ATTACHMENT C3:
TREATMENT COST METHODOLOGY DETAILS

Attachment to the State Water Resources Control Board
2021 Drinking Water Needs Assessment
Cost Assessment Methodology Appendix C
https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2021_needs_assessment.pdf

COST METHODOLOGY BY CONTAMINANT & TREATMENT

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 U.S. 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. The multiplier is detailed in Table C3.1.

Table C3.1: GAC Engineering Multiplier Breakdown

Category	Denotation	Percentage	Formula
Treatment Capital	A		
Installation	B	20%	A x 0.20
Electrical and I&C	C	5%	A x 0.05
General Site Civil	D	15%	A x 0.15
Subtotal	**E**		**A + B + C + D**
Overhead and Profit	F	10%	E x 0.10

Category	Denotation	Percentage	Formula
Contingency	G	25%	E x 0.25
Total Construction Capital Costs	**H**		**E + F + G**
Planning, Engineering, Legal & Administration	I	15%	H x 0.15
Construction Administration	J	10%	H x 0.10
TOTAL			**H + I +J**

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 C3.2 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 by adjusting the assumption used to develop the operational costs as summarized in Table C3.2.

Table C3.2: 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	$437,000
8	10,000	251 – 425	$536,000
12	20,000	426 – 875	$745,000
Two Pair - 12	20,000	876 – 1,750	$1,490,000

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 additional $30,000 for a pump station to overcome the headloss caused by the GAC treatment.

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 U.S. 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 ($2.02/lb-GAC), transportation ($0.29/lb-GAC), and disposal ($0.004/lb-GAC). These costs were normalized to a standard production cost equivalent to $0.28/1,000 gallons of water produced. Additional costs were then applied analytical costs, and increased electrical costs required to pump the water through the treatment system.

A summary of the of the estimated throughput that were used to develop operational costs regression curves for other contaminants are provided in Table C3.3.

Table C3.3: GAC Operational Cost Regressions

Contaminant	Raw Water Concentration	Treatment Objective	Estimated Throughput[1] (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
1,2,3-TCP	0.1 µg/L	0.005 µg/L	38,000
TOC	3 mg/L	2 mg/L	5,000[2]

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)[3]. 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 2.8 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

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[1] 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

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

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

recent bid costs and contingency were used in place of an engineering multiplier for this treatment method. 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
    - **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.

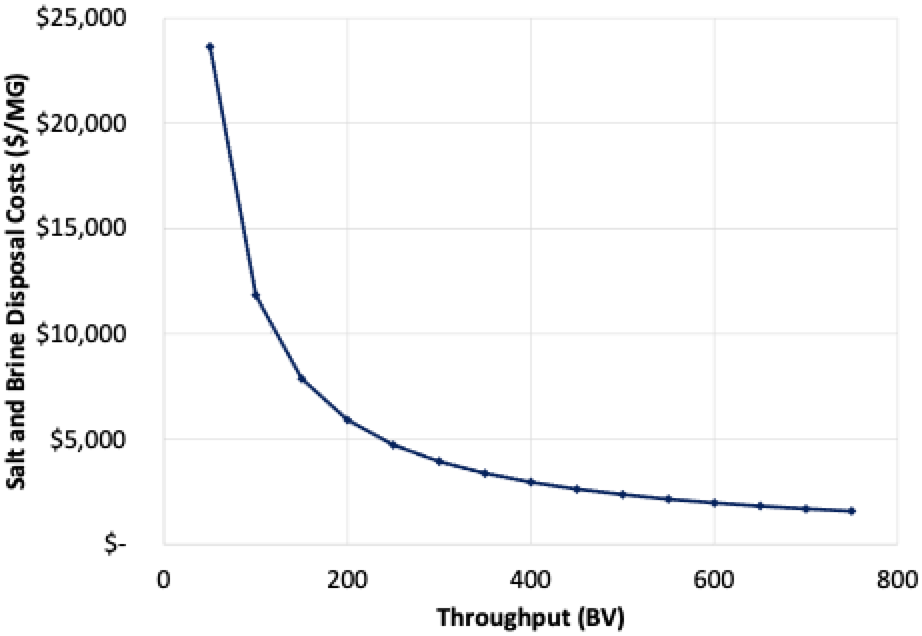
The flow rates and corresponding model developed installed capital costs are summarized in Table C3.4.

Table C3.4: Installed Capital Cost Estimates for SBA-IX Nitrate Removal

Flow Rate (gpm)	Installed Capital Cost
1-125	$764,000
126-275	$1,118,000
276-400	1,370,000
401-550	$1,656,000
551-700	$2,045,000
701-850	$2,753,000
851-1000	$2,972,000

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 C3.1 illustrates the impact of throughput on the salt and brine disposal costs as a function of water production.

Figure C3.1: 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 C3.5, were modeled using an illustrative resin model.[4] The outputs from the modeling effort are shown graphically in Figure C3.2. Note the upper limits modeled for sulfate and nitrate are 200 mg/L and 25 mg/L, respectively, however there are maximum observed significantly higher than both of these concentrations and while included in this analysis, wells with these concentrations are not likely feasible treatment solutions.

Table C3.5: 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

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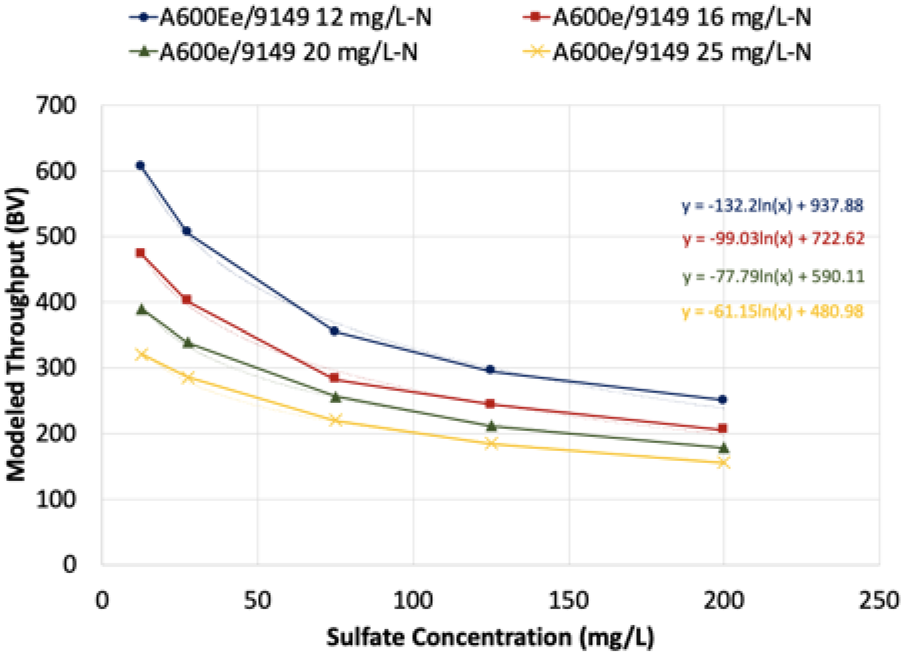
[4] Purolite, accessed October 8, 2020
https://www.purolite.com/resources

Bin ID	Sulfate Range (mg/L)	Modeled Sulfate (mg/L)	Nitrate Range (mg/L)	Modeled Nitrate (mg/L)
4	101 - 150	125	> 22.1	25
5	> 150	200		

Figure C3.2: 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 C3.2 and throughput was determined by its corresponding sulfate concentration. The calculated throughput was then applied to the curve shown in Figure C3.2 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 with strong base anion exchange will be used for radium cation exchange treatment with the exception of the cost of resin.

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. For this instance, the costs for nitrate disposal were applied.

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, 8-ft, 10-ft, and 2 x 10-ft pair. 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 as detailed in Table C3.1. 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 summarized in Table C3.6.

Table C3.6: Installed Capital Cost Estimates for Single Use IX

Flow Rate (gpm)	Installed Capital Cost
1-101	$357,000
102-225	$538,000
226-401	$713,000
402-627	$926,000
628-1256	$1,852,000

Operational Cost Methodology for Uranium, and Perchlorate using Ion Exchange: Spent resin replacement and disposal represent the bulk of operational costs for uranium and perchlorate removal with this technology. A review of service supplier cost estimates for these services resulted in a unit cost of $0.56/kgal of water produced for uranium and $0.10/kgal for perchlorate, with the primary difference being the disposal and handling of the uranium laden waste. This unit cost assumes a throughput of approximately 100,000 BV prior to replacement resin and reflects the cost for replacement, disposal, and associated services.

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.[5] Ion exchange is also listed as a best available technology; 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 co-occurring 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

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

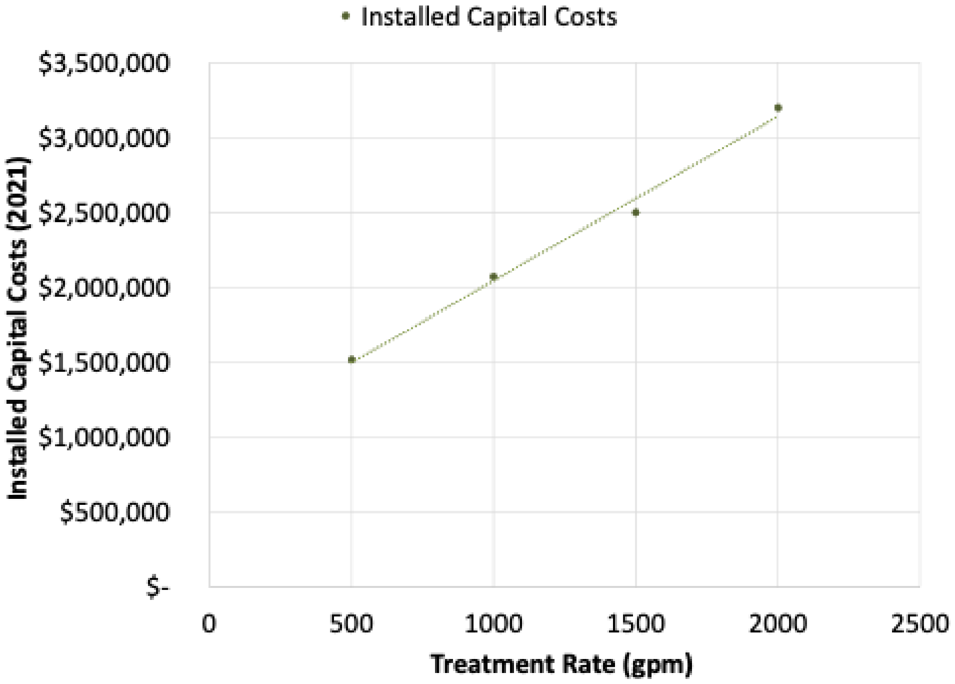
vessels are typically oriented in a lead/lag configuration. Capital cost estimates for arsenic adsorption systems reflect the methodology used for GAC capital costs and are based on achieving a minimum EBCT of 10 minutes between the two vessels. Due to the relative simplicity of this treatment approach, an installed capital multiplier of 2.36 was applied, as shown in Table C3.1. The estimated installed capital costs are shown in Table C3.7.

Table C3.7: Arsenic Adsorption Installed Capital Costs

Treatment Flow Range (gpm)	Installed Capital Cost
1-250	$437,000
251-425	$536,000
426-875	$745,000

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 given treatment rate based on the regression shown in Figure C3.3.

Figure C3.3: Installed Arsenic Coagulation Filtration Capital Costs

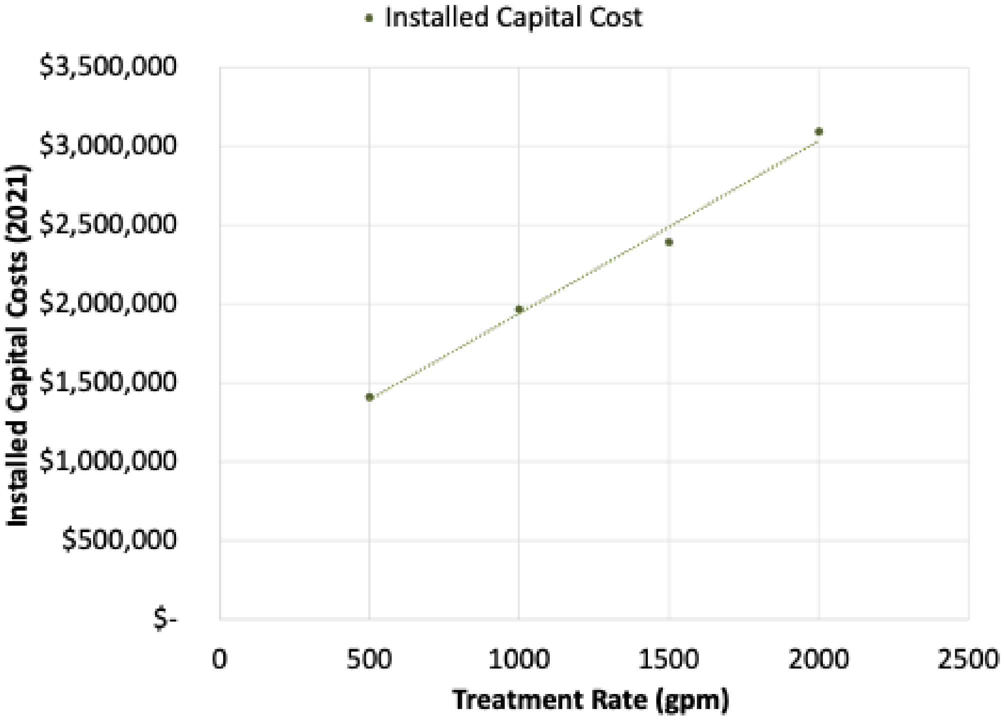


Operational Cost Methodology for Arsenic: A 2010 study[6] surveyed the costs for arsenic compliance including: media replacement, media disposal, chemicals, analytical testing, and labor. The median reported costs of compliance, adjusted to 2021 dollars were reported as follows

- Coagulation Filtration $1.07/kgal
- Adsorption $1.54/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 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 C3.4.

Figure C3.4: Installed Iron and Manganese Filtration Capital Costs



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[6] 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

Operational Cost Methodology for Iron and Manganese using Filtration: The operational costs for iron and manganese removal use arsenic removal with coagulation filtration as a surrogate which are anticipated to be a conservative estimate.

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 C3.8.

Table C3.8: Activated Alumina Installed Capital Costs

Treatment Flow Range (gpm)	Installed Capital Cost
1-250	$833,000
251-425	$949,000
426-675	$1,029,000
676-900	$1,199,000

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 $61/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. The multiplier is detailed in Table C3.9.

Table C3.9: Surface Water Package Plant Engineering Multiplier Breakdown

Category	Denotation	Percentage	Formula	% of Total
Treatment Capital	A			33%
Installation	B	30%	A x 0.30	10%
Electrical and I&C	C	25%	A x 0.25	8%
General Site Civil	D	20%	A x 0.20	7%
Subtotal	**E**		**A + B + C + D**	**57%**
Overhead and Profit	F	15%	E x 0.15	9%
Contingency	G	25%	E x 0.25	14%
Total Construction Capital Costs	**H**		**E + F + G**	**80%**
Planning, Engineering, Legal & Administration	I	15%	H x 0.15	12%
Construction Administration	J	10%	H x 0.10	8%
TOTAL			**H + I +J**	**100%**

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 C3.10.

Table C3.10: Installed Capital Cost Estimates for Package Treatment Systems

Flow Rate (gpm)	Installed Capital Cost
1-175	$703,000
175-300	$983,000
301-700	$1,461,000
701-1,400	$1,951,000
1,401-2,100	$3,012,000

Operational Cost Methodology for Surface Water Treatment using Package Plants:
Operations and maintenance cost estimates for surface water treatment technologies are not included, except for operator labor.

Capital Cost Methodology for 4-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 was assumed. A baffling factor of 0.9 was 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 C3.11 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 C3.11: Installed Capital Cost Estimates for 4-Log Virus Inactivation

Flow Rate (gpm)	Installed Capital Cost[7]
1-175	$23,000
176-300	$38,000
301-700	$196,000
701-1,400	$416,000
1,401-2,100	$627,000

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