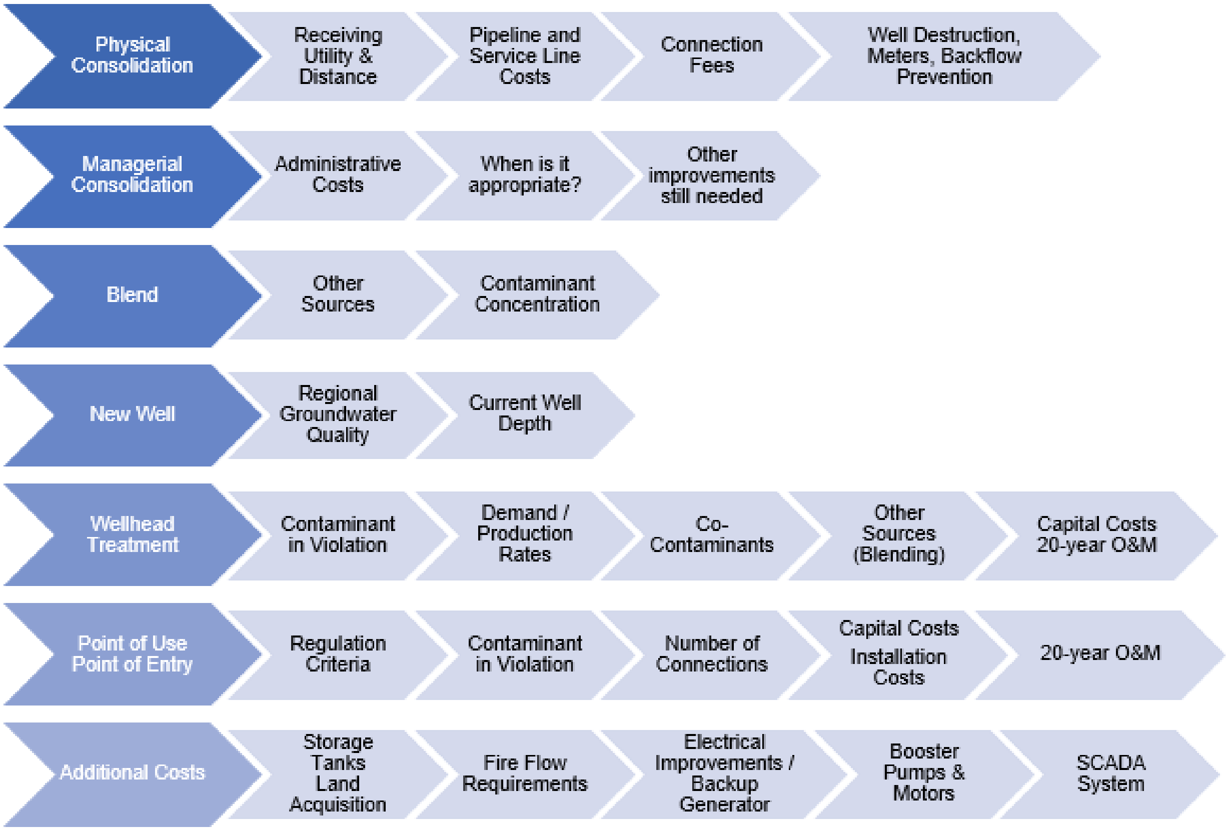
State Small Water Systems and Domestic Wells that are **Not At-Risk**	• Incorporation in regional projects:
	  • Physical consolidation, if along anticipated pipeline alignments for other purposes
	  • Managerial consolidation, for State Small Water Systems.

The following sections of this paper explain in greater detail the potential solutions.

Modeled Solutions Considerations

The methodology considers a range of regional and individual system-based solutions for water systems and domestic wells as illustrated in Figure 6 along with additional considerations that are important to each potential modeled solution. The following section describes the range of solutions in more detail. In some cases, multiple solutions may be viable to address a water system’s challenges.

Figure 6. Solutions and Considerations Appraised



It is important to note that the possible solutions utilized in the Cost Assessment Model are only intended to provide a statewide cost estimate for implementing solutions for HR2W Systems and At-Risk systems. Solutions modeled for individual systems in the Cost Assessment Model will not be utilized by the State Water Board to make funding or technical assistance decisions. The State Water Boards recognize that HR2W Systems and At-Risk systems will require a site-specific detailed evaluation conducted by a qualified engineer or technical assistance provider, or other specialized firm, to identify implementable solutions for communities.

Regional Solutions

The challenges that water systems experience are often regional issues that stem from degraded source water quality, inconsistent source water availability, or serving communities that are economically disadvantaged. Once challenges are identified at a regional and individual water system level, potential long-term solutions can be considered to eliminate current water quality violations and ensure long-term water quantity and water quality sustainability.

This methodology includes a regional component to identify opportunities where water systems and communities can work together to solve common issues. Some of the solutions evaluated that are aimed at resolving regional issues include:

Physical consolidation of two or more water suppliers that are geographically close. Please refer to Appendix A for more information on the GIS methodology developed for this evaluation.

Physical consolidation is the joining of two or more water systems. For example, a small mobile home park that has its own water system may be near or within a city (i.e. receiving system) and decides it no longer wishes to be responsible for providing drinking water. The city can begin providing water to the mobile home park through a master meter or other type of connection.

Some of the benefits of physical consolidation include:

- The receiving water system may already have adequate treatment or the ability to construct water treatment that is designed to address the water quality challenges that impact area water supplies.

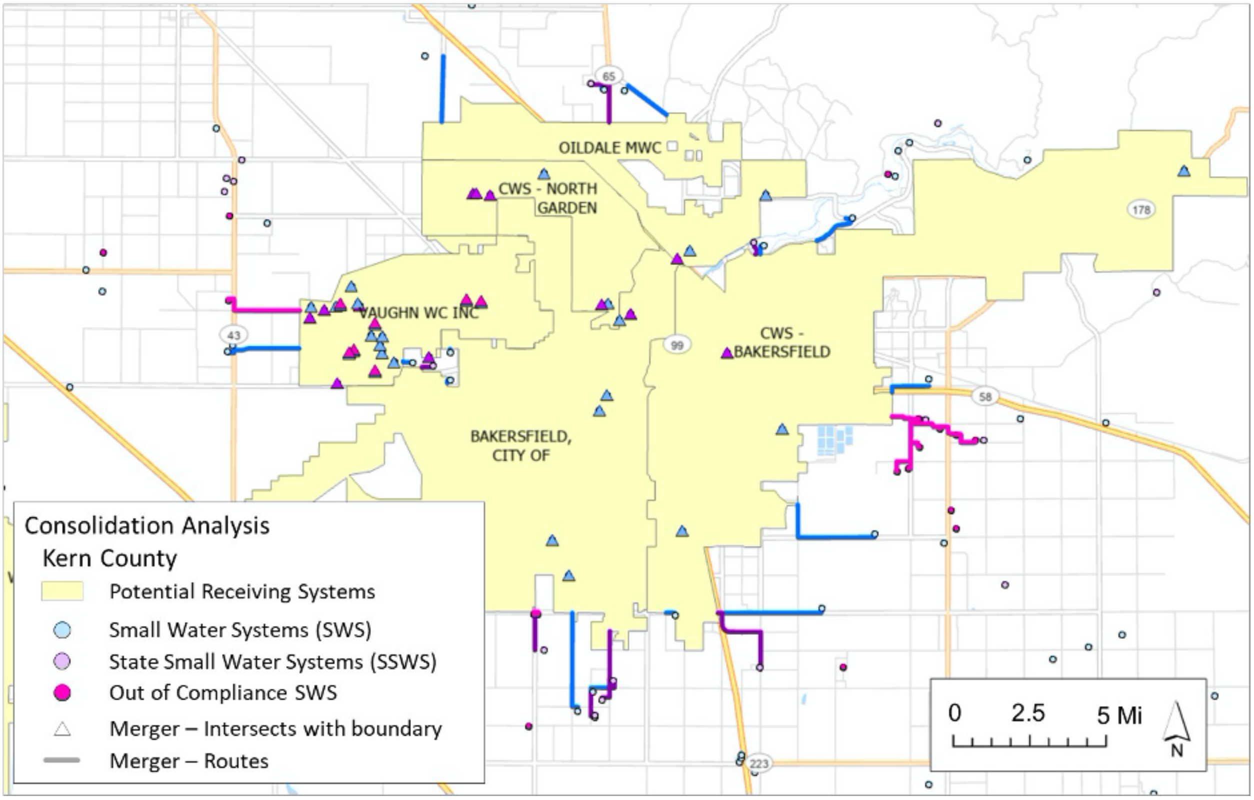
- The receiving water system may offer a diversified water supply portfolio affording optimization of available area water supplies to ensure that its population will not be faced with shortages. This alleviates small systems issues due to a lack of storage, inadequate pumping capacity, or inadequate individual well productivity.

- Consolidation of treatment and operations can improve water rate affordability by spreading costs over a larger customer base, decreasing redundant efforts and decreasing treatment costs through larger bulk purchases.

- Some physical consolidation projects may be in proximity to and allow connections with state small water systems, households served by domestic wells, and other At-Risk water systems, in addition to the targeted joining system. The physical consolidation analyses conducted as part of this methodology have determined the expected cost range of a given project.

Figure 7 shows an example physical consolidation analysis map. This methodology identifies potential physical consolidation projects and even larger scale regional projects. While engineering and cost-modeling play a large role in consolidation and regionalization, the actual solution that will be implemented may be highly variable depending on other factors such as political boundaries, water rights boundaries, community interest etc.

Figure 7. Example Physical Consolidation Analysis Map



Managerial consolidation. Managerial consolidation can refer to a water system having an outside administrator appointed, having shared services contracts with other utilities, having an outside administrator appointed, or when a small water system becomes part of a larger water system for all managerial purposes but continues to use their original water supply and distribution system without physically connecting. For example, a small community may once have had an all-volunteer staff. The volunteer staff may be aging and no longer want to be responsible for the water system. The water system may be too far from the large water system to make it cost-effective to physically consolidate. The larger water system can legally take over the water system functions such as regulatory reporting, billing, operations, etc., but uses the existing infrastructure. The smaller water system governance structure dissolves and is no longer legally responsible for water service.

Local Solutions

As consolidation and regionalization solutions are not always possible or practical for the challenges faced by individual water systems, solutions that are aimed at resolving challenges on a case-by-case basis are also evaluated. Some examples of solutions evaluated to solve individual water system challenges include:

Blending water sources. Blending is a possibility when water systems have multiple sources. When a source with a low concentration of the target contaminant is available, it can be cost effective to blend it with the source in violation of a water quality standard. This methodology has identified some water systems that should further investigate blending as a potential solution. In the case of 1,2,3-TCP violations, blending is not considered as an option because the drinking water standard is often much lower than the raw water concentrations, therefore blending is not generally a viable solution given required flow rates to achieve compliance. While blending can be cost effective, it also limits operational flexibility and can create significant vulnerabilities if a utility does not have a robust water supply portfolio, a common challenge faced by smaller systems.

Drilling new wells. In some locations, drilling a new well that is constructed differently than the existing well may allow a water system to avoid treatment. Drilling a new well does not guarantee that water quality issues can be avoided. In circumstances where the well in violation of a water quality standard is also at the end of the expected useful life, then this option certainly warrants further investigation.

Treatment of groundwater or surface water to address contaminants that exceed water quality standards. Many of the water systems that are under evaluation, in particular those that have been added to the HR2W list for recurring water quality violations, may require new or additional treatment. Some of the contaminants that have resulted in water quality violations in the systems under evaluation include:

- Arsenic
- Nitrate
- 1,2,3-TCP
- Disinfection byproducts - trihalomethanes (THM) and haloacetic acids (HAA)
- Perchlorate
- Uranium
- Surface Water Treatment and/or extensive bacteriological failures

In some cases, there are multiple treatment options that may effectively remove a contaminant. In other cases, there may only be a single treatment option that is currently available to treat a contaminant. And in yet other cases, there may be multiple contaminants that a water system needs treatment for. These realities ultimately impact the type of treatment required. An example of wellhead treatment utilized for many types of contaminant removal is shown in Figure 8.

Figure 8. Example of Wellhead Treatment

Providing point-of-use (POU) or point-of-entry (POE) treatment to customers served by affected water systems with less than 200 connections or domestic wells may be a viable option to address contaminants that exceed water quality standards. POU treatment is considered for most commonly occurring inorganic contaminants (for example nitrate or arsenic) and is not recommended when bacteriological contaminants exist. An example POU treatment device is shown in Figure 9.

Figure 9. Example Point of Use Treatment Device[19]

POE treatment must be considered in the case of 1,2,3-TCP, or other volatile organic compounds, to address health impacts of inhaling the compounds during exposure in the shower for example. POU treatment is not acceptable for any contaminant that has a risk pathway beyond ingestion.

Installation of other needed infrastructure. In addition to water quality challenges, many identified systems have additional infrastructure needs to address reliability and basic system operation. Examples of these items include storage tanks and booster pumps, replacement well(s), back-up generators, main replacement, and/or supervisory control and data acquisition (SCADA) systems.

Solution Options for Domestic Wells

Physical consolidation and POU or POE treatment are considered the primary potential solution for domestic wells. However, bottled water is also considered for those domestic wells that are believed to have nitrate levels exceeding 25 mg/L[20] as nitrate because POU devices do not work at these levels.

No detailed information about the water quality of individual domestic wells is available and therefore broad assumptions are required to be made. Locations of domestic wells are available as a count of wells in a square mile area. The status of the wells is unknown. Given the limitations of the existing data, this methodology

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[19] Photo courtesy of Arvin and RCAC

[20] NSF/ANSI 58 – 2018, *Reverse Osmosis Drinking Water Treatment Systems*. Lists an influent nitrate concentration of 30 mg/L-N to achieve a treated water of 10 mg/L-N in the treated water. A safety factor has been applied to keep the treated water below 10 mg/L-N.

will assume that all locations with domestic wells along a possible physical consolidation route could be connected to a public water system. Regional water quality maps for selected constituents have been developed statewide by the State Water Board's Groundwater Ambient Monitoring and Assessment (GAMA) program.[21] As appropriate, POU or POE treatment will, or bottled water for some nitrate levels, be budgeted for any domestic wells in areas of the state that are expected to have the water quality issues mapped in the GAMA project and are not along a potential physical consolidation route.

Step 4.a: Sustainability and Resiliency Assessment

The State Water Board recognizes that the lowest-cost model solution may not be the best long-term solution of a system or community. It is important that the Cost Assessment Model incorporate a sustainability and resiliency assessment of modeled possible solutions to better refine the results of the Model. The Sustainability and Resiliency Assessment Framework proposed in this step was prepared in collaboration with UCLA and Sacramento State University's Office of Water Programs (OWP).

OWP performed a literature review on four primary categories of sustainability and resiliency: technical performance, economic viability, environmental sustainability and social acceptability. OWP then screened potential metrics through internal consultation with project collaborators and evaluated data availability to provide a list of recommended metrics for inclusion in the Sustainability and Resiliency Assessment Framework. The recommended metrics include:

- Relative Operational Difficulty
- Operator Training Requirements
- Asset Useful Life
- Number of Current Service Connections
- O&M Cost/Household
- Waste Stream Generation

These metrics will be utilized to develop a Sustainability and Resiliency score for various modeled solution alternatives. For example, an alternative with a long asset useful life, no waste stream generation and relatively high ease of operation would score better than an alternative with a shorter asset useful life, a generated waste stream and a highly complex treatment process. The development process for these metrics as well as the proposed scoring methodology is provided in Appendix

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[21] State Water Resources Control Board. 2020. Needs Analysis Groundwater Ambient Monitoring and Assessment (GAMA) Tool, GAMA Program. https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=292dd4434c9c4c1ab8291b94a91cee85

C.

It is important to note that the Sustainability and Resiliency score for various alternatives does not provide a direct estimated fiscal impact. However, relative scores will be utilized to prioritize sustainability and resiliency factors over fiscal impacts particularly when two solution alternatives are in the same order of magnitude. Once public input has been considered, the final sustainability and resiliency criteria will be incorporated into the Cost Assessment Model.

Step 4.b: Develop Screening-Level Costs Estimates for Potential Solutions

The Model methodology develops high-level cost estimates for the solutions that are identified as viable options to address water system challenges. The generalized costs developed are devoid of site-specific details that will significantly impact total project costs and should be considered as planning numbers on a statewide level rather than a decision-making tool for a specific system. The following sections provides a summary of the potential modeled solutions considered and how the solution costs are being developed.

Cost Estimation Level of Accuracy

The methodology described above corresponds with a Class 5 cost estimate as defined by AACE International. Class 5 cost estimates are considered appropriate for screening level efforts and have a level of accuracy ranging from -20% to -50% on the low end and +30% to +100% for an encompassing range of -50% to +100%. For the developed costs, the central tendency of the cost estimates will be shown; however, it is important the reader view each value with the accuracy in mind. For example, if a cost of $100 is presented the corresponding range of anticipated costs is $50 to $200.

Regional Cost Adjustment

To adjust the cost estimates presented in the subsequent sections for regional cost variance, the Model applies an RSMeans[22] City Cost Index (CCI). RSMeans catalogs a database of material, labor and equipment costs across the United States and creates an RSMeans CCI number for selected cities. This CCI is used to compare or adjust costs between locations and a national average. For 2019, the most recent data publicly available, the national average CCI is 3.0. Not all cities have a CCI assigned, but a relatively similar CCI will be selected by county based upon urban and rural considerations.

Cost estimates for treatment equipment and general civil site work will be assigned

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[22] RSMeans City Cost Index
https://www.rsmeans.com/rsmeans-city-cost-index

the national average CCI of 3.0. The California CCI shown in Table 3 will then be applied to adjust Model costs based on each water system's generalized location.

Table 3. RSMeans CCI Selected for Locational Cost Estimating

RSMeans City	Generalized Model Location	RSMeans CCI	Percent Adjustment
National Average	**Central Valley**	+3.0	0%
Oakland	**Urban**	+3.97	+32%
San Jose	**Suburban**	+3.89	+30%

Physical Consolidation Costs

Capital Costs

The cost methodology for physical consolidation is based on previous work, titled Cost Analysis of California Drinking Water System Mergers[23] completed by Corona for the Water Foundation with cost details updated. The costs accounted for in the physical consolidation of systems include:

- The capital costs of pipeline[24] needed to connect systems.
- Connection fees[25] charged by the receiving water system.
- Legal and administrative costs[26] to develop necessary agreements between connecting systems.
- Services lines for systems already within the service area of another system (intersecting systems)
- 20% contingency on the total.

Upgrades, such as back flow prevention, tanks, and metering required by receiving water system are addressed in the other infrastructure needs section. The State Water Board recognizes that further analysis of corrosion control issues, disinfection byproduct formation, and residual degradation will need to be considered on a case by case basis but that it is highly location dependent and thus is out of the scope for this cost model.

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[23] Henrie, Tarrah and Chad Seidel, 2019. *Cost Analysis of California Drinking Water System Mergers*. Water Foundation.
https://waterfdn.org/wp-content/uploads/2019/08/COSTAN1.pdf

[24] Provided by QK, Incorporated, which is an engineering design firm in the Central Valley.

[25] Based on the connection fees of 42 water systems reviewed.

[26] The legal and administrative cost assumption is based on information from an Investor Owned Utility for recent acquisitions in California. No other data or case studies are available.

The cost of physically consolidating systems can vary widely depending on a number of factors. High-level cost estimates have been developed in the context of this methodology leveraging existing California case studies from systems that have accomplished physical consolidation.

The distance along roadways from a joining system to a receiving system was determined using the methodology described in Appendix A. Physical consolidation costs were calculated as the sum of pipeline costs, service line costs, connection fees, and legal and administrative costs for system acquisition, with a 20% contingency. Cost assumptions are included in Table 4.

Table 4. Physical Consolidation Costs

Item	Cost Assumption
Pipeline Cost[1]	$155 per linear foot
Service Line Cost	$5,000
Connection Fees[2]	$6,600 per connection[4]
Legal and Administrative Costs for System Acquisition[3]	$200,000
Contingency	20% applied to total

[1] Provided by QK, Incorporated, which is an engineering design firm in the Central Valley. 12" C-900 PVC main was selected in order to achieve 1,500 gpm flow to accommodate fire flow.

[2] Based on the connection fees of 42 water systems reviewed.

[3] The legal and administrative cost assumption is based on information from an Investor Owned Utility for recent acquisitions in California. No other data or case studies are available. CEQA costs are included in this cost assumption.

[4] For some systems (many state small water systems (SSWS)) population and connection information was not available; for these systems the number of connections was set to eight. The connection fee is based on the average connection fee reported in the 2018 Electronic Annual Report for large systems (3,000 connections or more), excluding connection fees of $500 or less. This resulted in data from 180 systems being included in the average.

An additional construction multiplier will be used to account for engineering, permitting, and other construction costs, such as mobilization and demobilization on each pipeline construction project. The multiplier is still under development.

In the case of elevation changes that would result in a pressure loss over 10 psi, two booster stations will be budgeted: one for fire flow, and another capable of meeting Maximum Day Demand (MDD). Property cost is assumed to be $150,000 for a 100-foot by 100-foot lot. The booster station cost is discussed in the Other Infrastructure Needs section.

Operational Costs

Physical consolidation will result in additional electrical costs due to pumping water to overcome head loss due to pipeline friction and elevation changes. The elevation changes along pipeline routes will be determined, along with the pipeline length. These will be used to estimate the additional electrical costs.

Managerial Consolidation Costs

Managerial consolidation encompasses a spectrum of options, ranging from independent ownership and management with shared contracts for goods and services to common ownership and services for systems that are physically not connected. In many cases managerial consolidation will not eliminate the need for other capital improvements, but it should increase the technical, managerial, and financial capacity of systems to address issues in each system.

Available data on the costs associated with managerial consolidation are sparse. Limited case studies,[27] summarized in Table 5, have been gathered to inform managerial consolidation costs. In the case of a system needing an Administrator, service is assumed to be needed for 5 years, because this is considered an interim solution to assist a system in solving the challenges that it faces. As more systems implement managerial consolidation, more case studies will become available and the cost model will become more informed.

Table 5. Managerial Consolidation Costs

Annual Cost for Administration in a Lower Need System	Annual Cost for Administration in a Higher Need System	Average one time Legal and Administrative Costs for System Acquisition
$12,000 ($60,000 for 5 years)	$60,000 ($300,000 for 5 years)	$200,000

Blending Costs

Based on an analysis of Kern County HR2W systems, blending will not be a feasible modeled solution for a majority of HR2W and At-Risk systems. Forty-eight percent of the Kern County HR2W systems only have one source. Some systems also have contaminant concentrations that make blending infeasible. Out of the 61 systems examined in Kern County, only 12 could consider blending as a potential solution. With this in mind, meaningful costs for blending cannot be developed as part of this methodology due to the following information gaps:

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[27] Two case studies of receivership costs have been provided by the State Water Board. An Investor Owned Utility has provided an average cost for the legal and administrative fees associated with system acquisition in California.

- For water systems with multiple wells, individual well production information is not available in a digitized format for all systems, so the blend ratio cannot be calculated.
- Well locations and the distribution system configuration are not known, so pipeline distances cannot be calculated.
- Information about emergency interties with potential water wholesaler, that could be considered as a blending source, is also unknown.

Although costs cannot be developed at this time for the purposes of the model, blending can be a cost-effective solution for some utilities, and it should be considered in future iterations of the model as Statewide data becomes available.

New Well Costs

Many systems need a new well to replace aging infrastructure or provide reliable production capacity. For the HR2W systems, the Model methodology includes costs for an additional well for systems that only have one source. New wells will be sized to meet MDD in systems with only one existing source in accordance with regulatory requirements for new water systems.[28] Based on the Kern County HR2W systems analysis, detailed in Appendix B, the following assumptions were developed for HR2W and At-Risk Public Water Systems:

- 48% need a second well
- 46% need a replacement well due to well age

Costs, shown in Table 6 for a range of new well sizes and flow rates have been developed by QK, Incorporated, a design-engineering firm located in the Central Valley. Cost for land purchase of a 100-foot by 100-foot lot is assumed to be $150,000. These costs are likely more representative of costs in the Central Valley than more expensive parts of the state. However, a CCI index will be applied based on location, this will make the costs more comparative. Additionally, a 1,000-foot well depth costs will be used in the cost model. In other regions across the state, well costs may be higher, but wells tend to be shallower. Also, in hard rock regions two wells may be required instead of one in order to achieve adequate capacity.

Test holes are assumed to be needed in order to understand the water quality at different depths since contamination is likely present.

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[28] Title 22 California Code of Regulations, 2019. section 64554 (c) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dw_regulations_2019_04_16.pdf

Table 6. New Well Costs

Well drilling		
Depth (feet)	**Test hole drilling and zone sampling (5 zones) cost**	**Production well drilling cost**
500	$120,000	$500,000
1,000	$140,000	$650,000
1,500	$170,000	$770,000

Assumptions:

- Test holes drilled by casing hammer method
- Production well drilling is separate from test hole drilling

Well development	
Estimated production (gpm)	**Cost**
200	$60,000
440	$100,000
780	$140,000
1,000	TBD

Well pump and motor		
Motor size (HP)	**Rated flow (gpm)**	**Cost**
25	85	$125,000
50	170	$135,000
75	255	$155,000
100	340	$165,000
TBD	500	TBD
TBD	1,000	TBD

List of Well Assumptions:

- 1000-foot depth
- Vertical turbine pumps
- Variable Frequency Drive (VFD) equipped
- Discharge pressure of 55 psi
- 20 feet draw down
- 800-foot static water level
- Surface mounted motor
- New power and control connection

Electrical upgrades	
SCADA (cost per site)	**Electrical upgrades (cost per site)**
$100,000	$440,000

Assumptions:

- Main switchboard and motor control center
- Electrical conduit and wire - all equipment on a single 200' x 200' site
- Site lighting
- Transformer slab

An additional construction multiplier will be used to account for engineering, permitting, and other construction costs, such as mobilization and demobilization. This multiplier is still under development.

In some cases, a new well can successfully be installed to avoid the local contaminant of concern and the corresponding cost of treatment. However, newly drilled wells often face the same water quality issue or a different water quality issue requiring treatment. A new well, for the purpose of this methodology, is not assumed to alleviate the need for treatment.

Well Head Treatment Costs

Treatment costs rely on three components: (1) estimating water demand, design and average flow rates, (2) determining the appropriate treatment solution, and (3) developing capital and operational cost details. The following sub-sections describe the methodology for each.

Estimating Water Demand, Design, and Average Flow Rates

The development of suitable water demand approximations for each drinking water system is required for the selection of a successful treatment or non-treatment option. Water demand approximations are especially important when developing capital costs and ongoing operations and maintenance costs. As there will be no site-specific information for the systems included on the HR2W and At-Risk lists, system water demands will be calculated based on the methodology outlined in the *1,2,3-Trichloropropane Maximum Contaminant Level Regulations Initial Statement of Reasons* [29].

An average daily demand (ADD) of 150 gallons/person/day will be applied to the system population obtained from the SDWIS database. This ADD is based on the water usage provided to the California Water Boards by 386 California urban water suppliers in June 2014 with an additional 10% demand (California Water Boards, 2017). This value can be adjusted in the future to better reflect the water usage at that time. A peaking factor of 1.5 will be applied to the ADD to calculate the MDD as stated in the *1,2,3-Trichloropropane Maximum Contaminant Level Regulations Initial Statement of Reasons* and in the California Code of Regulations title 22,

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[29] California Water Boards. (2017). Initial Statement of Reasons 1,2,3-Trichloropropane Maximum Contaminant Level Regulations. Title 22, California Code of Regulations: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/123-tcp/sbddw17_001/isor.pdf

division 4, chapter 16, section 64454.

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 will be calculated by assuming the MDD must be produced during 16 hours of operation. This assumption will result in a 33% increase in capacity for treatment units and back-up wells.

Identifying Appropriate Treatment Solutions

Violation types are determined from the HR2W database. Once a violation is determined, only approaches listed as Best Available Technologies (BAT) in Title 22[30] are considered for treatment. A summary of the BATs for many of the violation types found in the HR2W data are summarized in Table 7 below. Although adsorption is not listed as a BAT for arsenic removal, it is be considered for small systems because of demonstrated performance and ease of operation. Additionally, anion exchange for arsenic removal may be considered for some systems if nitrate is found to be co-occurring.

Table 7. Summary of Drinking Water Best Available Technologies (BATs) for common groundwater violations

Violation Type	Regulatory Limit (MCL)	Chemical Class	Best Available Technology
Arsenic[1]	10 µg/L	Inorganic	Activated Alumina, **Coagulation/Filtration[2]**, Lime Softening[2], Reverse Osmosis, Electrodialysis, Oxidation Filtration
1,2,3-TCP	5 ng/L	Organic	GAC
Nitrate	10 mg/L as NO_3	Inorganic	**Ion Exchange**, Reverse Osmosis, Electrodialysis
Uranium (Combined)	20 pCi/L	Radionuclides	**Ion Exchange**, Reverse Osmosis, Lime Softening[2], Coagulation/Filtration
Fluoride	2 mg/L	Inorganic	Activated Alumina

[1] Adsorption technology, although not listed as a BAT, will be considered for arsenic treatment in small systems because of demonstrated experience and ease of operation

[2] Not considered BAT for systems <500 service connections

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[30] Drinking Water-Related Regulations
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Lawbook.html

With the exception of 1,2,3-TCP and fluoride, each of the violation types shown in the table have multiple BATs. For this methodology, treatment approaches were limited based on the assumption that liquid stream residuals disposal is not available on-site at impacted systems. This assumption eliminates processes like reverse osmosis and electrodialysis 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 impacted systems. Capital and operational costs are developed for the technologies in bold in Table 7, with the exception of arsenic where adsorption was assumed for systems of with less than 500 service connections due the relatively simple operations when compared to coagulation/filtration.

Estimating Water Treatment System Capital Costs

Water treatment solutions vary considerably based upon site-specific considerations. In some cases, water systems that have multiple wells install water treatment systems on only the wells that are impacted by contaminants that pose a threat to human health. In other cases, if multiple wells in a water system are impacted by the same contaminant(s), pumping the impacted groundwater to a centralized treatment facility may be more cost effective. Due to the lack of individual well location data, this methodology cannot develop costs associated with centralized treatment.

The methodology cost models consider the fact that treatment costs are generally non-linear as a function of source capacity where the unit cost of water produced tends to increase as production capacity decreases.

Some of the factors that may influence the capital cost associated with installing new treatment systems include:

- Land that may need to be purchased to accommodate treatment system facilities
- The availability of pre-constructed treatment systems vs. the need to construct customized treatment
- Treatment system capacity requirements
- Complexity of system, if treating multiple contaminants
- Electrical improvements for system operation
- Wellhead improvements to overcome additional head loss

For the methodology, treatment system capital costs were derived from a variety of sources including costs models, peer reviewed articles and manufacturer supplied information. An example of sources used is provided in Table 8 by example contaminant type.

Table 8. Data sources used for the development capital cost estimates

Technology	Contaminants	Data Source	Notes
Granular Activated Carbon (GAC)	Volatile organics and Total Organic Carbon (TTHM, HAA)	Vendor Supplied Quotes	Outputs developed over a range of system sizes, based on commercially available equipment
Anion/Cation Exchange	Nitrate, uranium gross alpha due to uranium, radium, and perchlorate	EPA Work Breakdown Structure[31]; calibrated to recent bid costs	Calibrated to recent bid costs for small-scale treatment systems
Coagulation Filtration	Arsenic, and iron and manganese	Vendor Supplied Quotes	Regressions for costs of coagulation filtration
Surface Water Package Plant	Surface Water Rule Treatment violations	Vendor Supplied Quotes	None
4-Log Virus Inactivation	Surface water and groundwater under the influence of surface water	Vendor Supplied Quotes	None
Adsorption	Arsenic and fluoride	Vendor Supplied Quotes	Regressions for costs of adsorption systems

An engineering multiplier was applied to the treatment equipment capital cost estimates to develop an estimate of the installed capital costs. Due to the varied data sources providing capital cost estimates for a range of equipment with unique installation requirements, the engineering multipliers were modified for each treatment technology. Included in the multipliers are cost estimates for installation of the treatment equipment, general site work, electrical, contingency, and other planning and administrative fees. Installation costs can vary widely depending on the individual site constraints, and these multipliers are only used to provide a Class 5 estimate. Table 9 displays the engineering multipliers used for each treatment technology.

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[31] Drinking Water Treatment Technology Unit Cost Models https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

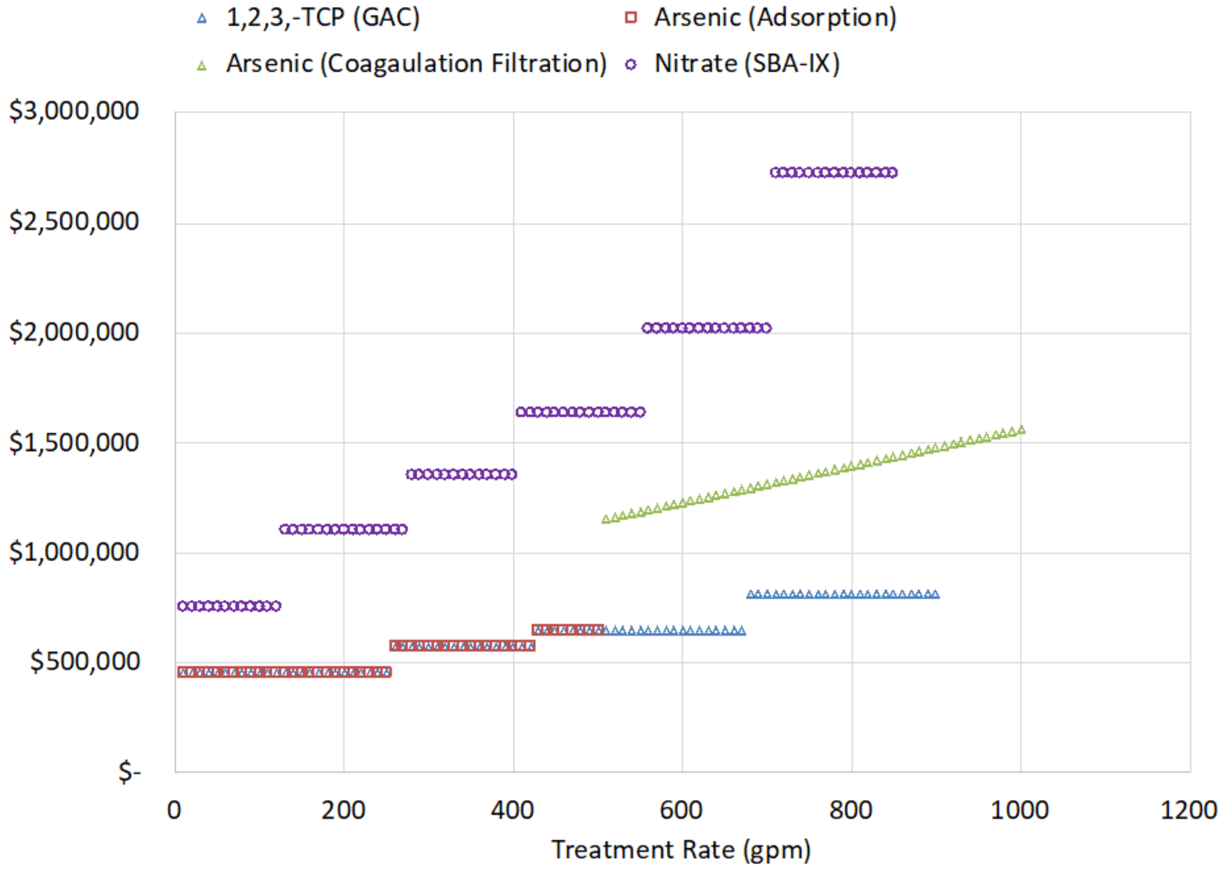
Table 9. Engineering multipliers applied to treatment technology capital costs

Technology	GAC	Anion/ Cation Exchange	Coagulation Filtration	Surface Water Package Plant	4-Log Virus Inactivation	Adsorption
Multiplier	2.36	2.4 to 3.0[1]	2.36	3.06	3.06	2.36

[1] Indirect/installation costs included in the EPA Work Breakdown Structure plus 20% contingency

Appendix D contains the detailed methodology for each capital cost by technology. An example of the resulting treatment costs for the most commonly applied treatment solutions is shown in Figure 10 as a function of flow rate. The treatment approach is shown in parenthesis following the contaminant's name. As described below, the same capital costs were applied for arsenic adsorption and GAC treatment which is illustrated by the overlap of these data series.

Figure 10. Installed treatment capital cost comparison between common contaminants



Estimating Water Treatment System Operation and Maintenance Costs

While capital costs are an important factor to consider in the evaluation of water treatment solutions, it is just as important to have an understanding of the expected annual costs to operate and maintain a water treatment system. Operational costs for consumables are typically driven by the volume of water that requires treatment annually and the expense of having a certified operator oversee the treatment process. Examples of operational costs to be considered will include the following:

- Consumables
    - Chemicals such as ferric chloride, sulfuric acid, caustic soda, etc.
    - Media replacement
        - Granular activated carbon (GAC), ion exchange resin, green sand, activated alumina, other adsorbents, etc.
    - Pre-filter replacement
- Disposal of water treatment residuals
    - Ion exchange brine, coagulation filtration dewatered solids, spent media
- Electricity
- Additional monitoring and reporting
- Labor

Appendix D contains the detailed methodology of the Operational and Maintenance cost by technology. Operational costs have been estimated soliciting costs for consumables including chemicals and media. The cost of water treatment residuals disposal can be more variable. Options available for disposal may vary depending on the volume of residuals that are estimated annually. For this analysis is it assumed sewer access is not available and all residuals will require off-site management. A 20-year operations and maintenance cost will be used to develop a lifecycle cost comparison. Electrical costs were estimated based on the median cost of electricity in California ($0.1646/kWh[32]) and assuming a 10 PSI pressure loss across the system.

An example of relative O&M for different treatment approaches is summarized in Figure 11. Note that the costs displayed only account for consumables and residual disposal as these components are modeled linearly as a function of water produced.

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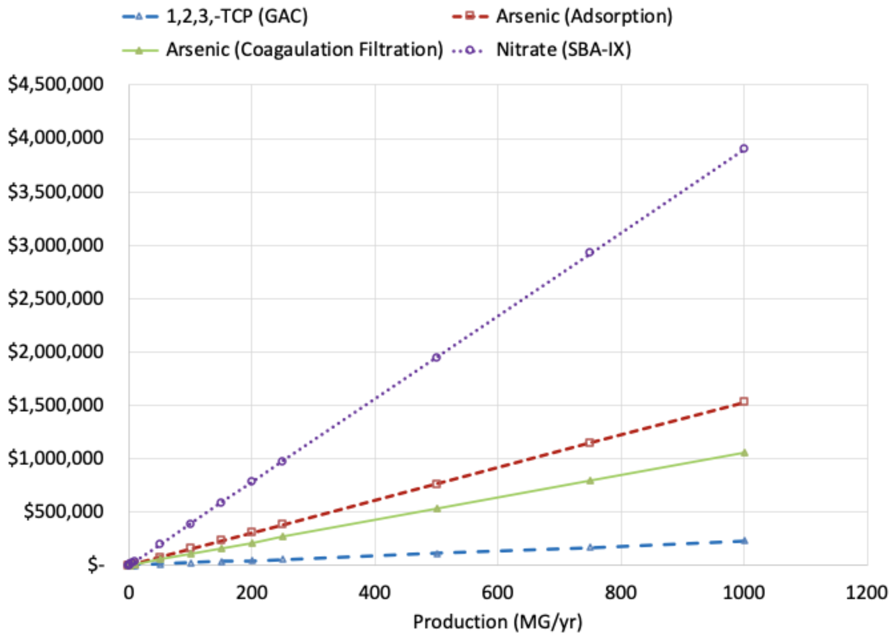
[32] U.S. Energy Information Administration https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

Figure 11. Comparison of annual O&M Consumable and Disposal Costs by Treatment



Operator Labor Costs

Labor costs are included in the estimate based on the average salaries for operators with appropriate certification levels in California as shown in Table 10.

Table 10. Operator salary and benefits by certification levels[33]

Certification Level	Average of Total Pay, including Benefits
T1	$ 97,000
T2	$ 105,000
T3	$ 132,000
T4	$ 164,000
T5	$ 181,000

Operator certification requirements are determined by the DDW, and for this Model operator certification requirements were assumed as shown in Table 11. For budgeting purposes, operator labor cost has been estimated by bins. Costs are

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[33] Transparent California
https://transparentcalifornia.com/salaries/search/?page=20&y=2018&q=treatment+operator&s=-base

Base salaries and benefits from Transparent California were analyzed by Nicholas Chow and Gregory Pierce at the UCLA Luskin Center using 2018 data. Outliers were removed. Labor cost was adjusted to 2020 dollars.

binned by probable operator certification requirement and how much labor is required for each type of treatment. For example, both surface water treatment and nitrate treatment are considered to take 25% of a full-time operator. Surface water treatment is assumed to need a T4 operator, while nitrate treatment is assumed to need a T2 operator.

Table 11. Annual operator labor cost estimate

Certification and Treatment Type	Percent of Full Time	Annual Cost
T4 Surface Water with high levels of source contamination	25%	$41,000
T3 Multiple contaminants with different treatment technologies; Surface Water/Groundwater under the Direct Influence of Surface Water	25%	$34,000
T2 High time intensity treatment (nitrate)	25%	$27,000
T2 Medium time intensity (U, As using CF)	20%	$22,000
T2 Low time intensity (GAC, Fe/Mn removal)	10%	$11,000

Operator labor costs, for many small systems, will be a substantial part of annual operations and maintenance costs. Therefore, operator labor will be kept as a separate line item in the operations and maintenance category for clarity.

Point of Use/Point of Entry Treatment Costs

Point of Use or Point of Entry treatment is considered an option for water systems with less than 200 connections and for domestic wells due to the complexity of monitoring and addressing units with individual residences. As previously discussed, Point of Entry Granular Activated Carbon (GAC) treatment is considered in the case of 1,2,3-TCP, or other volatile organic compounds to address health impacts of breathing the compounds during exposure in the shower. Point of Use treatment is considered for most commonly occurring inorganic contaminants (for example nitrate or arsenic). Point of Use is not recommended for nitrate over 25 mg/L[34] as nitrate or wells with bacteriological problems.

Limited installations of this type of treatment have been completed in California, and the costs are not always clearly documented. The costs of POU and POE treatment have been developed based on projected costs detailed in Table 12 and Table 13. The methodology assumes full replacement of the POU or POE treatment unit at 10 years. The cost for communication for POU or POE treatment is summarized in the next section.

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[34] NSF/ANSI 58 – 2018, *Reverse Osmosis Drinking Water Treatment Systems*. Lists an influent nitrate concentration of 30 mg/L-N to achieve a treated water of 10 mg/L-N in the treated water. A safety factor has been applied to keep the treated water below 10 mg/L-N.

Table 12. Estimated Capital Cost for POE and POU Treatment

Capital Cost per Connection for POE GAC Treatment			
POE Cost per Unit[35]	Installation Labor Cost per Unit ($100/hr)	Admin/Project Man.	Communication Cost
$3,700	$1,000	$1,000	$300
Capital Cost per Connection for POU Reverse Osmosis Treatment			
POU Cost per Unit[36]	Installation Labor Cost per Unit ($100/hr)	Admin/Project Man.	Communication Cost
$1,500	$200	$1,000	$300

Note: For Domestic Wells and State Small Water Systems an additional initial analytical budget of $500 is included because these wells rarely have water quality data.

Table 13. Estimated Annual Operations and Maintenance (O&M) for POE and POU Treatment

POE GAC Annual O&M per Connection			
Prefilter and GAC Replacement (2x/year)[37]	Operator and Communication Labor ($100/hr)	Analytical ($125 2x/year)[38]	Total
$410	$300	$250	$960
POU RO Annual O&M per Connection			
Prefilter and Membrane Replacement (2x/year)[39]	Operator and Communication Labor ($100/hr)	Analytical (2x/yr)[56]	Annual Total
$100	$300	$40 - $110	$440 - 510

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[35] Based on costs of available POE treatment units in California.

[36] Porse, Erik, 2019. Sacramento State Office of Water Programs. Unpublished. Also used in the interim solutions cost part of the Needs Assessment project completed by Gregory Pierce at UCLA. Corona added operator labor costs and analytical costs on an annual basis.

[37] Based on vendor recommendations and pricing.

[38] Pricing quotes provided by BSK Analytical, in Fresno, California.

[39] Based on vendor recommendations and pricing, with freight.

Considerations Beyond Construction of Water Treatment Facilities

Many of the HR2W and At-Risk Public Water Systems have additional infrastructure needs. For instance, a system may not have enough storage to meet MDD, thereby requiring a storage tank to alleviate the problem. With this in mind, examples of needs for which high-level cost[40] estimates that have been developed are shown in Table 14.

Table 14. Other infrastructure costs

Pipelines C-900 PVC		
Pipeline diameter	Cost per foot	Rated flow (gpm)
4"	$75	195
6"	$90	440
8"	$100	780
12"	$140	1750

Assumptions:
- 3 feet burial, C900 pipe
- Open trenching (add $15/LF for asphalt replacement)
- Maximum velocity of 5 fps

Hydro-pneumatic tanks	
Volume (gallons)	Cost
2,000	$35,000
4,000	$41,750
10,000	$62,100

Assumptions:
- Gross Volume (water storage volume roughly 50% of gross)
- Includes top mounted air compressor

Ground level tanks	
Volume (gallons)	Cost
50,000	$150,000
100,000	$250,000
250,000	$500,000
500,000	$875,000
1,000,000	$1,200,000

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[40] Costs for the major capital improvements provided by QK, Incorporated, which is an engineering design firm in the Central Valley.

Assumptions:

- Bolted steel
- Ring wall base
- No corrosion protection

Booster pump systems (one operational and one standby)

Capacity (gpm)	Motor size (HP)	Cost
100	5	$40,000
200	10	$70,000
300	15	$82,000
400	20	$100,000
500	25	$115,000
750	35	$130,000
1,000	60	$150,000

Assumptions:

- VFD Package system - skid mounted with PLC and controls
- Piping and valving between pumps included
- Electrical costs not included
- Discharge pressure of 55 psi assumed

Well pump and motor replacement

Motor size (HP)	Rated flow (gpm)	Cost
25	85	$125,000
50	170	$135,000
75	255	$155,000
100	340	$165,000

Assumptions:

- 1,000-foot depth
- Vertical turbine pumps
- VFD equipped
- Discharge pressure of 55 psi
- 20 feet draw down
- 800-foot static water level
- Surface mounted motor
- New power and control connection

Electrical upgrades

SCADA (cost per site)	Electrical upgrades (cost per site)
$100,000	$440,000

Assumptions:

- Main switchboard and motor control center
- Electrical conduit and wire - all equipment on a single 200' x 200' site
- Site lighting
- Transformer slab

Generators

Size (KW)	Rated flow (gpm)	Cost
5	18	$50,000
30	110	$64,000
50	180	$80,000
75	270	$110,000
100	365	$160,000

Assumptions:

- Sized with 25% reserve
- Based on powering well pump based on the assumptions above
- Power to booster pumps and ancillary equipment
- Diesel generators
- Automatic transfer switch

Residential Water Meters

Equipment and Software (drive by)	1" meters (drive by)
$29,000	$825

Assumption:
Installation on an existing service

All costs include:

- Shoring
- Storm Water Pollution Prevention Plan
- Prevailing Wage
- Associated taxes and delivery

Costs do not include:

- Land acquisition
- CEQA
- Permitting with PGE or SCE
- Engineering, design, permitting
- Mobilization/demobilization

The costs that are not included above (for example CEQA, permitting, and engineering) will be handled with a construction multiplier that is still under development.

The information gathered during the review of limited data in the sanitary surveys for HR2W systems in Kern County have been used to identify additional costs that should be expected for other challenges that HR2W and At-Risk systems may be experiencing. The following assumptions for additional infrastructure needs will be applied to HR2W Systems:

- 48% need a second well
- 46% need a replacement well due to well age
- 29% need pump and motor replacement due to age
- 29% need electrical upgrades due to age
- 56% need additional storage
- 58% need back up power
- 66% need distribution system replacement due to main age
- 82% need meters

Appendix B contains the details of the Kern County analysis and how these assumptions were derived.

Assumptions for At-Risk Water Systems

At-Risk water systems are expected to have a variety of technical, managerial and financial capacity issues in addition to significant infrastructure needs. At-Risk systems will be evaluated for physical consolidation. Where physical consolidation is cost-effective, particularly as part of a regional project that cost will be utilized.

Where physical consolidation is not an option, cost estimates will be developed by combining managerial and financial support through the costs previously developed for administrator costs, in Table 6 -- Managerial Consolidation combined with the infrastructure support needs applied to the HR2W systems previously discussed.

The managerial and financial support from Table 6 would include $12,000 per year for 5 years, representing a lower need system. The funding would be designed to assist water systems in developing the financial and managerial structures to ensure a sustainable water system, including asset management plans, water rate studies, fiscal policies, drought plans, etc.

Additionally, the following “additional infrastructure needs”, similar to HR2W systems, would be applied to these systems:

- 48% need a second well
- 46% need a replacement well due to well age
- 29% need pump and motor replacement due to age
- 29% need electrical upgrades due to age

- 56% need additional storage
- 58% need back up power
- 66% need distribution system replacement due to main age
- 82% need meters

The combination of updated infrastructure combined with long-term managerial and fiscal policies would help elevate affordability issues and preventatively address the needs of these water systems before expensive emergency responses are necessary. Implementation of rate structures and fiscal policies to ensure repair and replacement of any installed infrastructure upgrades, funded by State grants, is anticipated to be a funding requirement. Therefore, long-term O&M was not included in the cost estimate.

Additional general assumptions used:

- 100% of wells at schools that may use physical consolidation as a solution will be assumed to be destroyed. Some schools may decide to use the contaminated well for irrigation. There is significant cost associated with separating a potable water system from an irrigation system.
- 100% of systems identified for nitrate treatment will have SCADA.
- Many of the systems with some storage are counting small pressure tanks. We have assumed that any system needing storage will need a tank sized to meet MDD.
- For main replacement costs we are assuming a 4-inch PVC main, and that each customer connection is associated with 80 feet of main, along the property fronts.
- For residential connections 1” meters will be assumed, and for non-residential connections, such as schools, 1.5” meters will be assumed.

Backflow prevention assemblies should be installed to protect customers from backflow events. Many water systems require the business owner to pay for the installation and testing of backflow prevention assemblies. However, in economically disadvantaged areas, the water systems may need to consider paying for the assemblies to avoid undue hardship on businesses. Costs for backflow prevention assemblies are summarized in Table 15. Only smaller sized assemblies have been included because larger connections are generally associated with bigger businesses that are not as common is small water systems. We will assume that backflow prevention assemblies need to be installed at all non-residential connections, such as schools. The cost of annual testing will be assumed to be the responsibility of the customer.

Table 15. Backflow prevention assembly costs

Size	Total Cost
3/4"	$ 5,840
1"	$ 6,090
1 1/4"	$ 7,000

Size	Total Cost
1 1/2"	$ 7,080
2"	$ 7,710

Costs courtesy of Ben Bennet, owner of Backflow Prevention Specialists, Inc., in Sunnyvale, CA

Costs included: labor, material, testing, and taxes.

Costs excluded: fees charged by water systems for shutting off water, permit fees, as built drawings, or any blueprints, water system hydraulic calculations.

Step 5: Select Solution for Fund Expenditure Plan Purposes

Once the Cost Assessment Model assesses the long-term sustainability and reliability of the potential modeled solutions in conjunction with costs, a final modeled solution will be selected for the system or domestic well. This selected modeled solution is only for the purpose of developing an overall projected budget need for the State, does not dictate the solution that a system will select to achieve compliance and long-term resiliency. The ultimate solution that will be implemented should involve more detailed investigation of each water system and should include the input of the community and other stakeholders.

Step 6: Roll-up of Estimated Costs

The estimated costs of the selected solutions for HR2W systems, At-Risk public water systems, tribal water systems, state small water systems, and domestic wells will be aggregated into a statewide cost estimate. This cumulative statewide cost estimate is meant to provide a broad overview of the potential projected demand for the Safe and Affordable Drinking Water Fund. The aggregated cost estimate will be conducted annually and will be included in the Fund Expenditure Plan.

Step 7: Identify Funding Needs and Funding Gap

Although the SAFER Program has been allocated up to $130 million and year for ten years. It is anticipated that it will not be sufficient to address all of the issues identified by the Need Assessment. Therefore, Pacific Institute, a subcontractor to the UCLA contract is developing an approach to (1) evaluate the funding alternatives available for both interim and long-term solutions identified by the Cost Assessment Model and (2) estimate the gap between the funding potentially available and the amount needed over time. These tasks will help the State Water Board inform future Fund Expenditure Plans and be used to communicate the SAFER Program’s funding needs to decision makers and stakeholders.

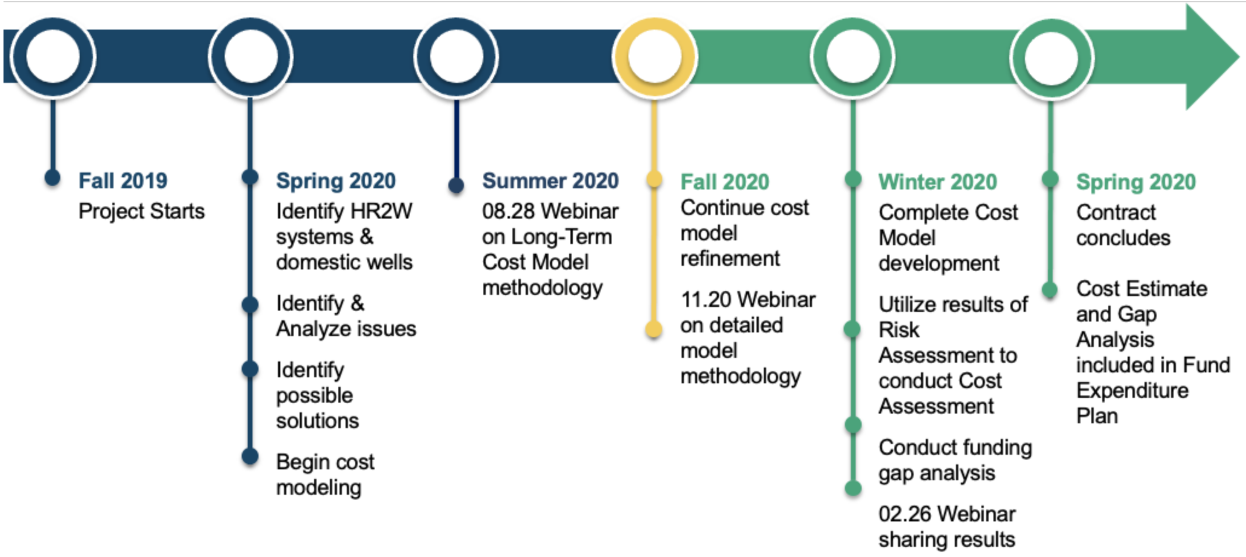
To accomplish these tasks, the Pacific Institute is, first, compiling a list of state, federal, and private funding options potentially available to support the modeled solutions for HR2W systems and At-Risk systems. Second, the Pacific Institute is designing a process to efficiently match identified solutions with potential funding sources and to prioritize matches to ensure that the available funds address the greatest need. Third, the amount of potential funding needed will be compared to the amount of funding available, over time.

Current Status and Next Steps

Figure 12 provides a summary of the development timeline. The Cost Assessment Model will be completed by the first quarter of 2021. The treatment cost models are currently undergoing quality assurance and quality control review. Estimated costs for non-treatment items are anticipated to be developed and reviewed in September 2020; they will then be incorporated into the existing cost models. In the last quarter of 2020, work will continue on the physical consolidation analysis, and the cost models will be applied statewide for the most up-to-date list of HR2W systems and domestic wells. In December 2020, the list of water systems that are considered At-Risk is anticipated from UCLA and the sustainability and resilience assessment from Sacramento State. After the list of At-Risk systems is received, the solutions cost estimates will be completed for those systems.

At the conclusion of this project, the methodology and data developed will be used by the State Water Board's Needs Analysis Unit to update the 2021-22 Fund Expenditure Plan. Moving forward, the State Water Board will continue to refine the Cost Assessment Model through a stakeholder-driven process.

Figure 12. Long-Term Costs Assessment Model Development Timeline



Appendix A – Geographic Information System and Database Methodologies

GIS Methodology

Table A1 provides a list of data sources for water system locations, boundaries, compliance status and economic status estimation that have been identified for use in the GIS effort. At this time, we have identified and gathered data for 9,802 water systems.

Table A1. Data Sources for GIS Analysis

Dataset	Source Agency	Original Feature Count	Notes
Human Right to Water[41]	State Water Board	3,279	Compliance status, analyte data
Monterey County SWS Out-of-Compliance 2019 03	Environmental Justice Coalition for Water (EJCW)	233	Merged with Human-Right-to-Water compliance data
California Census Block Groups[42]	U.S. Census Bureau Tiger/Line Shapefiles	23,212	GIS polygon data
Median Household Income 2013-2017 California Block Group[43]	U.S. Census Bureau American Fact Finder	23,213	Joined to block groups to provide DAC statuses. Includes average MHI data for 2013-2017.

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[41] Human Right to Water
https://www.arcgis.com/apps/MapJournal/index.html?appid=143794cd74e344a29eb8b96190f4658b

[42] US Census Bureau-Current Block Group
https://catalog.data.gov/dataset/tiger-line-shapefile-2016-state-california-current-block-group-state-based

[43] US Census Bureau-Median Household Income
https://data.census.gov/cedsci/table?q=B19013&tid=ACSDT1Y2018.B19013&hidePreview=false

Water System or Domestic Well Locational Data			
Dataset	**Source Agency**	**Original Feature Count**	**Notes**
California Water System Service Areas[44]	Tracking California	4,696	Waters system boundaries
RCAC Small Water Systems[45]	Rural Community Assistance Corporation (RCAC)	1,132	Merged with California Water System Service Areas
Monterey County Revised Water System Boundaries[46]	State Water Board staff	6,676	Multiple parcel features per system. These corrected boundaries were used in the physical consolidation analysis.
Monterey County Small Water Systems[47]	Environmental Justice Coalition for Water (EJCW)	2,935	Merged with California Water System Service Areas
Water System Well Locations[48]	State Water Board's GAMA Program	22,672	Used to better locate Human Right to Water Systems without accurate boundaries
Domestic Well Locations and Modeled Water	State Water Board's GAMA Program	347,592	Domestic wells by square mile section and modeled water quality

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[44] Tracking California Water Boundary Tool used for Water System Service Areas was retried on July 1, 2020.
https://trackingcalifornia.org/water/map-viewer

[45] RCAC Small Water System dataset contains information from the following counties; Colusa, Contra, El Dorado, Fresno, Glen, Humboldt, Kern, Kings, Lake, Mariposa, Merced, Mono, Nevada, Plumas, Riverside, San Bernardino, San Diego, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Shasta, Solano, Sutter, Tulare, Ventura and Yolo counties. Unpublished.

[46] Provided by William Allen with the Board. Unpublished.

[47] A pdf version of the map can be viewed at Monterey County Water System Quality
https://www.co.monterey.ca.us/home/showdocument?id=67378

The GIS data was provided by EJCW. Unpublished.

[48] GAMA Groundwater
https://gamagroundwater.waterboards.ca.gov/gama/gamamap/public/Default.asp

Dataset	Source Agency	Original Feature Count	Notes
Quality[49]			from the Needs Analysis GAMA Tool
Building Footprint Method Water System Boundaries [50]	Pacific Institute	56	Revised boundaries based on where buildings are within a system. Used in selected situations for the physical consolidation analysis.

Water System Locations and Boundaries

To support cost estimates based on potential pipeline lengths and other factors, the accuracy of water system locations and service area boundaries is important. Where available, more detailed estimates of water system locations, especially for small systems, and boundaries have been integrated into the water systems dataset.

Water system boundaries from the California Water System Service Areas serve as the starting point for this dataset. However, this dataset does not include locations or boundaries for most small systems. To incorporate small systems, multiple small system datasets have been mined, merged and joined with the California Water System Service Area dataset. As needed, the small systems have been located in GIS using the Groundwater Ambient Monitoring and Assessment (GAMA) Program Groundwater Information System's Groundwater Well Locations dataset based on water system identification, or reverse geocoded to addresses provided from the raw sources. State small water system locational data from a recent RCAC project was incorporated. Data was not available for all counties, and the data was provided in a variety of formats. Domestic well locational data is only available as a count per square mile. Each dataset has limitations and inaccuracies and pending improvements to the locations of water systems and boundaries will increase the accuracy of future analyses. These data, summarized in Table A1, have been integrated into the final water systems data layer.

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[49] Needs Analysis GAMA Tool https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=292dd4434c9c4c1ab8291b94a91cee85

[50] Shimabuku, Morgan, 2019. Pacific Institute. *Boundary Refinement Methods and Notes*. Unpublished.

Building Footprint Methodology for Refinement of Water System Boundaries

Excerpted from Pacific Institute Methodology:

Objective: To adjust water system boundaries (shapefile) so that the boundaries are reflective of the extent of each system's existing infrastructure.

Assumption: This analysis is based on the assumption that in some cases, system boundaries mapped in the California Water System Boundary Layer extend beyond the actual system distribution infrastructure such as water mains. Clipping water system boundaries to the extent of extant buildings (commercial or residential) within their jurisdiction provides a more conservative estimate of the extent of system's distribution system. This approach will allow us to flag cases where the distance for a physical consolidation may in fact be much greater than indicated using reported system boundaries. Unfortunately, this approach is only useful for identifying large unbuilt areas within system boundaries and flagging them as potential overestimates. We are unable to identify a) misleading system boundaries in heavily built areas, and b) system boundaries that are smaller than the actual extent of system distribution infrastructure.

Data/Files Used

- Polygon shapefiles of 32 small systems (J_Bounds selection.shp, renamed SmSystQuarterMile.shp) and 20 large systems (R_Bounds selection.shp, renamed LrgSysQuarterMile.shp) from Corona.
- GeoJSON file of all building footprints in the state of California, created by Microsoft Bing: USBuildingFootprints (https://github.com/microsoft/USBuildingFootprints). 10,988,525 individual buildings included. Data vintage: variable. No dates provided, but publication date was late 2018.

Data processing steps (All performed in ArcGIS Pro 2.4.2)

1. Converted GeoJSON to ArcGIS feature class, polygon shapefile. Tool: Json to Feature Class. Input: California.geojson
   Output: CA_BuildingFootprints.shp

2. Clipped CA_BuildingFootprints.shp to both the large and small system shapes. Tool: Clip.
   Input: CA_BuildingFootprints.shp
   Output: SmSysBFClip.shp and LrgSysBFClip.shp
   a. This step was to ensure that only building footprints within the water system boundaries would be used in the analysis.

3. Created a random raster with 0.03 mi x 0.03 mi cells covering the extent (i.e., bounding geometry) of the LrgSysQuarterMile.shp. Tool: Random Raster.
   Input: no input file
   Output: raster6

Other settings: Distribution = Integer, Min = 1, Max = 100, Cell Size = 0.0006

4. Clipped raster6 to the large water system geometries. Tool: Clip Raster.
   Input: raster6 & LrgSysQuarterMile.shp
   Output: raster6_ClipLrg1 & raster6_ClipLrg2 (difference is that one ran with "maintain clipping extent" checked and the other without it checked. Both still have some gaps between the large system boundaries and the cell boundaries, but overall, they match well).

5. Converted the rasters to polygon shapefiles to allow for additional geoprocessing (i.e., join). Tool: Raster to Polygon.
   Input: raster6_ClipLrg1 & raster6_ClipLrg2
   Output: LrgSysRasterCovg.shp & LrgSysRasterCovg2.shp
   Other settings: unchecked "simplify polygons" & "create multipart features"

6. Joined features, new polygons and building footprint clips to identify which cells in the new polygons intersected with building footprints (i.e., SmSysBFClip.shp and LrgSysBFClip.shp from Step 2). Tool: Spatial Join.
   Input: LrgSysRaterCovg.shp
   Join Features: LrgSysBFClip.shp
   Output: LrgSysRasterBFJoin.shp
   Other settings: Operation= one to many, unchecked "Keep all target features," match option= intersect, search radius = 150 ft.
   a. Did not do with small systems because BFs in small systems essentially cover entire area.
   b. Note: the 150 ft search radius effectively "adds" 150 ft of a buffer around each 0.03 mi x 0.03 mi polygon that intersects a building footprint.

7. Dissolved cells of LrgSysRasterBFJoin.shp to create a seamless polygon feature for each water system. Tool: Dissolve
   Input: LrgSysRasterBFJoin.shp
   Output: LrgSysRasterDissolve.shp
   Other settings: Dissolve field = Join_Count (had values of all 1), checked "multipart feature"

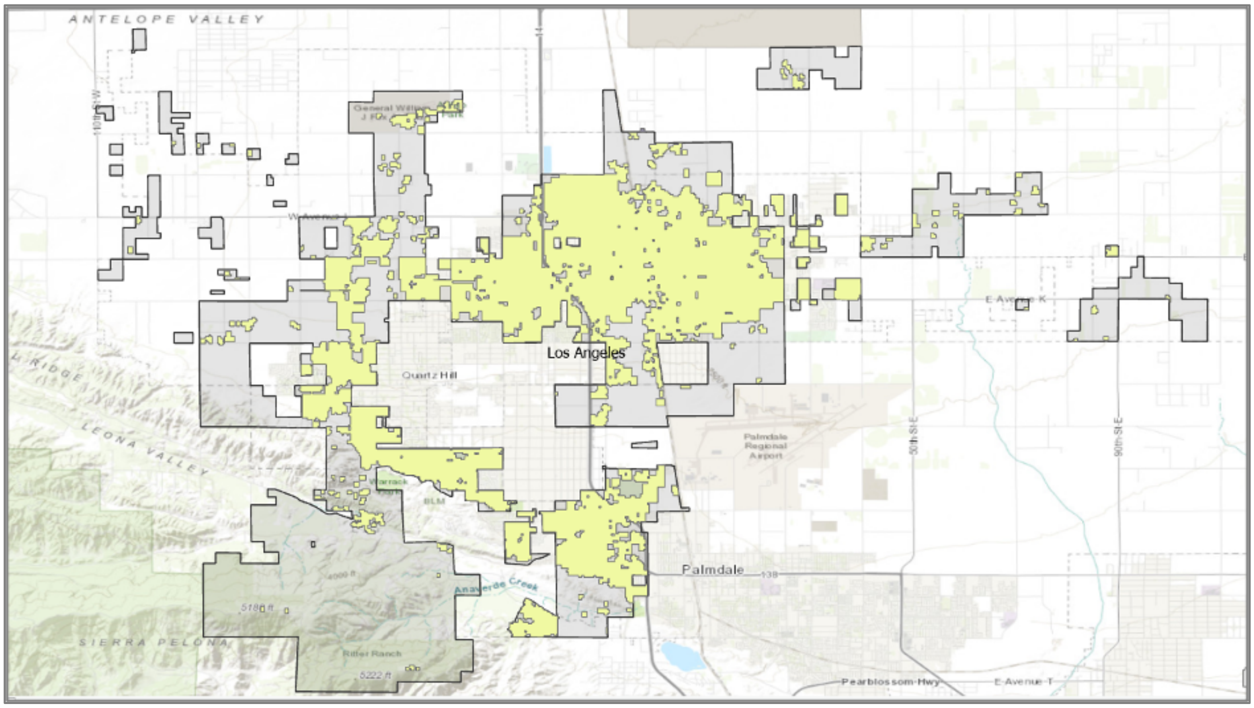
8. The dissolve tool created a single, multi-part polygon, so no data was maintained on individual water systems. To re-distribute the single polygon multi-part polygon to the 20 different large water systems, LrgSysQuarterMile.shp was clipped with the LrgSysRasterDissolve.shp. Tool: Clip
   Input: LrgSysQuarterMile.shp
   Clip Features: LargSysRasterDissolve.shp
   Output: LrgSysRasterDissolve_Clip1.shp
   a. This final shapefile now contains 20 separate multipart features that each retain the attributes of the large water systems (e.g. name,

county, address, etc.).

Outcomes

- The final shapefile created, LrgSysRasterDissovle_Clip1.shp, will be useful for updating the distance analysis between small potential joining systems and potential consolidating large systems.
- The LrgSysRasterDissolve_Clip1.shp contains multipart features (i.e. a "single" polygon and its corresponding attributes are connected to two or more individual polygons, see Figure A1, below). Note that the original Large System polygon shapefile from Corona (LrgSysQuarterMile.shp) also contained multipart features for systems with noncontiguous service areas.
- The multipart polygons may pose a challenge to assessing the extent of water system infrastructure because infrastructure may exist in between two or more physically separated polygons that are part of the same system. This should be considered when performing additional analyses with the updated water system boundary shapefiles.

Figure A1. Los Angeles CO WW Dist 4 & 34-Lancaster polygons. The grey, transparent polygon is the original large water system polygon (LrgSysQuarterMile.shp) and the yellow, opaque polygon are the areas within that polygon that contain building footprints (LrgSysRasterDissolve_ Clip1.shp)



- Spot-checking between the 32 joining small systems and the 20 potentially receiving large systems indicates that the small systems are all still within 0.25 miles of a large system, along roadways. This is likely because many of the small systems in this shapefile are completely contained within the larger system already and so boundary changes did not often impact the distance. If the new system boundaries are used to re-analyze the distance between small systems that were originally found to be greater than 0.25 miles to 3 miles from large system boundaries, there may be more changes to the distances calculated.

Physical Consolidation GIS Methodology

Using "Network Analysis" in GIS, the shortest path along roadways from a Joining system to the nearest Receiving system was determined.

General assumptions for consolidation include:

- < 1 mile is favorable, 1 – 3 miles may be possible, and > 3 miles is not feasible for consolidation
- 1000-foot buffer was added for each path
- 1000-foot buffer was added for systems that intersect with an existing receiving system boundary
- For SSWS pickups (routes and intersects)
  - Maximum distance to merger route = 0.38 mi (~2000 ft)
  - No addition of 1000 ft for route or intersect
- Regional solutions consider up to 3 miles for both SWS and SSWS

Steps to perform and/or update the analysis are included in detail below.

- Software requirements
  - ArcGIS Pro
  - Network Analysis Extension
  - Street Map Premium for California
- Update location information, boundaries, and system attributes (e.g., population, connections, compliance status, system type)
  - The boundary file and associated attributes used in this analysis were compiled from multiple sources
    - Tracking CA boundaries
    - GAMA DDW PWS Well locations plus DDW Siteloc
    - EPA SDWIS Active CA systems
    - HR2W OOC, RTC, IC
    - RCAC and County datasets for SSWS
  - Any improvement to water system boundaries should be included in the ca_system_layer shapefile
  - Any new systems should be added including all relevant data fields (e.g., name, pwsid, population, connections, system type…etc.)
  - Compliance information should be updated from the HR2W dataset
  - System type should be included from EPA SDWIS, HR2W, DDW data sources, or any other available source
  - Population and connections should be updated from the DDW database, if available, otherwise from EPA SDWIS, or any updated

files from other sources (e.g., population and connection information is included in RCAC data for most counties). If either population or connections is blank/null, set to 0.

- For any system with a PWSID, County is populated based on the County code in the PWSID number. For any system without a PWSID for which location information is available, County is populated based on a spatial join with California County boundaries
- ClassID is populated as follows:
  - Population > 3300 = NON-SWS
  - Population < 3301 = SWS
  - Population < 26 and Connections < 15 = SSWS
- PWSID_Name field is filled in concatenating PWSID + ” “ + the system name (this is because some systems (e.g., SSWS) do not have PWSIDs and must be identified by system name).
- Based on the updated population, connection, and compliance information, potential receiving and potential joining systems are selected from the fully updated ca_system_layer
  - Receiving system criteria: CWS, population > 3300, HR2W IC/RTC
  - Joining system criteria: All system types, population <= 3300, includes SSWS
  - Repair polygons: [Toolbox: Repair geometry]
- Develop Inputs for the ArcGIS Pro Network Analysis Closest Facility
  - Receiving systems:
    - Boundary layer from ca_system_layer based on above criteria
    - Facilities layer from intersection of Receiving Boundary layer with roads layer
    - Intersect the boundaries with the road 1k layer, then explode multipoint to get all the points (edit, features, modify, modify features, divide, explode)
  - Joining systems:
    - Boundary layer from ca_system_layer based on above criteria
    - Incidents layer from centroids/point locations of Joining Boundary layer. Add CentroidX and CentroidY fields (double) to attribute table, then [Toolbox: Calculate geometry attributes], then export as table and display XY data
- Prior to performing the network analysis to find the shortest path between receiving and joining systems, INTERSECTING systems need to be identified.
  - Check for any Joining systems that intersect with Receiving system boundaries.
  - Spatial join was used to find any points within boundaries, pulling the PWSID_Name of each system, then, in the intersection layer, delete any null matches.
  - Move these to the potential consolidation list and remove them from the closest facility analysis incidents layer (since these joining systems are within a receiving system boundary, we do not want to include

        them in the path analysis).
        - To delete the intersecting small systems in the incidents layer (to exclude from the closest facility analysis), select by location with boundaries and delete from the incidents table.
- Network Analysis
    - Using Facilities/Receiving systems and Incidents/Joining systems layers from above (with intersecting Joining systems removed).
    - Make sure Analysis tab → Network Analysis → Drop-down Network Data Source: Should be Routing_ND (North America geodatabase)
    - Analysis → Network Analysis → Closest Facility
    - Mode: Change from Driving time to Driving distance
    - Change Travel Settings properties (the small arrow lower right of the Travel Settings section of the menu bar)
        - Costs → change km to mi
        - Restrictions → Adjust as needed. Unchecked avoid private roads, avoid unpaved roads, under construction prohibited, and through traffic prohibited.
    - Cutoff: 3 (miles)
    - Import Facilities – Receiving System points that intersected with 1k Roads: selected 500 ft search tolerance, select PWSID_Name for Name (this is how the system will be identified once the analysis is complete)
    - Import Incidents – Joining Systems: used 2000 ft search tolerance with 7550 located
    - FOR ALL IMPORTS MAKE SURE Name is set to the water system id or PWSID_Name as specified above. This is needed to identify which systems are associated with each route.
    - For first file import of facilities (and again for incidents), uncheck append (then make sure append is checked for the second layer if using more than one layer for facilities or incidents).
    - Then hit “Run” and once complete, the routes layer can be exported and results can be analyzed in Excel, for cost estimations, etc.
- Additional notes:
    - Note on wholesalers: Inclusion of wholesalers with a population of at least 3,300. We had discussed removal of wholesalers; however, systems marked as wholesalers in the EPA SDWIS data were not specifically removed. This was because some regular water systems were also marked as wholesalers, so removal of wholesalers would exclude systems that should be included. Many wholesalers are listed with a population of 0 or 1, so they were ultimately removed by the population screening for receiving systems (minimum population of 3,300 people). Systems identified as wholesalers in SDWIS data WITH population < 25 were removed--> removed 24 systems. AVEK was separately removed as a potential receiving system in Kern County; this is a wholesaler that was not screened out by population.
- SSWS Pickups

    - Remove SSWS direct routes from the All SWS scenario
    - Generate points along routes
    - Perform network analysis as above
        - Facilities: Points along “Receiving path” – either AllSWS (excluding SSWS) or HR2W
        - Incidents: SSWS (non-intersects)
        - Maximum distance: 0.38 mi (~2000ft)
- To convert multiple branching routes to one continuous route to a Receiving system
    - Copy the Routes layer → include Receiving system ID and any other details about the merging systems
    - Use the Integrate tool to merge any overlapping routes that are not perfectly overlapping→ XY tolerance of 10 feet
    - Use the Dissolve tool to merge the single lines into one line
        - Dissolve Field (to aggregate) = R_PWSID
        - Statistics Fields
            - J_ID Count
            - Ttl Mile Sum
            - J_conn Sum
            - J_pop Sum
        - CHECK “Create multipart features”
        - Uncheck “Unsplit lines”
        - Provides distance per receiving system for regional solutions.
    - This results in routes merged by Rpwsid, but each merged route (of overlapping route) has its own distance.--> Add new field CalcNewLen and Calculate Geometry to get updated merged path distance.
    - THEN do a spatial join of J systems from CA_Routes with new merged routes and created a field in CA_Routes that has the object id of the new merged route. This way we can link all the J systems to the correct merged cluster route.
- For identification of clusters
    - Density based clustering, within 0.38 miles

Identification of At-Risk Domestic Wells and SSWS

The GAMA Needs Analysis Tool[51] was developed by the Division of Water Quality Groundwater Ambient Monitoring and Assessment (GAMA) Unit of the State Water Resources Control Board to identify at-risk domestic wells and state small water systems.[52] The dataset includes the domestic well count in one square mile

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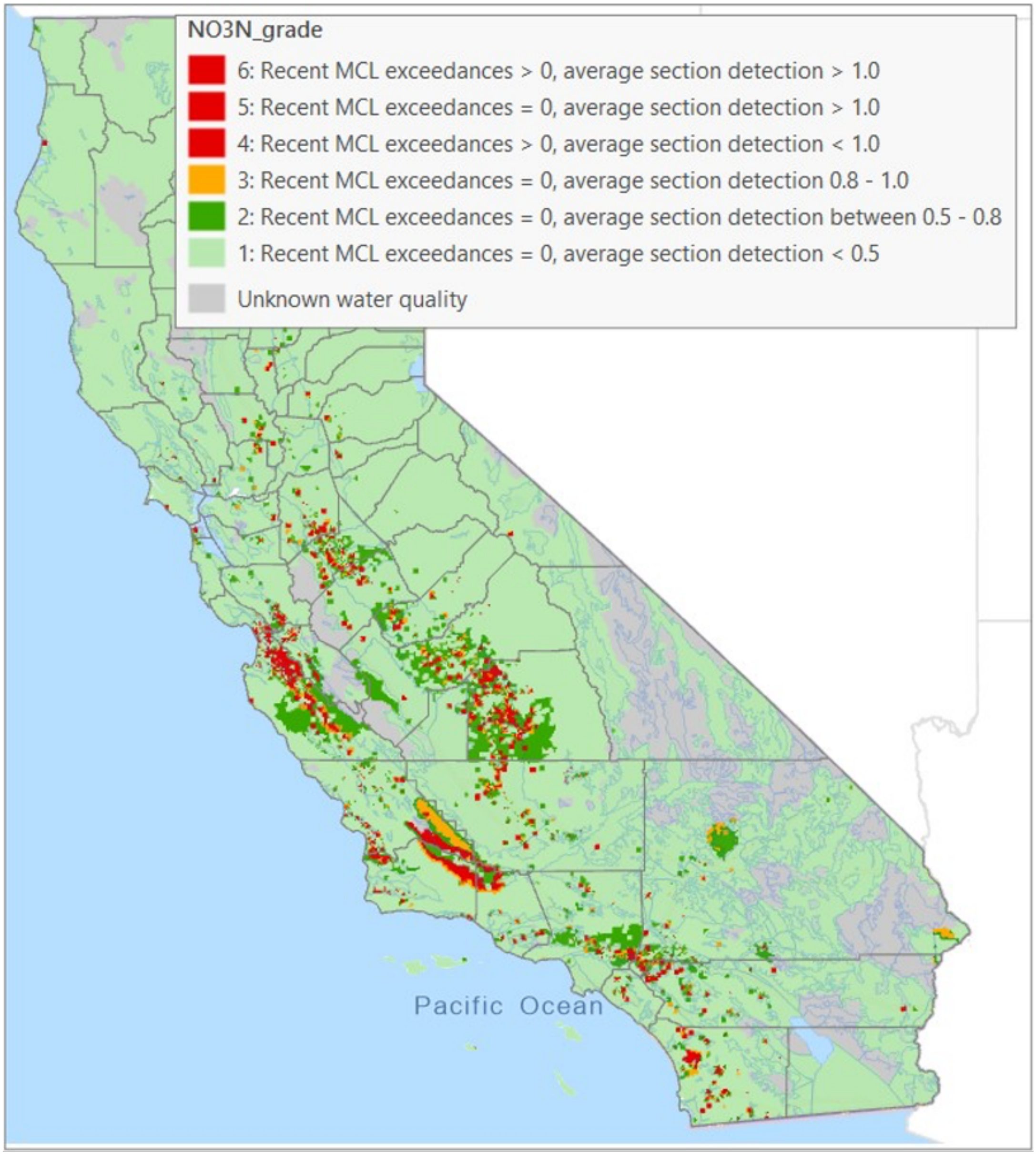
[51] State Water Resources Control Board. (2020). Needs Analysis GAMA Tool. GAMA Groundwater Ambient Monitoring and Assessment Program. https://gispublic.waterboards.ca.gov/portal/apps/webappviewer/index.html?id=292dd4434c9c4c1ab8291b94a91cee85

[52] State Water Resources Control Board. (2020). Methodology to Estimate Groundwater Quality Accessed by Domestic Wells in California, Draft 2/14/2020. Division of Water Quality, Groundwater Ambient Monitoring and Assessment Unit.

sections by Public Land Survey System (PLSS) sections from Department of Water Resources Online System of Well Completion Reports. Water quality information for nitrate, arsenic, hexavalent chromium, uranium, 1,2,3 trichloropropane (123-TCP), and perchlorate was downloaded from the GAMA tool to assess the incidence of these contaminants individually and as co-contaminants. This water quality information informs the assessment of costs for POU and POE treatment systems needed for impacted domestic wells and SSWSs.

The GAMA tool provides water quality data by grade based on the ratio of the average section detection to the MCL for a given constituent; the water quality grades also factor in MCL exceedances. For example, nitrate grades by PLSS section are mapped Figure A2.

Figure A2. Map of GAMA Needs Analysis Tool nitrate grade



Database Methodology

The database houses all relevant data for the project, including information required for and generated by the GIS and cost evaluation efforts. The database is a PostgreSQL (Postgres) database managed using pgAdmin, an open source administration and development platform for Postgres. The open source software R for statistical computing is used as needed for data analysis and formatting data tables ahead of uploading to the PostgreSQL database. The following sources have been incorporated into the database:

- Safe Drinking Water Information System (SDWIS) federal reports data[53]
- State Water Board’s Division of Drinking Water (DDW) water quality data[54]
- Water system economic status from the GIS analysis
- Human Right to Water (HR2W) data[55]
- Water system demand calculations data

The SDWIS federal reports for Water System Summary, Water System Detail, Facilities, and Violations were downloaded as csv files from the SDWIS Federal Reports Advanced Search online portal: (https://ofmpub.epa.gov/apex/sfdw/f?p=108:1:::NO:1). The csv files were then uploaded to the database as individual data tables.

The DDW water quality data tables were downloaded from the California Water Boards Electronic Data Transfer (EDT) Library and Water Quality Analyses Data and Download Page (https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/EDTlibrary.html). The data tables that were downloaded include Chemical.dbf, Chemhist.dbf, Chemarch.dbf, Chemxarc.dbf, Siteloc.dbf, Storet.dbf, and Watsys.dbf. The tables were read into R and a quality assurance and quality check (QA/QC) process was performed to ensure that all sample results had a valid collection date and sample location indicated by the primary station code, all sample locations had a valid primary station code associated with a unique and valid source name and a unique and valid system number, and all system names and source names used valid encoding. A data field for the public water system identification number (PWSID) was added for each system number. The PWSIDs were formed by adding a “0” at the beginning of any water system number with six characters to ensure all system numbers were seven characters in length and then adding “CA” at the beginning of all water system numbers such that each PWSID was nine characters in length and consistent with the US EPA PWSIDs. After the QA/QC process was performed, the R script exported the data tables as csv files that were then uploaded to the Postgres database.

A SQL query was developed and run using pgAdmin to create a data table of DDW water quality data for samples collected between January 1, 2009 and the present (currently up to April 29, 2019), including:

- Water system ID (system_no)
- Water system name (system_nam)

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[53] USEPA. SDWIS Federal Reporting Services System. https://ofmpub.epa.gov/apex/sfdw/f?p=108:200:::NO::: Accessed December 5, 2019.

[54] California SWRCB. EDT Library and Water Quality Analyses Data and Download Page. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/EDTlibrary.html Accessed March 17, 2020.

[55] California SWRCB. Human Right to Water Portal: Water System Drinking Water Data. https://www.waterboards.ca.gov/water_issues/programs/hr2w/ Accessed October 28, 2019.

- Sample collection date (samp_date)
- Sample collection time (samp_time)
- Primary station code or state source number/sample location ID (prim_sta_c)
- Source/sample location name (source_nam)
- Status of the source/sample location
    - AB = abandoned
    - DS = destroyed
    - IR = inactive raw
    - IT = inactive treated
    - IU = inactive untreated
    - SR = standby raw
    - ST = standby treated
    - SU = standby untreated
    - AR = active raw
    - AT = active treated
    - AU = active untreated
    - MW = monitoring (not a drinking water source)
    - AG = agricultural/irrigation well (not a drinking water well)
    - DT = distribution system sample point, treated
    - DR = distribution system sample point, raw
    - CT = combined treated
    - CU = combined sources which are not treated
    - CR = combined raw
    - CM = combined mixed (combined sources)
    - PN = pending (source not yet established)
    - PR = purchased raw
    - PT = purchased treated
    - PU = purchased untreated
    - WW = wastewater (not for drinking)
- Water type/source of water:
    - G = well/groundwater
    - M = mixed (mixture of surface and ground water, i.e. well/river)
    - S = surface water
    - W = waste (wastewater generator)
- Chemical/analyte
- Detection level for purposes of reporting (DLR)
- US EPA STORET number for chemical/parameter (store_num)
- Modifier for chemical finding (xmod)
    - “<” = Not Detected
    - “F” = False Positive confirmed with two or more follow-up samples
    - “I” = Invalid
    - “Q” = Questionable
    - “-“ for Langelier Index findings
- Numerical finding/result of analysis
- Reporting unit for chemical/analyte

An R script was developed to format the resulting DDW data table prior to uploading to the Postgres database as follows:

1. Remove invalid, questionable, and false positive data as indicated by the xmod data field (xmod = "F", "I", or "Q")
2. Create data fields for the 'method detection limit' and 'below detection' indication. For non-detect data records as indicated by the xmod data field (xmod = "<"), set the 'method detection limit' field equal to the value in the 'finding' field, set the 'below detection' field equal to "Y" for yes, and replace the value in the 'finding' field with "0". By doing so, all non-detect data are set equal to zero for data analysis purposes. For data records with detected results, the 'method detection limit' field is set to "NA" and the 'below detection' field is set to "N" for no.
3. Nitrate data are currently reported in mg/L as N, but previously in California, nitrate data were reported in mg/L as NO_3. As a result, the DDW data contains two different chemicals: "NITRATE (AS N)" and "NITRATE (AS NO3)". Data for "NITRATE (AS NO3)" are converted from mg/L as NO_3 to mg/L as N by multiplying by the molecular weight of nitrogen divided by the molecular weight of nitrate, 14.0067/62.0037. The chemical name for "NITRATE (AS NO3)" data is then changed to "NITRATE (AS N)".
4. Create a data field for the maximum contaminant level (MCL). First create a MCL data table including data fields: chemicals, reporting units, and detection limits for reporting purposes from the DDW data, and MCLs from the California Water Boards (https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/mclreview/mcls_dlrs_phgs.xls) last updated March 13, 2019, in R and upload to the Postgres database. The MCL data table is merged with the DDW data to include the MCL data field. For unregulated chemicals, the MCL data field is set to "NA".

The formatted DDW data table was then written to a comma-separated values (csv) file and uploaded to the Postgres database, using the table name: "ddw_wqdata". This data table can be used to find detailed sample results data for a given water system, a given source/sample location, or a given analyte as needed.

For the costing efforts, it is important to use the DDW data to identify water quality concerns that could impact treatment processes. An R script was developed to create a table summarizing data for analytes that could be a concern for some treatment technologies. For each analyte and each source/sample location with data for the given analyte, the sample results for that analyte are summarized by the minimum result, median result, mean result, 95th percentile result, and the maximum result. Note that non-detect data are treated as zero for the purpose of averaging. The table was then uploaded to the Postgres database using the table name: 'ddw_wq_treatment'. The analytes that are included in this table are arsenic, chloride, iron, manganese, nitrate, pH, sulfate, total alkalinity, total dissolved solids (TDS), total hardness, and total organic carbon (TOC).

The DDW water quality data can also be used to prioritize systems by identifying systems that may not yet have a violation but have water quality data close to and/or approaching an MCL exceedance. In order to identify systems meeting this criterion, an R script was developed to create a table summarizing data for chemicals that have been detected at 80% of the MCL or greater. For each chemical and each source/sample location with a detected result at 80% of the MCL or greater for the given chemical, the chemical results are summarized by the minimum result, median result, mean result, 95th percentile result, and the maximum result. Note that non-detect data are treated as zero for the purpose of averaging. Additionally, a 'trend' data field is created. For each chemical and source/sample location included in the data table where there are available data results for the given chemical at the given source/sample location for each year from 2009 through 2018, the Mann Kendall statistical test was applied to test for a monotonic increasing or decreasing trend over time. If the resulting p-value is less than 0.05 and the test statistic is positive, the given chemical at the given source/sample location is identified as increasing. If the p-value is less than 0.05 and the test statistic is negative, the given chemical at the given source/sample location is identified as decreasing. If the p-value is greater than 0.05, there is not sufficient evidence to identify a trend over time. If there was not sufficient data to apply the Mann Kendall test, the 'trend' data field is set to "NA". The resulting table is uploaded to the Postgres database using the table name: 'ddw_wq_80permcl'.

The DAC/SDAC status for each water system will be identified in the GIS effort. The output of this effort will include a table identifying the DAC/SDAC status for each water system. The table will be uploaded to the database.

The HR2W data was used to identify systems with health-based violations. The data includes information regarding the contaminant resulting in a violation for each out of compliance system. The excel spreadsheet of Exceedance/Compliance Status of PWSs Data available on the California Water Boards website (https://www.waterboards.ca.gov/water_issues/programs/hr2w/) was downloaded, saved as a csv file, and then uploaded to the database.

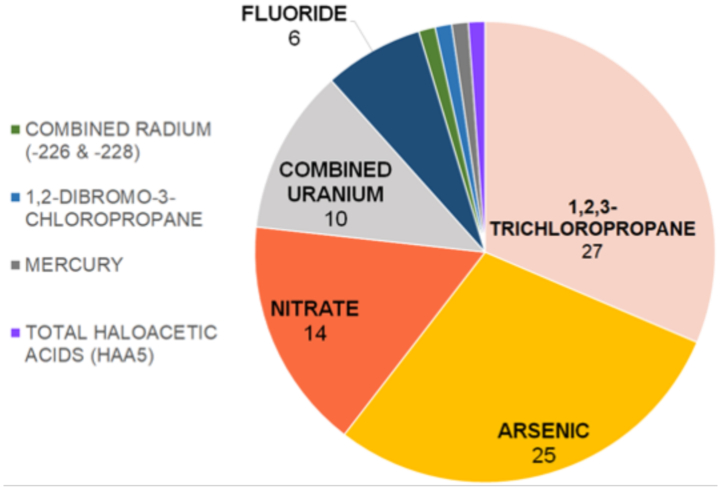
The water system demand calculations were developed for the cost assessment process. The calculations, which include ADD, maximum daily demand under different operational scenarios, and peak hourly demand, were developed in an excel spreadsheet. This spreadsheet was then saved as a csv file and uploaded to the Postgres database as a data table.

A data table containing all relevant data for the cost assessment was then created by running a SQL query which pulled desired information from the various data tables described above. For each water system, the table includes system information (PWSID, system name, county, population served, and number of connections), the analyte for which the system is in violation, the percent of the system that is a severely disadvantaged community (SDAC), disadvantaged community (DAC), not a disadvantaged community, and unknown DAC status, the ADD estimate, and the maximum daily demand estimate. For each system and violation analyte, there are then rows of data for each primary station code where the violation analyte has been detected at 80% of the MCL or greater. For each primary station code, the table contains data for the source name, status, water type, and the number of data records, mean result and max result for the violation analyte and other analytes that may impact treatment, including arsenic, chloride, TOC, alkalinity, pH, iron, manganese, sulfate, TDS, nitrate, and hardness.

Appendix B – Kern County Case Study

In order to estimate the cost of providing solutions to HR2W systems and At-Risk systems, the Cost Assessment Model (Model) needs to identify the challenges and issues, beyond water quality, that these systems are struggling with in order to provide sustained safe and accessible drinking water. Due to the timing of this project, the Risk Assessment risk indicators are still under development and could not be utilized to determine possible challenges. Therefore, Corona conducted a case study of the HR2W systems in Kern County to identify and refine the possible challenges the Model may need to address. Kern County was selected for initial analysis because it has 61 of the state's 311 HR2W listed systems. Figure 4 summarizes the different water quality violations in Kern County.

Figure B1. Kern County HR2W Systems Water Quality Violations



1,2,3-Trichloropropane (TCP) violations are the most numerous in Kern County. This is a fairly new regulation, which became effective in December of 2017[56], and the Central Valley is heavily impacted by TCP groundwater contamination. Although the federal arsenic MCL was announce in 2001[57] and became effective in 2006, there are still 25 systems in Kern County that have not been able to come into compliance.

One of the common factors shared by HR2W systems is small system size. Smaller systems often have fewer technical, managerial, and financial resources to leverage. The size distribution of the Kern County HR2W systems is shown in Figure B2 with 75% of systems serving fewer than 200 connections.

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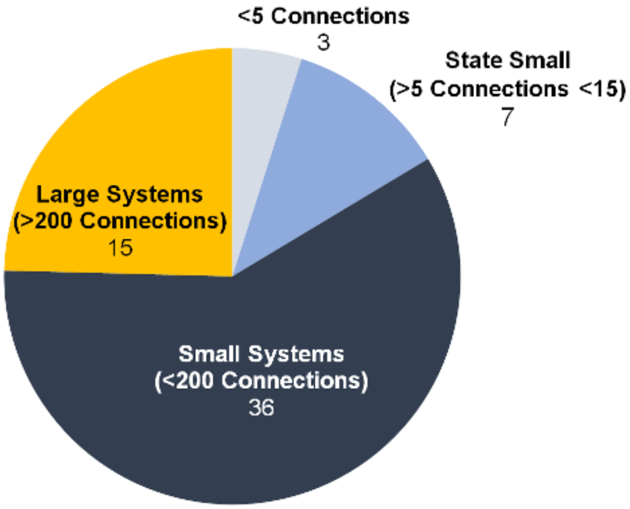
[56] State Water Board, 2017. *Information Pertaining to this Regulatory Proposal*. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/SBDDW-17-001_123TCP_MCL.html

[57] US EPA, 2001. *Technical Fact Sheet: Final Rule for Arsenic in Drinking Water*. https://nepis.epa.gov/Exe/ZyPdf.cgi?Dockey=20001XXE.txt

Figure B2. Kern County HR2W Systems by Number of Service Connections



In addition to the water quality challenges, these systems also often face other infrastructure issues. To examine these challenges in a more quantitative way, the sanitary surveys[58] for 60 of the HR2W systems in Kern County were analyzed to look at source age, source capacity, and storage capacity. This detailed analysis will not be performed for systems in other counties, but this data will be used to inform the overall cost analysis statewide.

Nearly half (48%) of these systems only have one water source, which would not be allowed in a newly constructed water system.[59] In order to provide adequate reliability we have assumed that 48% of HR2W and At-Risk systems will need an additional well.

Figures B3 and B4 summarize the proportion of systems that may have additional infrastructure needs.

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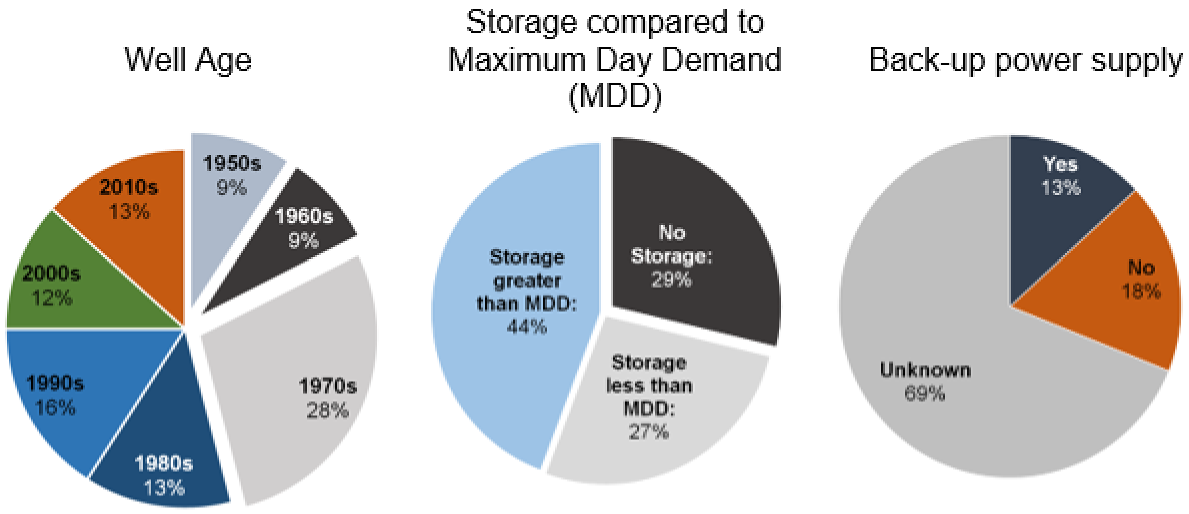
[58] The most recent Sanitary Surveys for Kern County Human Right to Water systems were provided by the State Water Board in PDF format.

[59] Title 22 Code of Regulations, 2019. Section 64554, (c) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dw_regulations_2019_04_16.pdf

Figure B3. Additional Issues Identified – Well Age, Storage, & Back-Up Power



Although regularly maintained wells can have a life span much longer than 40 years, in HR2W and At-Risk systems the maintenance can be less consistent. Therefore, wells older than 40 years are assumed to need replacement due to age, which is 46% of wells in this data set. Wells in the age range of 20 to 40 years old, which is 29% of the wells, are assumed to need a new pump and motor and electrical upgrades.

A more system specific analysis would be required to understand how many of these systems meet the storage requirements outlined in the regulations,[60] however it is worth noting that only 44% of the systems clearly have enough storage to meet MDD. This leads to the assumption that 56% of systems need additional storage.

In the case of back-up power supply 69% of systems were reported to have an unknown status. We have assumed that the unknown systems have the same distribution of yes/no answers as the systems with reported data. We have assumed that 58% of the HR2W and At-Risk systems need back-up power.

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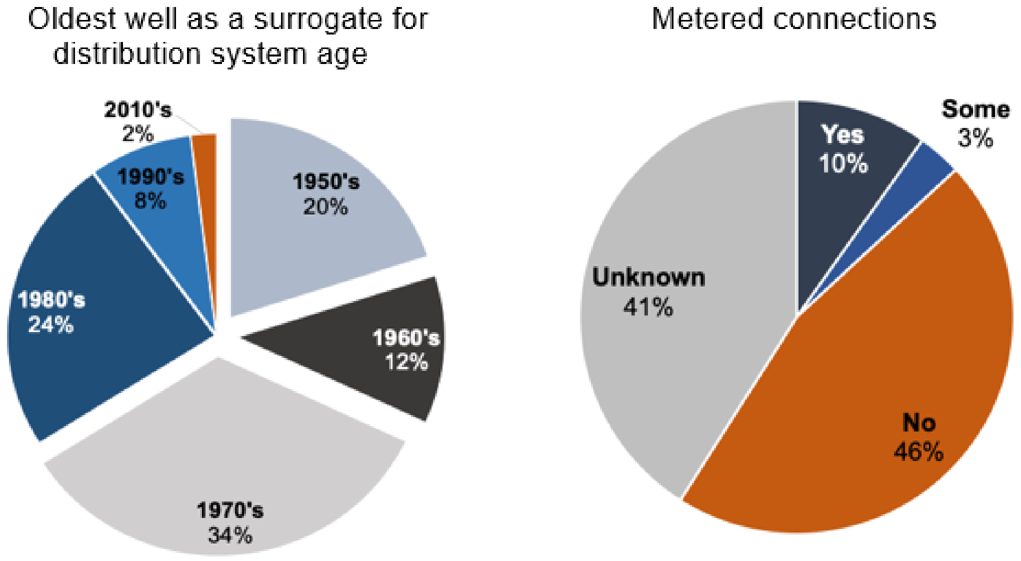
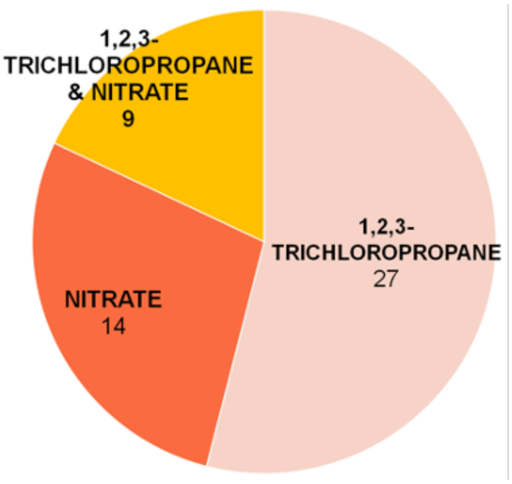
[60] Title 22 Code of Regulations, 2019. Section 64554, (a) (2) https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dw_regulations_2019_04_16.pdf

Figure B4. Additional Issues Identified – Distribution System Age and Meters



Unfortunately, information on the age of the distribution system is not available. The age of the oldest well in a system has been used as a surrogate. As can be seen in Figure B4, 66% of the oldest wells are 40-years old or more. We have assumed that 66% of the systems need distribution system main replacement based on age. When a water source has co-occurring contaminants (e.g. more than a single contaminant) that require treatment, the cost to treat the water can increase dramatically. In Kern County, the most common example of co-occurring contaminants requiring treatment includes both nitrate and TCP at levels over the MCL, as shown in Figure B5. Another group of systems to consider are those with co-occurring contaminants that are not yet over the MCL, but impact treatment decisions.

Figure B5. Co-occurring Contamination of Wells with Nitrate and TCP in Kern County HR2W Systems



Appendix C – Sustainability and Resiliency Assessment

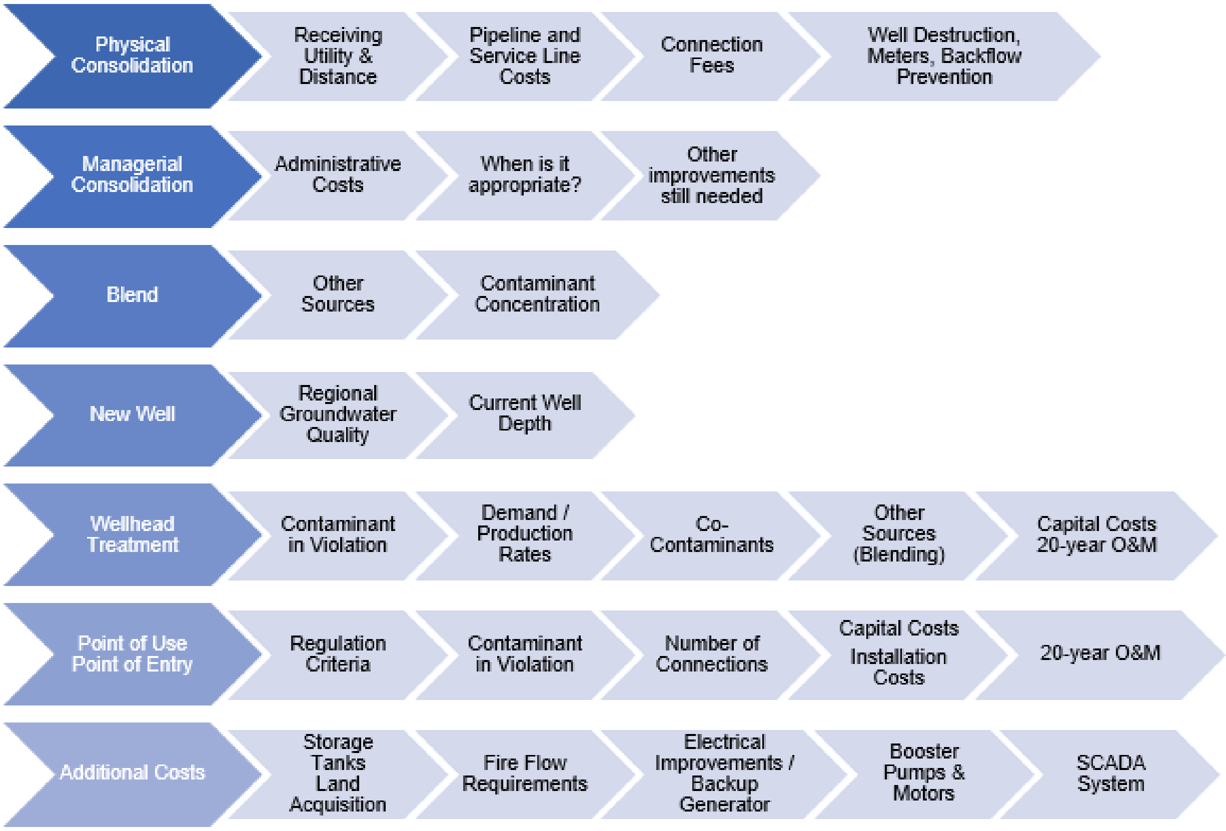
Scope and Objectives

The *Sustainability and Resiliency Assessment Framework* was constructed to compare modeled solutions for safe drinking water systems across a range of technical, economic, environmental, and social criteria. The proposed framework uses multi-criteria decision analysis to comprehensively evaluate eleven screened sustainability and resiliency metrics for potential solutions for public water systems in violation or At Risk. The sustainability and resiliency metrics will be implemented to evaluate solutions modeled in step 3 of the cost assessment model process (Figure 3).

Method

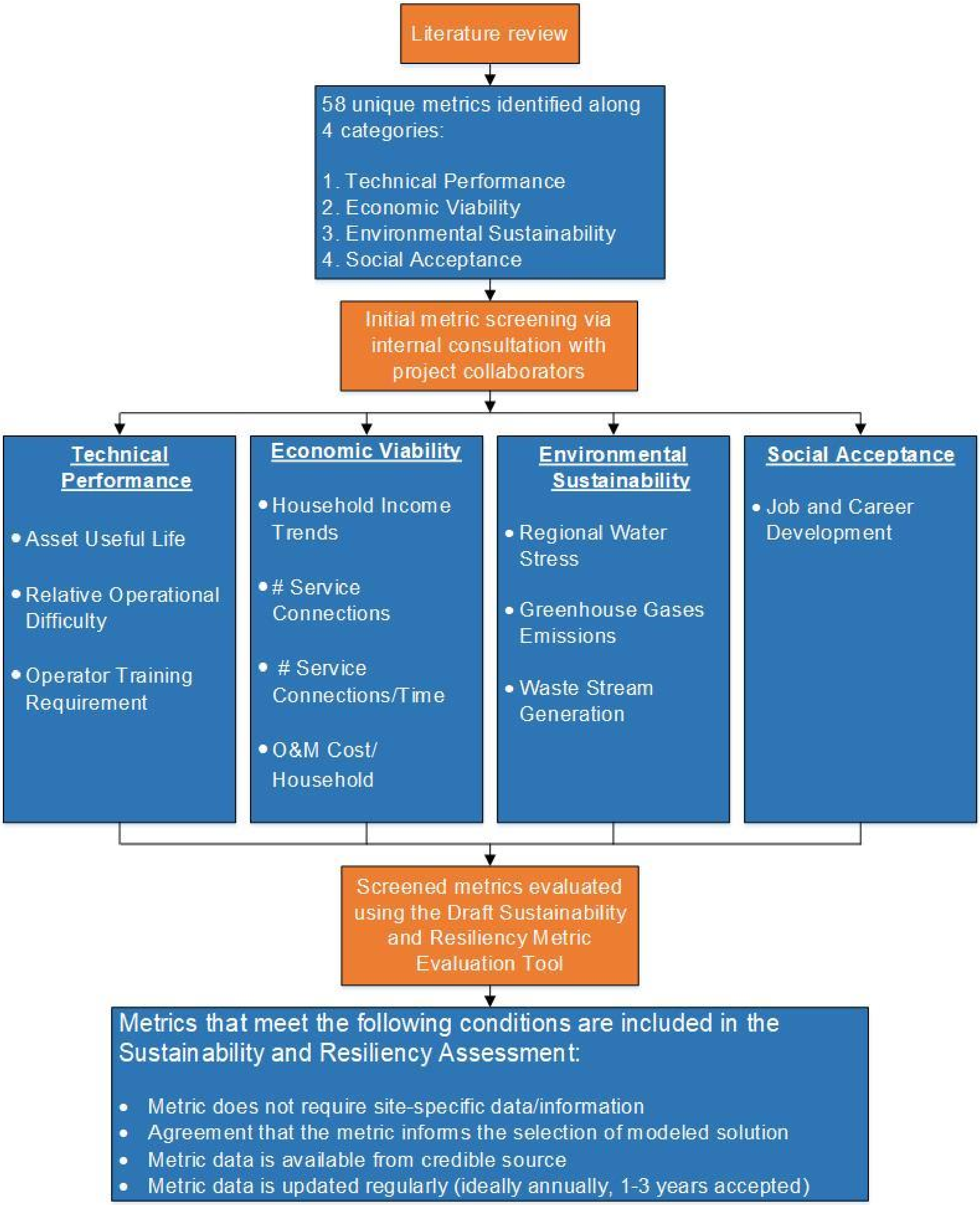
The method for developing metrics of long-term sustainability and resiliency for drinking water solutions using a multi-criteria decision analysis approach capitalized on existing literature, tools, and best practices. Initially, metrics were chosen to measure and compare the variables of interest – in this case, modeled solutions (Figure C1) developed in step 3 of the cost assessment process (Figure 6). Thoughtful selection of metrics for comparing the modeled solutions, which address the needs of HR2W and At-Risk systems, is critical to improving the quality and usefulness of metrics. Many frameworks and criteria are potentially available within the literature on sustainability, covering typical components that consider technical, economic, environmental, and social factors and impacts. Yet, a framework must also incorporate implementation considerations, such as availability of data, replicability over time, and input from stakeholders.

Figure C1. Modeled Treatment Solutions and Considerations



This section provides more details on the process used to select and propose sustainability and resiliency metrics (Figure C2).

Figure C2. Methodology used to propose and select sustainability and resiliency metrics



Literature Review

A literature review was conducted to identify up-to-date available research that addresses comprehensive frameworks for small drinking water system sustainability support and decision-making.

Reviewing the content of published papers yielded a list of 58 unique metrics that are potentially applicable to tracking sustainability and resiliency of modeled solutions for HR2W and At-Risk systems. The 58 metrics were organized across four criteria categories (Table C1): Technical Performance, Economic Viability, Environmental Sustainability, and Social Acceptance.

While established metrics from peer-reviewed literature offer the benefit of being developed through thoughtful and deliberative analysis, a drawback of relying on metrics from published literature is their rooting in historical precedence. The metrics are assumed to be applicable for consideration as they were developed to evaluate water system projects with similar objectives, regional characteristics, and involvement of stakeholders. While using existing literature streamlines the process of developing metrics and indicators for cross-comparison among projects, it may neglect context. Additional considerations of data availability and institutional dynamics may have as much or more influence on what metrics are ultimately viable.

Table C1. The count and scientific literature sources of sustainability and resiliency metrics in every criteria category

Criteria Categories	**Metrics identified**	**Literature Sources**
Technical Performance	25	Cornejo et al. (2019) Jones et al. (2019) Fuller and Petersen (1996) Kumar, Groth, and Vlacic (2016) Pagsuyoin et al. (2015)
Economic Viability	10	Cornejo et al. (2019) Fuller and Petersen (1996) Jones et al. (2019) Khera, Ransom, and Speth (2013) Kumar, Groth, and Vlacic (2016) Pagsuyoin et al. (2015)
Environmental Sustainability	16	Cornejo et al. (2019) Godskesen et al. (2018) Jolliet et al. (2003) Santos, Pagsuyoin, and Latayan (2016) Pagsuyoin et al. (2015)
Social Acceptance	7	Cornejo et al. (2019) Hunkeler (2006) Hutchins and Sutherland (2008) Santos, Pagsuyoin, and Latayan (2016)

Criteria Categories	Metrics identified	Literature Sources
		Pagsuyoin et al. (2015)

Selection of Tentative Metrics and Internal Consultation

Next, the selection process for proposing metrics of sustainability and resiliency incorporated professional judgment to account for project-specific considerations.

After identifying the possible metrics from the literature review, OWP narrowed the list to focus on practical sustainability and resiliency applicable to the Cost Assessment Model's scope at a state-wide level. The following criteria were used to identify a tentative list of metrics that could be considered:

- Metrics should be reflective of the non-monetizable aspects of the modeled water system solutions (the sustainability and resiliency assessment was intended to evaluate feasibility beyond costs)
- Metrics are applicable on a statewide large-scale analysis and do not rely on local-scale conditions, contexts, considerations, or data requirements (i.e., they are generally not site-specific measures).

Selection of Proposed Metrics

Well-thought and clearly defined metrics create effective and targeted instruments for evaluation, which augment technical and economic feasibility assessments of drinking water systems and help reduce uncertainty in comparing potential modeled solutions. However, given the complexity of drinking water systems, proposing metrics is a challenging process that depends on: a project's objective; technical, managerial, and financial (TMF) feasibility (indicators of sustainability); and stakeholder preferences.

Through the iterative process described above that included initial screening and subsequent discussion, the initial list of 58 metrics was reduced to 11 proposed metrics. The inclusion of specific metrics was primarily based on discussions in the project-team meetings on the effective purpose, utility, and merit of each metric relative to assessing the sustainability and resiliency of modeled solutions.

Proposed Sustainability and Resiliency Metrics

This section includes a draft list of proposed metrics to assess and compare the sustainability and resiliency of modeled solutions (Figure C1) identified for the Cost Assessment Model. These indicators are organized into the following four categories: Technical Performance, Economic Viability, Environmental Sustainability, and Social Acceptance. The following sections discuss and tabulate the proposed metrics.

Technical Performance Metrics

Technical performance refers to the capacity of a modeled solution to execute its primary function of providing safe and affordable access to drinking water that can be sustained in the long term. Technical performance may also specify the formal, information-based routines, procedures, and processes needed for maintaining water quality standards and accessibility.

Table C2 includes a draft list of proposed metrics that are recommended to use in assessing the technical performance of modeled solutions. These metrics measure the efficiency and effectiveness of the modeled solutions in complying with water quality and treatment technique regulatory requirements.

Table C2. Proposed technical performance metrics

Metric	Definition	Relationship to Sustainability and Resiliency Score
Asset useful life	The period of time (or the total amount of activity) for which the solution will be economically feasible for use. In other words, it is the period of time that the asset will be in service.	Directly Proportional Relationship: Higher asset useful life value contributes positively to the sustainability and resiliency score
Relative Operational Difficulty	An evaluation of the difficulty and complexity of treating water, using the identified possible modeled water solutions, to comply with water quality regulatory requirements Relative Operational Difficulty would be evaluated as a function of the: (1) number of contaminants, (2) the type of contaminant(s), and (3) the difficulty of treating the contaminant(s).	Inversely Proportional Relationship: Higher Relative Operational Difficulty contributes negatively to the sustainability and resiliency score
Operator Training Requirement	The grade level certification an operator must hold to operate a treatment/distribution system	Inversely Proportional Relationship: Higher Operator Training Requirement contributes negatively to the sustainability and resiliency score

Economic Viability Metrics

Economic viability is a measure of the affordability of a modeled solution for residents and the capacity of the system’s owner/operator to manage and maintain its operation in the long term. Table C3 includes a draft list of proposed metrics for assessing the economic viability of modeled solutions. Traditionally, economic viability studies focus on using the normalized cost of treatment (cost/water unit) to consider economic factors. However, the sustainability and resiliency assessment's intent is to look beyond just cost and therefore attempts to identify metrics with a more expansive perspective – those that measure the long-term ability of a community to afford a modeled solution.

Table C3. Proposed economic viability metrics

Metric	Definition	Relationship to Sustainability and Resiliency Score
Household income trends	The combined gross income of all members of a household over a period of time. Individuals do not have to be related in any way to be considered members of the same household	Directly Proportional Relationship: An Upward trend in household incomes contributes positively to the sustainability and resiliency score
Number of service connections	Current water lines or pipes connected to a distribution supply main or pipe to convey water to water users' systems	Directly Proportional Relationship: A higher number of service connections contributes positively to the sustainability and resiliency score
Number of service connections over time	Water lines or pipes, over a period of time, connected to a distribution supply main or pipe to convey water to water users' systems	Directly Proportional Relationship: An upward trend in service connections contributes positively to the sustainability and resiliency score
O&M Cost/household	Continuous operation and maintenance costs including labor, energy, chemicals, staffing, spare parts, and facility management per household	Inversely Proportional Relationship: A higher O&M cost per household contribute negatively to the sustainability and resiliency score

Environmental Sustainability Metrics

Environmental sustainability measures the environmental impacts of modeled solutions during operation. The environmental sustainability of a modeled solution is assessed through the lens of trade-offs where the benefits are weighed against the negative impacts on the environment. While other metrics focus on public water systems and the customers they serve, this category highlights the need to consider the lifetime environmental impacts of operations. Generation of waste streams, emissions, and regional ecological considerations are all important potential components to environmental sustainability.

Table C4 includes a draft list of proposed metrics to use in assessing the environmental sustainability of modeled solutions. In this context, a sustainable alternative is one that minimizes its greenhouse emissions and water footprint and reduces harmful waste stream generation and residual by-products.

Table C4. Proposed environmental sustainability metrics

Metric	Definition	Relationship to Sustainability and Resiliency Score
Regional Water Stress	Refers to the ability, or lack thereof, to meet human and ecological water demand. It may consider several aspects, including but not limited to: physical water availability, baseline water stress, water quality, source vulnerability, and drought risk.	Inversely Proportional Relationship: A higher Regional Water Stress contributes negatively to the sustainability and resiliency score
Greenhouse Gases	Refers to the level or amount of greenhouses gases (GHG) emissions by a modeled solution during its lifetime. GHG can be assessed by relating emissions to energy costs and GHG intensity of electricity production for each solution. This includes evaluating the energy associated with a solution (e.g., groundwater pumping, centralized treatment, physical consolidation) and estimating GHG intensity of electricity.	Inversely Proportional Relationship: Higher Greenhouse Gases emissions contribute negatively to the sustainability and resiliency score
Waste Stream Generation	Refers to the residuals generated from a modeled solution processes (e.g., sludge, brine concentrates, Ion exchange resins, spent granular activated carbon, non-GHG air emissions)	Inversely Proportional Relationship: Higher Waste Stream Generation, including more pollutants included in the generation stream, contributes negatively to the sustainability and resiliency score

Social Acceptance Metrics

Social acceptance is a measure of a community's willingness to adopt a modeled solution based on its perceived effectiveness and benefits. Social acceptance is difficult to gauge due to subjectivity and local context. Within literature, many criteria for social acceptance were identified as immediately relevant or were addressed through other steps in the Needs Assessment.

The proposed social acceptance metrics are particularly at a scoping level and need further consideration and investigation. Table C5 includes a proposed metric to use in assessing the social acceptance of modeled solutions.

Table C5. Proposed social acceptance metric

Metric	Definition	Relationship to Sustainability and Resiliency Score
Job and career development	Jobs or opportunities for career development offered by a modeled solution	Directly Proportional Relationship: Higher values of Job and Career Development contribute positively to the sustainability and resiliency score

Draft Sustainability and Resiliency Metric Evaluation Tool

OWP developed a Sustainability and Resiliency Metric Evaluation Tool to assist in determining appropriate metrics drawn from the proposed Sustainability and Resiliency Metrics list (Tables C2-C5) as well as stakeholder input for inclusion in the Sustainability and Resiliency Assessment of modeled solutions for public water systems and domestic wells. The draft evaluation tool consists of three steps: an evaluation of a metric's need for site-specific data; the applicability of the metric in informing modeled solution selection; and the data properties associated with each metric, such as data availability and data accuracy/quality.

Step 1 Site-Specific Data Requirements

This step evaluated whether a metric requires site-specific information to adequately assess modeled solutions and if site-specific data is readily available and accessible for use as metric input.

The evaluation scoring criteria for Step 1 are:

- **Readily-available site-specific data**: a metric that depends on site-specific data that is readily available and accessible from a database. For example, data for the *Number of Service Connections* and *Asset Useful Life* metrics can be obtained from a State Water Board database and an U.S. EPA technical report, respectively, without further local-level data collection.

- **Site-specific data requires local investigation (i.e. data is not readily available)**: a metric that requires site-specific data to be accurately evaluated that is not readily available or accessible. For instance, the *Greenhouses Gases Emissions* and *Job and Career Development* metrics require highly contextual local-level data and analysis for evaluation.

Metrics with readily-available site-specific data will be included in the statewide Sustainability and Resiliency Assessment. Metrics that require site-specific data that is not readily available and necessitates local-level data collection and analysis efforts will not be included in this assessment but may be considered for an independent prospective site-specific assessment of sustainability and resiliency in the future during site specific planning and design (i.e., implementation, not modeled under the Needs Assessment project). While a site-specific assessment will follow a similar evaluation process as the statewide assessment, it will additionally evaluate metric data coverage – whether the data associated with a metric is available for a sufficient number of California public water systems.

Step 2 Applicability

This step evaluated whether the proposed metric influences and informs the sustainability and resiliency of modeled treatment solutions for public water systems and domestic wells. The evaluation is based on the professional judgement of project team members and collaborators involved in this effort.

The Applicability ratings proposed are:

- **Good**: there is agreement that a metric influences and informs the selection of a modeled solution
- **Fair**: there is debate whether a metric influences and informs the selection of a modeled solution
- **Poor**: there is an agreement that a metric does not influence and inform the selection of a model solution

Step 3 Metric Data Properties

This step evaluated whether the required data for each sustainability and resiliency metric meets the following criteria:

Data Availability

This criterion evaluated whether the data associated with the metric is available in a final format that is ready for use in the Sustainability and Resiliency Assessment. In contrast to step 1, this criterion is not evaluating whether site-specific data is readily available, rather it is evaluating the availability of all associated data (regardless of their spatial level), their format, and the degree of processing required for use in metric calculations.

The availability ratings proposed are:

- **Good**: data is readily available in a usable format and does not require significant data processing and/or analysis for use in the assessment
- **Fair**: data is not readily available in a usable format and requires significant processing and/or analysis for use in the assessment
- **Poor**: data is not available

Data Accuracy and Quality

This criterion evaluated whether the data associated with the metric accurately reflects what the data is meant to measure or demonstrate.

The Data Accuracy and Quality ratings proposed are:

- **Good**: data obtained from credible source(s) and is updated annually.
- **Fair**: data obtained from credible source(s) and is updated less than annually but at least every three years
- **Poor**: data obtained from an unreliable source and/or is not regularly updated.

Step 4 Combined Evaluation

The Evaluation Tool combined the evaluations from steps 1 to 3 to determine if Sustainability and Resiliency Metrics should be considered for inclusion in the Sustainability and Resiliency Assessment of modeled solutions for public water systems and domestic wells.

It was anticipated that there may be multiple metrics that rate highly on the applicability test but perform poorly on the Metric Data Properties (Step 3) evaluation.

The Combined Evaluation outcomes proposed are:

- **Yes** if:
    - Step 1 result is *Readily Available*
    - Step 2 result is *Good*
    - Step 3 results are either (a) all *Good*, (b) all *Fair*, or (c) a combination of *Good* and *Fair*
- **Maybe** if:
    - Step 1 result is *Readily Available*
    - Step 2 result is *Fair*
    - Step 3 results are either (a) all *Good*, (b) all *Fair*, or (c) a combination of *Good* and *Fair*
- **No** if:

  - Step 1 result is *Readily Available*
  - Step 2 result is *Good* or *Fair*
  - Steps 3 results have more than one criteria with a *Poor* evaluation

  Or

  - Step 1 result is *State-wide*
  - Step 2 result is Poor
- **Future** if:
  - Step 1 result is *Not Readily Available*

  These will be retained for future consideration for a separate future assessment that focuses on evaluating the sustainability and resiliency of model solutions for public water systems and domestics wells at a site-specific level.

Draft Evaluation Tool Results for Proposed Sustainability and Resiliency Metrics

Table C6 demonstrates how the draft evaluation tool evaluated the proposed metrics for inclusion in the Sustainability and Resiliency Assessment. The results were based on the conclusions of the internal stakeholder discussions and on preliminary efforts to collect data and establish methodologies to develop each proposed metric's measurement variable. The final evaluation results may vary based on received public feedback.

Table C6. Draft Evaluation Tool Results for Proposed Sustainability and Resiliency Metrics

Metrics	Step 1	Step 2	Step 3		Step 4
	Site-Specific Data Requirements?	**Applicability**	**Data Availability**	**Data Accuracy/ Quality**	**Decision on Inclusion in Assessment**
# Current Service Connections	Readily Available	Fair	Good	Good	Maybe
# Service Connections/ Time	Readily Available	Fair	Good	Good	Maybe
Household Income Trends	Not Readily Available	Good	Poor to Fair	Poor to Fair	Future
O&M Cost/ Household	Readily Available	Good	Good	Good	Yes
Operator Training	Readily Available	Good	Good	Good	Yes

Metrics	Step 1 Site-Specific Data Requirements?	Step 2 Applicability	Step 3 Data Availability	 Data Accuracy/ Quality	Step 4 Decision on Inclusion in Assessment
Requirement					
Asset Useful Life	Readily Available	Good	Good	Good	Yes
Relative Operational Difficulty	Readily Available	Good	Good	Fair	Yes
Greenhouse Gases	Not Readily Available	Good	Fair	Fair	Future
Waste Stream Generation	Readily Available	Good	Good	Good	Yes
Regional Water Stress	Not Readily Available	Fair	Fair	Fair	Future
Job and Career Development	Not Readily Available	Poor	Poor	Poor	Future

Out of the 11 proposed metrics, the evaluation tool recommends including the following 5 metrics in the Sustainability and Resiliency Assessment:

- O&M Cost /Household
- Operator Training Requirement
- Asset Useful Life
- Relative Operational Difficulty
- Waste Stream Generation

Additionally, the evaluation tool supports further consideration of the following metrics for possible inclusion in the assessment pending a deeper appraisal of their applicability:

- Number of Current Service Connections
- Number of Current Service Connections/Time

Table C7 presents the preliminary data source(s), data properties, and methodologies for sustainability and resiliency metrics that have been recommended for inclusion or possible inclusion in the assessment based on the results of the draft evaluation tool.

Table C7. Preliminary Data Source(s), Data Properties, and Methodologies of Metrics Recommend for Inclusion or Possible Inclusion in the Sustainability and Resiliency Assessment Framework

Metric	Data Variable	Data Source(s)	Data Type	Data Timeframe	Preliminary Methodology
Relative Operational Difficulty	Difficulty of Treatment Solution	1) Water Quality Treatment and Solution Matrix developed by State Water Board and OWP Staff 2) State Water Board's Drinking Water Operator Certification Program	Categorical, Point-Based System	Snapshot (at time of application)	1) Determine number and type of contaminants being treated 2) Determine treatment solution for number and type of contaminants 3) Assign score based on difficulty level of the treatment solution
Operator Training Requirement	Water Treatment Plant Operator Certification	1) State Water Board's Drinking Water Operator Certification Program 2) SDWIS/State V3.21 Database (Drinking Water Watch dataset) 3) *Relative Operational Difficulty* metric results	Categorical, Point-Based System	Snapshot (at time of application)	1) Use the results of the *Relative Operational Difficulty* metric to infer Max Treatment Plant Classification 2) Determine operator certification requirement from the inferred Max Treatment Plant Classification, using the Drinking Water Operator Certification Program 3) Assign score based on operator certification requirement

Metric	Data Variable	Data Source(s)	Data Type	Data Timeframe	Preliminary Methodology
Asset Useful Life	Life Expectancy in Years for Typical Equipment (e.g. Sources of Water Supply, Pumping Plants, Treatment Plants)	Asset Management: A Handbook for Small and Small Drinking Water Systems (EPA 816-R-03-016)	Integer Values	Snapshot (at time of application)	1) Calculate the average useful life for relevant assets 2) Assign score based on the average useful life of assets
# Current Service Connections	Number of Connections	State Water Board Electronic Annual Reports	Integer Values	2018	1) Assign score based on number of connections
# Service Connections/ Time	Percent Change in Number of Connections	State Water Board Electronic Annual Reports	Integer Values	2012-2018	1) Calculate % change in the number of service connections between 2012 and 2018 2) Assign score based on percent change in number of connections
O&M Cost/ Household	O&M Cost/ Household	1) State Water Board - Cost Assessment	Continuous Values	Varied	1) Divide O&M costs for modeled solutions by the number of houses in a service area 2) Assign score based on

Metric	Data Variable	Data Source(s)	Data Type	Data Timeframe	Preliminary Methodology
		Model[61] 2) Microsoft Bing Building Footprint Data[62] 3) LandVision Tax Assessor Data[63]			O&M Cost/Household
Waste Stream Generation	Presence of pollutants in residuals	Drinking Water Treatment Plant Residuals Management Technical Report (EPA 820-R-11-003)	Continuous Values	Varied	1) Determine the presence of certain pollutants of concern in the waste stream based on the source water quality and type of source water treatment 2) Assign score based on the number of pollutants of concern present in the waste stream

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[61] California Water Boards. (2020). Long Term Solutions Cost Methodology for Public Water Systems and Domestic Wells (pp. 19-23, Rep.) https://www.waterboards.ca.gov/safer/docs/draft_whitepaper_lt_solutions_cost_meth_pws_dom_wells_updated.pdf

[62] Microsoft (Bing Maps Team). (2018). *Computer Generated Building Footprints for the United States* https://github.com/microsoft/USBuildingFootprints

[63] LandVision. (2020). Parcel Data.

Next Steps

Several planned next steps are expected to further refine and improve the list of proposed metrics, with the intent of implementing the framework for evaluating non-monetary aspects of modeled solutions through the Cost Assessment Model.

Soliciting Expert and Public Feedback on Proposed Metrics

Through this White Paper, public and advisory committee comments on the proposed list of metrics will be gathered and considered for incorporation. As deemed appropriate for the context, scale, and feasibility of the Cost Assessment Model and this Sustainability and Resiliency Assessment, the team will make any refinements to the set of proposed metrics.

Mapping Metrics and Modeled Solutions: Case Studies

To ensure that the Sustainability and Resiliency Assessment Framework yields results that are comparable across the modeled treatment solutions and reproducible for HR2W and At-Risk systems, it is critical to test how metrics and their associated data align with modeled solutions. To do so, a multistep process will be used.

1. Using existing frameworks and expert opinion, the team will develop a matrix that identifies appropriate treatment solutions with known water contaminant issues, which represent typical combinations (single or multiple) or constituents that community water systems must address across California. , The matrix will support how metric ratings are applied to groupings of managerial or technical solutions.
2. The framework will be implemented and tested for several case studies of past drinking water infrastructure projects in small communities in California. Using recent examples of projects funded through the State Revolving Fund, the team will use available project documentation to implement the metrics and develop comparative scores of solutions.
3. The team will evaluate data normalization, weighting, and aggregation schemes that allow for metric comparability and aggregation of scores for modeled solutions.
4. The team will evaluate the scoring criteria, assessing if the proposed metrics capture sufficient detail to differentiate solutions.

The sustainability and resiliency assessment will ultimately capitalize on data generated through the identification of modeled solutions as part of the Costs Assessment Model, combined with expert opinion on factors contributing to the complexity of modeled solutions.

Since the full results of modeled solutions across the state will continue to be finalized in coming months, a smaller set of case study systems is useful to test the method for evaluating sustainability and resiliency metrics. Funded grant applications to California’s Drinking Water State Revolving Fund (DWSRF), which can fund drinking water system improvements in qualifying communities, offer a source of technical and financial documentation to evaluate the metrics. One or more test cases may be used to accrue data (sufficiently anonymized) that informs the selection of reasonable criteria for evaluating sustainability and resiliency over time.

Appendix D – Treatment Cost Details

Capital Cost Methodology by Contaminant and Treatment

Capital Cost Methodology GAC: GAC is the assumed treatment technology for organic contaminants, such as 1,2,3-trichloropropane (1,2,3-TCP), trichloroethylene (TCE), perchloroethylene (PCE), or dibromochloropropane (DBCP), as well as for Total Organic Carbon removal to address disinfection by-products. Capital costs for GAC were derived using recently received vendor quotes for water treatment pressure vessel pairs updated to 2020 dollars using Construction Cost Indices published by Engineering News Record. The EPA Work Breakdown Structure for Granular Activated Carbon cost model was considered for this purpose; however, the resulting cost estimates were consistently well below both vendor supplied numbers and recently bid projects in California. The vendor-supplied estimates were averaged by vessel size and translated to an installed cost using an engineering multiplier of approximately 2.36x equipment cost. The multiplier accounts for items such as installation, electrical and instrumentation and controls, general civil, planning, engineering, legal and permitting, construction administration services, and project contingency.

Treatment equipment was sized assuming lead-lag configuration with a minimum combined empty bed contact time (EBCT) of 10-minutes. Lead-lag vessel pairs were assumed to have diameters of either 6, 8, 10, or 12 feet which are readily commercially available. GAC bed depths were fixed based on the standard weight of carbon for a given vessel size assuming GAC with a specific gravity of 0.54. Note that the mass and therefore volume of carbon in the 10-ft and 12-ft vessels is the same. The benefit of 12-ft vessels is realized through lower headloss and therefore lower operational cost and were selected for this reason. Table C1 shows the vessel diameter, accommodated flow ranges, and corresponding mass of GAC in each vessel. In the cases where the flow rate is greater than can be accommodated by a single pair of 12-ft vessels (e.g. > 875 gpm) a configuration with multiple vessel pairs is considered for the capital cost estimate. The capital cost methodology was developed specifically for 1,2,3-TCP, however it can be deployed for any source that requires treatment for other organic contaminants [e.g. trichloroethylene (TCE), perchloroethylene (PCE), or dibromochloropropane (DBCP)] by adjusting the assumption used to develop the operational costs as summarized in Table D1.

Table D1. GAC vessel diameter, mass of carbon and flow range

Vessel Diameter (ft)	Mass of GAC (lb/vessel)	Flow Range (gpm)	Equipment Cost ($)
6	6,000	0 – 250	$431,000
8	10,000	251 – 425	$530,000
12	20,000	426 – 875	$736,000
Two Pair - 12	20,000	876 – 1,750	$1,440,000

Total Organic Carbon Removal: Several systems are on the HR2W list as a result of violations with the Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR). The violations are result of the formation of total trihalomethane and/or haloacetic acids as a result of the requisite chlorine disinfection and its reaction with total organic carbon (TOC) in the water source. TOC can readily be removed by GAC, thus reducing the extent of disinfection byproduct formation. For systems with Stage 2 DBPR violations the GAC capital costs as described above were applied along with an addition $30,000 for a pump station to overcome the additional headloss caused by the GAC treatment. The operation and maintenance cost for TOC removal is still under development.

Operational Cost Methodology for 1,2,3-TCP and other organic contaminants using GAC: The primary driver for 1,2,3-TCP operational cost is the periodic replacement and disposal of the spent GAC media. In this case, the throughput performance estimate of 38,200 bed volumes cited in the EPA Work Breakdown Structure (WBS) model was found to be sufficiently adequate for this purpose of this analysis. The WBS also cites costs for virgin carbon ($1.89/lb-GAC), transportation ($0.27/lb-GAC), and disposal ($0.004/lb-GAC). These costs were normalized to a standard production cost equivalent to $0.22/1,000 gallons of water produced. Additional costs were then applied analytical costs, and increased electrical costs required to pump the water through the treatment system. The operation and maintenance costs for other organic contaminant treatment is under development.

A summary of the of the estimated throughput that will be used to develop operational costs regression curves for other contaminants are provided in Table D2.

Table D2. GAC operational cost regressions

Contaminant	Raw Water Concentration	Treatment Objective	Estimated Throughput[64] (BV)
1,1-DCE	7 µg/L	3.5 µg/L	10,000
DBCP	0.2 µg/L	0.1 µg/L	65,000
EDB	0.06 µg/L	0.03 µg/L	60,000
PCE	Still under development		
TCE	Still under development		
1,2,3-TCP	0.1 µg/L	0.005 µg/L	38,000
TOC	3 mg/L	2 mg/L	5,000[65]

Capital Cost Methodology for Nitrate using Anion Exchange: Nitrate capital cost estimates were developed utilizing the Work Breakdown Structure-Based Cost Model for Anion Exchange Drinking Water Treatment (Anion Model)[66]. The modeling effort assumed a minimum empty bed contact time of 3 minutes and was standardized using pairs of 3-ft diameter treatment vessels, each containing 27 cu.ft. of strong base anion exchange resin. The flow rate for each vessel pair was constrained by providing at least 2.5 minutes of empty bed contact time with a maximum hydraulic loading rate of 10 gpm/sq.ft with full-flow treatment. In this case model inputs were adjusted to reflect recent bid costs for SBA-IX treatment systems in the Central Valley (Kern and Tulare counties) by adding 20% contingency to the calculated. The following parameters with the justification were adjusted in the Anion Model:

- Model Input
    - **Component level** = "High Cost" Ion exchange components are exposed to high concentration salt solutions which is corrosive and as a result require materials of better construction to defer maintenance costs

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[64] AdDesignS using isotherms from Speth, T. F, & Miltner, R.(1990) Technical Note: Adsorption Capacity of GAC for Synthetic Organics. JournalAWWA, Vol. 82, Issue 2, 72-75 https://doi.org/10.1002/j.1551-8833.1990.tb06922.x

[65] Zachman, B.A., & Summers, R. (2010). Modeling TOC Breakthrough in Granular Activated Carbon Adsorbers. Journal of Environmental Engineering, 136, 204-210.

[66] Drinking Water Treatment Technology Unit Cost Models
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

    - **System automation** = “Fully automated” Frequent regeneration of these systems requires them to be fully automated
- Critical Design Assumptions
    - “Flow meters for process line per vessel” value changed to 1. Flow balancing is critical for optimizing ion exchange performance and reducing operational costs
    - “Additional conductivity meters” value changed to 2. Assumes metering of regenerant brine concentration, regenerant outlet, and finished water
    - “Headloss sensors per vessel” value changed to 1. Pressure changes in an ion exchange system alerts the operator to potential hydraulic issues that can adversely impact performance.
    - “Number of electrical enclosures” value changed to 1. An electrical enclosure is necessary for a fully automated ion exchange system.

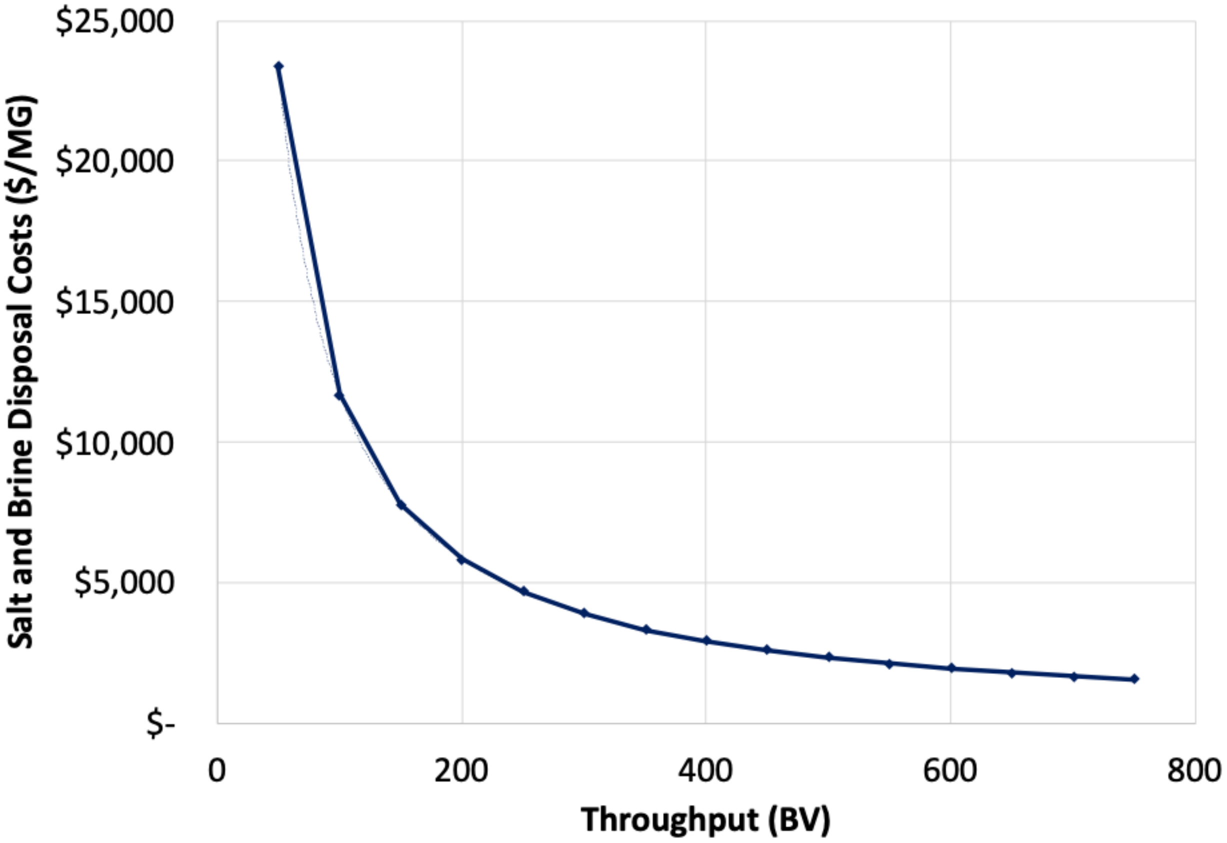
The flow rates and corresponding model developed installed capital costs are summarized in Table D2.

Table D2. Installed capital cost estimates for SBA-IX nitrate removal

Flow Rate (gpm)	Installed Capital Cost
1-125	$756,000
126-275	$1,106,000
276-400	1,355,000
401-550	$1,637,000
551-700	$2,022,000
701-850	$2,722,000

Operational Cost Methodology for Nitrate using Anion Exchange: The primary operational cost driver for SBA-IX nitrate treatment is the costs associated with spent regenerant brine disposal and the associated consumables, namely salt. For this assessment it was assumed that off-site disposal will be required with a unit cost of $0.20/gallon and a salt cost of $0.16/lb. For each regeneration, 3 bed volumes of spent regenerant brine and 2 bed volume of rinse will be directed to the spent brine waste tank and require offsite disposal. Applying these assumptions results in the following Figure D1 illustrates the impact of throughput on the salt and brine disposal costs as a function of water production.

Figure D1. SBA-IX salt and brine disposal costs for nitrate removal with SBA-IX



The throughput a given system will achieve is generally considered a function of the raw water nitrate and sulfate concentrations with lower concentration of each resulting in greater performance. To estimate the throughput for individual systems requiring nitrate treatment, a range of water quality parameters, summarized in Table D3, were modeled using an illustrative resin model[67]. The outputs from the modeling effort are shown graphically in Figure D2.

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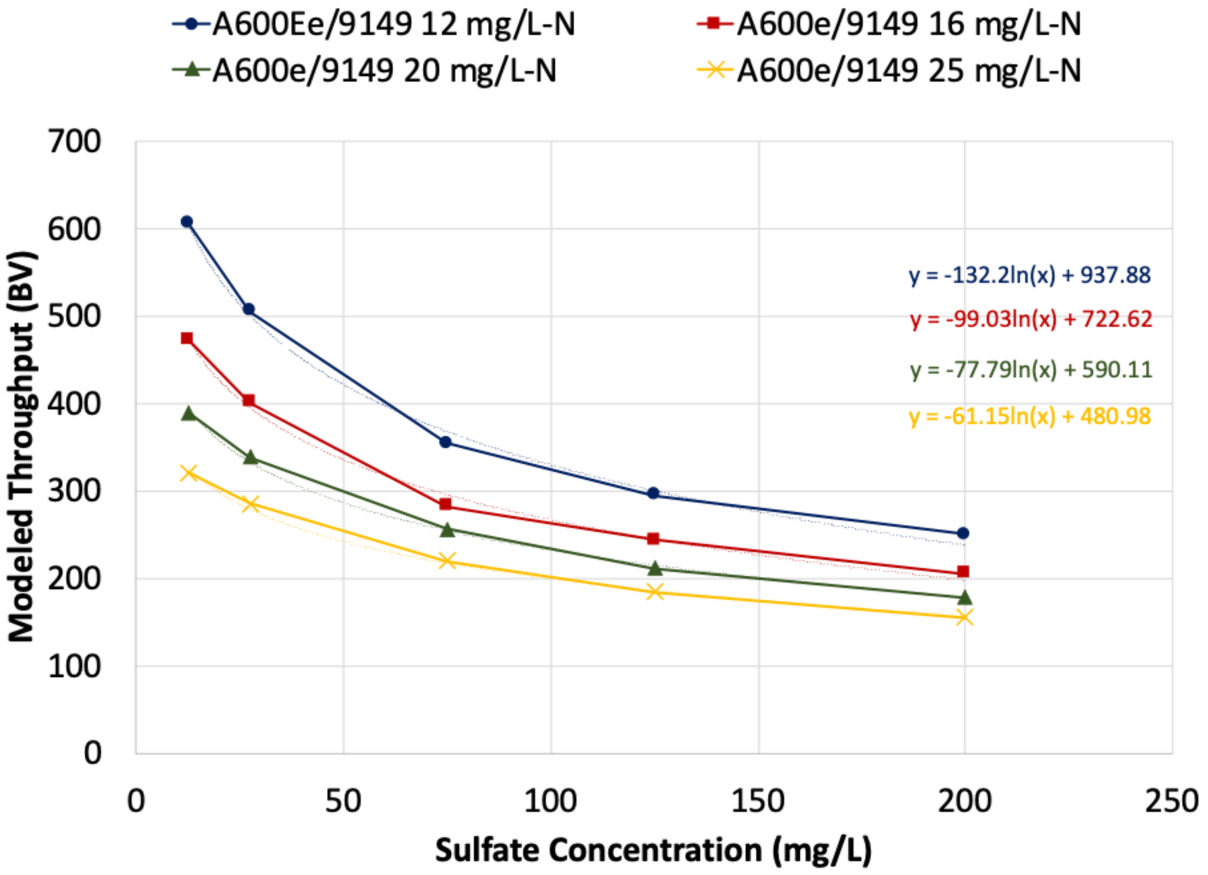
[67] Purolite
https://www.purolite.com/resources accessed October 8, 2020

Table D3. Modeled water quality parameters for nitrate treatment performance with SBA-IX

Bin ID	Sulfate Range (mg/L)	Modeled Sulfate (mg/L)	Nitrate Range (mg/L)	Modeled Nitrate (mg/L)
1	0 - 25	12.5	10.1 - 14	12
2	26 -50	27.5	14.1 - 18	16
3	50 - 100	75	18.1 - 22	20
4	101 - 150	125	> 22.1	25

Figure D2. Modeled SBA-IX throughput



Each system on the HR2W list requiring nitrate treatment was grouped by its raw water nitrate concentration represented by one of the curves in Figure D2 and throughput was determined by its corresponding sulfate concentration. The calculated throughput was then applied to the curve shown in Figure C1 to estimate the production cost for salt and brine disposal. In addition, electrical costs assuming a 10 psi headloss through the system and operator labor costs will be included as a separate budgetary line item.

Capital Cost Methodology for Radium using Cation Exchange: The same capital cost estimates that were developed for nitrate treatment will be used for radium cation exchange treatment with the exception of the cost of resin. The cost of resin is still under development.

Operational Cost Methodology for Radium using Cation Exchange: The primary operational cost driver for IX treatment is the costs associated with spent regenerant brine disposal and the associated consumables, namely salt. The operational costs for radium treatment are still under development.

Capital Cost Methodology for Uranium, Gross Alpha as a result of Uranium, and Perchlorate using Ion Exchange: Uranium and perchlorate are typically treated via single use strong base anion exchange. In concept, these are passive treatment systems much like GAC, where water is passed through pressure vessels and the media, in this case ion exchange resin is replaced when it is exhausted with respect to its target contaminant. For this cost estimating effort, a lead-lag vessel configuration was assumed with a maximum hydraulic loading rate of 8 gpm/ft.sq. Capital cost estimates were developed though an analysis of recent bid costs for single use ion exchange vessels. In total bid costs were reviewed for 6 systems, each with as many as five bidders for treatment vessel pairs with diameters of 4-ft, 6-ft, and 8-ft. the average bid cost for each vessel size was adjusted to 2020 dollars and a standard engineering multiplier of 2.36 was applied to develop an estimate of the installed capital costs. In addition to the bid costs, it was assumed each vessel would have a resin depth of 36” and with a corresponding cost of $300/cu.ft. The capital cost estimate for single pass ion exchange treatment are summarize in Table D4.

Table D4. Installed capital cost estimates for single use IX

Flow Rate (gpm)	Installed Capital Cost
1-101	$364,000
126-275	$545,000
276-400	$720,000
401-550	$1,400,000

Operational Cost Methodology for Uranium, and Perchlorate using Ion Exchange: Spent resin replacement and disposal represent the bulk of operational costs for uranium, perchlorate, and radium removal with this technology. A review of cost estimates for these services resulted in a unit cost of $0.65/kgal of water produced for uranium. This unit cost assumes a throughput of 130,000 BV prior to replacement and reflects the cost for resin replacement, disposal, and associated services. Perchlorate operational costs are still under development.

Capital Cost Methodology for Arsenic using Adsorption: Two technologies are generally considered if arsenic is the sole contaminant of concern, adsorption and coagulation filtration. Coagulation filtration is only considered for utilities with greater than 500 service connections[68]. Ion exchange is also listed as a BAT; however, this technology is generally only applied in places that have a low-cost brine disposal option (i.e. brine line or sewer access) or a cooccurring contaminant due to its relative complexity and high operational costs.

Adsorption is a passive treatment approach where untreated water flows through pressure vessels loaded with media, typically iron based, that has an affinity for arsenic. The pressure vessels are typically oriented in a lead/lag configuration. Capital cost estimates for arsenic adsorption systems reflect the methodology used for GAC capital costs and are based on achieving a minimum EBCT of 10 minutes between the two vessels. Due to the relative simplicity of this treatment approach, an installed capital multiplier of 2.36 was applied. The estimated installed capital costs are shown in Table D5.

Table D5. Arsenic adsorption installed capital costs

Treatment Flow Range (gpm)	Installed Capital Cost
1-250	$455,000
251-425	$570,000
426 – 875	$817,000

Capital Cost Methodology for Arsenic using Coagulation Filtration: The coagulation filtration(C/F) process involves the use of a chemical coagulant, typically ferric chloride or ferric sulfate, to create iron particles and co-precipitate arsenic. The arsenic laden iron particles are then removed via media filtration. Like adsorption, the process is more efficient at lower pH values. C/F systems are periodically backwashed to remove the entrained particles. Treatment equipment capital costs were solicited over a range of flow rates (500 – 2,500 gpm) from two manufacturers. The costs include filter vessels, chemical feed and storage, instrumentation and controls, and backwash water reclaim tank and pumps. The average manufacturer costs were used to estimate treatment capital costs at a

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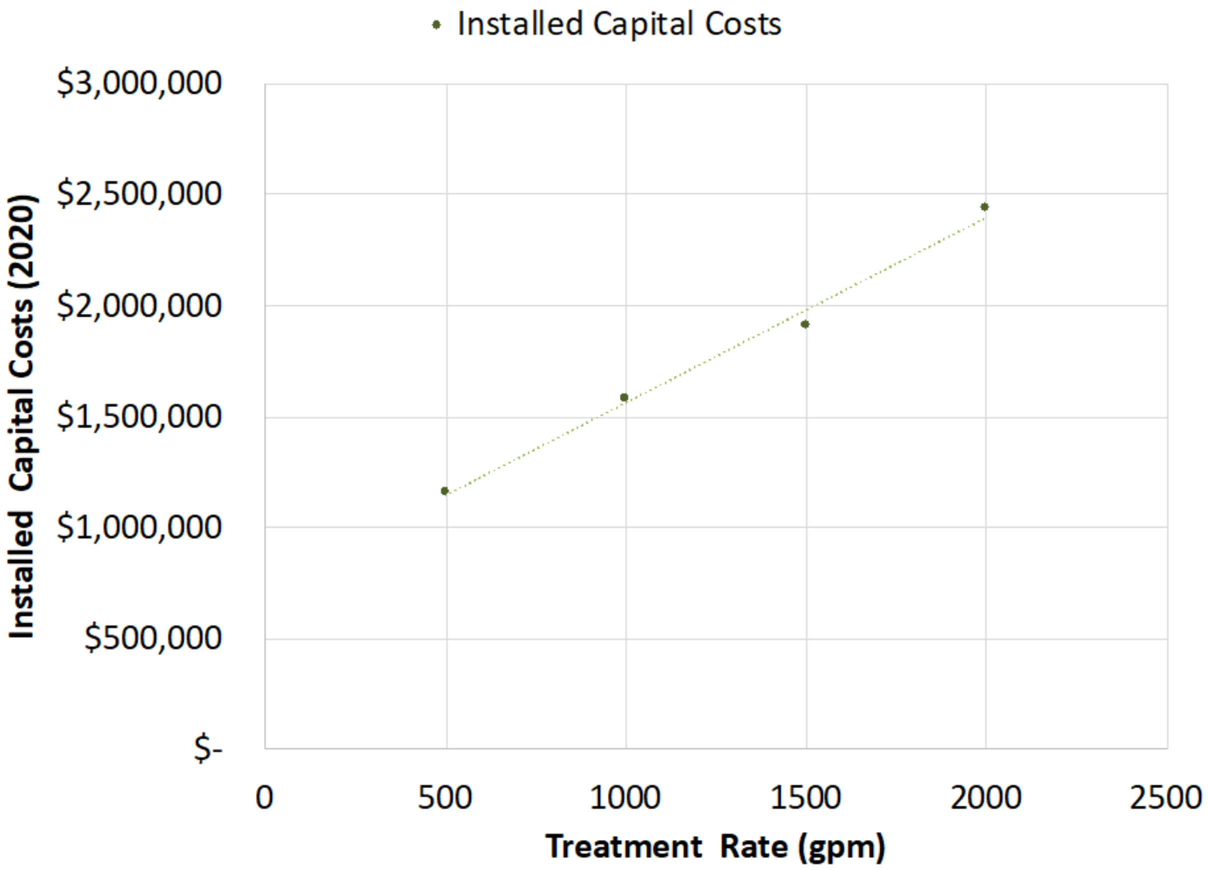
[68] California Regulations Related to Drinking Water https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/dw_regulations_2019_04_16.pdf, page 125

given treatment rate based on the regression shown in Figure D3.

Figure D3. Installed arsenic coagulation filtration capital costs



Operational Cost Methodology for Arsenic: A 2010 study[69] surveyed the costs for arsenic compliance including: media replacement, media disposal, chemicals, analytical testing, and labor. The median reported costs of compliance, adjusted to 2020 dollars were reported as follows

- Coagulation Filtration $1.05/kgal
- Adsorption $1.51/kgal

Capital Cost Methodology for Iron and Manganese using Filtration: For iron, the filtration process involves the use of a chemical oxidant, typically hypochlorite, to create hydroxide particles that are removed via media filtration. Manganese treatment relies on a catalytic surface reaction using greensand or pyrolusite media where it is oxidized and subsequently removed. The treatment systems are

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[69] 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

periodically backwashed to remove the entrained particles. The arsenic coagulation filtration capital costs were used for iron and manganese capital treatment costs. Treatment equipment capital costs were solicited over a range of flow rates (500 – 2,500 gpm) from two manufacturers. The costs include filter vessels, chemical feed and storage, instrumentation and controls, and backwash water reclaim tank and pumps. The average manufacturer costs were used to estimate treatment capital costs at a given treatment rate based on the regression shown in Figure C3.

Operational Cost Methodology for Iron and Manganese using Filtration: The operational costs for iron and manganese removal are not as substantial as arsenic removal. These costs are still under development.

Capital Cost Methodology for Fluoride using Activated Alumina: Fluoride removal can be accomplished with the use of activated alumina, an adsorptive media. In this approach, pH depression with sulfuric acid to approximately 5.5 is required to charge the functional sites of the media. Following pH depression, the water flows through pressure vessels loaded with activated alumina media where the fluoride is removed and then pH is readjusted, typically with caustic soda. Periodically the media is either replaced or regenerated on-site to restore the adsorptive capacity.

The capital cost estimates follow the approach used for arsenic adsorption with the addition of two chemical feed and storage systems (sulfuric acid and caustic soda) and enhanced instrumentation (pH and flow monitors) and a programmable logic controller (PLC), as shown in Table D6.

Table D6. Activated Alumina installed capital costs

Treatment Flow Range (gpm)	Installed Capital Cost
1-250	$657,000
251-425	$772,000
426 – 875	$1,019,000

Operational Cost Methodology for Fluoride using Activated Alumina: The costs for pH adjustment were modeled assuming an initial pH of 7.9 and alkalinity of 160 mg/L as $CaCO_3$. The pH was assumed to be adjusted to 5.5 with sulfuric acid and back to 7.9 using caustic soda following treatment. This results in a chemical cost of approximately $60/MG produced. The periodic media regeneration or replacement costs are not currently considered.

Capital Cost Methodology for Surface Water Treatment using Package Plants: For systems in consistent violation of the Surface Water Treatment Rules (SWTRs), a package treatment system may be considered. Package systems can reduce the system footprint and typically integrate the required treatment processes into a single skid for ease of operation and remote access.

Capital costs for both conventional and membrane package systems were estimated using recent vendor quotes. Equipment capital costs were averaged after units were grouped by treatment capacity. An engineering multiplier of 3.06 was applied to the average cost for each treatment capacity range to develop an estimate of the installed cost.

Selection of a membrane or conventional package system will require a review of the unique water quality parameters for individual systems. Costs for membrane and conventional treatment package systems were comparable and grouped together for averaging. Installed capital cost estimates are summarized in Table D7.

Table D7. Installed capital cost estimates for package treatment systems

Flow Rate (gpm)	Installed Capital Cost
1-175	$696,000
175-300	$972,000
300-700	$1,444,000
700-1,400	$1,929,000
1,400-2,100	$2,978,000

Operational Cost Methodology for Surface Water Treatment using Package Plants: Operations and maintenance cost estimates for surface water treatment technologies are in development. The estimates will include chemical additions such as coagulant, solids handling, and liquid waste disposal for membrane systems.

Capital Cost Methodology for Four-Log Virus Inactivation: Surface waters and groundwater under the influence of surface water need to achieve 4 log virus inactivation in addition to filtration. Inactivation will be met using chlorine contact time and the following conservative water quality assumption: a free chlorine of 1.0 mg/L, a water temperature of 15 C, and a pH of 8. For MDD flow conditions of 300 gpm or less, a 12-inch diameter pipeline, with length as necessary to provide required contact time will be assumed. A baffling factor of 0.9 will be used for the pipeline.

For MDD flow of 301 gpm and greater, a combination of 12-inch diameter pipeline and storage tanks (baffling factor 0.3) will be assumed to achieve the required inactivation. At these flows, the required length of pipe alone to achieve inactivation may become unreasonable for smaller treatment facilities. The capital cost estimates for 4 log virus inactivation are shown in Table D8 and were estimated conservatively using the high end of each flow range. 4-log virus inactivation costs can also be utilized to address water systems with bacteriological problems that may not rise to the level of surface water treatment but require 4-log inactivation under the Groundwater Rule.

Table D8. Installed capital cost estimates for 4 log virus inactivation

Flow Rate (gpm)	Installed Capital Cost[70]
1-175	$22,000
176-300	$37,000
301-700	$193,000
701-1,400	$411,000
1,401-2,100	$620,000

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[70] Costs for the major capital improvements (including pipeline installation) provided by QK, Incorporated, which is an engineering design firm in the Central Valley.