TECHNICAL MEMORANDUM

DATE:	March 28, 2017 (DRAFT) June 15, 2017 (REVISED DRAFT) July 7, 2017 (FINAL)	Project No.: 693-20-16-01 SENT VIA: EMAIL
TO:	SRWA Technical Advisory Committee	
FROM:	Andy Smith, West Yost Associates, PE, RCE #74673 Elaine Howe, Trussell Technologies, PE, RCE #21477 (New Mexico) Fred Gerringer, Trussell Technologies, PE, RCE #67467	
REVIEWED BY:	Rhodes Trussell, Trussell Technologies, PE, RCE #25107 Gerry Nakano, West Yost Associates, PE, RCE #29524 Lindsay Smith, West Yost Associates, PE, RCE #72996	
SUBJECT:	Treatment Process Alternatives Technical Memorandum No. 2	

1.0 INTRODUCTION

The Stanislaus Regional Water Authority (SRWA) is planning to construct a new surface water treatment plant (WTP) as part of a Surface Water Supply Project (Project) to provide a new, supplemental drinking water supply to the cities of Ceres and Turlock (Cities). To facilitate identification of a preferred treatment train by the SRWA Technical Advisory Committee (TAC), a variety of workshops were scheduled and two Technical Memoranda (TMs) were requested to develop and evaluate viable treatment options. The first workshop was held June 30, 2016 and included a robust discussion of treatment technologies and processes, and was followed by a TM titled "Treatment Process Alternatives, TM 1, Part 1" (Trussell Technologies [Trussell], September 6, 2016), referred to henceforth as TM 1. A second workshop was held January 12, 2017 and focused on the results of initial source water sampling and bench testing of potentially available treatment alternatives. The third workshop will be held on March 30, 2017.

This TM builds on information presented in TM 1. The draft version of this TM 2 (published in March 2017) was intended to aid the TAC in the ongoing evaluation and refinement of available treatment process alternatives, and to help guide discussion of this information at the March 30, 2017 TAC workshop. This revised draft of the TM reflects discussion at that workshop, as well as additional discussion at a subsequent TAC workshop on May 16, 2017.

This TM is organized as follows:

1. Introduction
2. Background and Purpose
3. Summary of Early Source Water Sampling and Bench Testing Results
4. Development of Refined Treatment Train Alternatives
5. Non-Cost Comparison of Unit Processes
6. Construction Cost Comparison of Unit Processes and Treatment Trains
7. Risk Assessment, Recommendations and Supplemental Evaluation Information
8. Next Steps
9. References

2.0 BACKGROUND AND PURPOSE

This section provides a summary of previous work completed by the Program Management (PM) Team (West Yost Associates [West Yost] and Trussell) and TAC, and describes the intended outcome of this TM. Previous work referenced herein includes the development of treatment performance goals and the first phase of evaluation of available treatment process alternatives.

2.1 Overview of Treatment Performance Goals

On May 12, 2016, the PM Team and TAC conducted a workshop to identify performance goals for the treatment and delivery of surface water to the Cities of Ceres and Turlock. The results of this workshop were captured in a TM titled “Treatment Performance Goals” (Trussell, July 21, 2016) and presented to the SRWA Board on August 10, 2016. As presented in the TM, the performance goals can be condensed as follows:

- **Employ a Reasonably Robust Treatment Train**: The treatment train should be robust to accommodate “normal” raw water quality variability, and to accommodate nighttime unmanned facility operations. Plant shutdown is acceptable under extreme water quality conditions, since groundwater will remain available.
- **Use Proven Processes**: Choose processes that are successfully operating at other plants. Demonstration testing will be required for membrane filtration, if selected.
- **Minimize Disinfection Byproduct (DBP) Formation**: Choose disinfection and total organic carbon (TOC) removal options that result in lower DBP concentrations. Chloramines will be considered for final disinfection, but only if upstream processes are not expected to sufficiently reduce DBP formation potential.
- **Design for Unmanned Night Operations**: Treatment process complexity and instrumentation and monitoring should be considered in meeting the goal of unmanned facility night operations.

The performance goals have established a general framework for evaluating a range of available treatment process alternatives to date, and will be returned to during discussion of the relative advantages and disadvantages of the treatment trains and unit processes presented in subsequent sections of this TM.

2.2 Overview of Treatment Process Alternatives TM No. 1

After the development of the treatment performance goals described above, and upon completion of a review of available historical Tuolumne River raw water quality data, the PM Team began the first phase of evaluating available treatment process alternatives for the Project. This first evaluation phase included a TAC workshop conducted by West Yost and Trussell on June 30, 2016 and culminated in TM 1.

The objectives and conclusions of TM 1 are summarized below:

- **Describe drivers expected to shape the TAC's evaluation of available alternatives**. Expected drivers included potential contamination sources, source water quality, treatment performance goals and input from Division of Drinking Water (DDW) staff.
- **Describe alternative treatment *processes* for achieving regulatory compliance and SRWA's adopted treatment performance goals**. Processes described include pretreatment (generally), direct filtration, conventional clarification and filtration, granular media filtration, membrane filtration, disinfection (generally), and ozone treatment.
- **Summarize and compare alternative treatment *trains* deemed potentially capable of achieving regulatory compliance and SRWA's adopted treatment performance goals**. Five treatment trains were developed. Three included the use of direct filtration and two included conventional clarification and filtration. In terms of disinfection, two trains included the use of ozone as a primary disinfectant and three trains assumed that primary disinfection is provided by free chlorine, ultraviolet light, or both. One of the trains included the use of membrane filters; the remaining trains relied on granular media filtration.
- **Identify information gaps affecting refinement of the list of potentially viable alternatives**. Information gaps identified in the TM include performance of the infiltration gallery, source water TOC concentrations at the infiltration gallery location, incidence of pesticide contamination in source water, incidence of algae-related taste and odors and/or toxins, TOC removal characteristics via enhanced coagulation, and ozone demand of raw and clarified source water.
- **Identify next steps in the alternatives evaluation process, including necessary TAC recommendation points.** Principal recommendation points identified in the TM include the recommendation of whether or not to include ozone and biologically active filters in the treatment train, and whether or not to include direct filtration.

Following the finalization of TM 1, a staff report was prepared for the SRWA Board to summarize key elements of the TM and to seek Board approval to proceed with the further evaluation of treatment trains including ozone and biologically active filters, and to further evaluate the feasibility of direct filtration. Board action concurred with the TAC's recommendation.

2.3 Purpose of Treatment Process Alternatives TM No. 2

This TM, referred to herein as TM 2, builds on the documents and SRWA Board actions described above. The purpose of TM 2 can be broadly summarized as follows:

- **Update the TAC on the results of source water sampling and bench-scale testing efforts** completed since TM 1 was finalized, and describe the impacts of these results on information gaps and preliminary recommendations described in TM 1.
- **Document discussion and TAC direction provided during a TAC workshop held on January 12, 2017**. This workshop included a brief summary of source water sampling and bench-scale testing activities to date and renewed discussion of previously identified treatment trains and their ability to achieve regulatory compliance and SRWA's treatment performance goals.
- **Provide a more detailed description and comparison of key treatment processes** that comprise the treatment trains which remain under consideration, including capital and operating cost information, to facilitate the TAC's evaluation of relative benefits of each potential treatment train.
- **Document treatment train recommendations** reached by the TAC, based on source water quality and bench-scale testing results to date and the comparative benefits and cost information presented herein.

3.0 SUMMARY OF EARLY SOURCE WATER SAMPLING AND BENCH TESTING RESULTS

This section summarizes the results of source water sampling and bench-scale testing activities conducted between October 2016 and February 2017. These results are representative of only a portion of the planned sampling period, which is intended to evaluate seasonal trends and changes. These sampling and testing periods capture a portion of the impacts from significant precipitation events in January and February 2017.

3.1 Source Water Quality

Table 1 presents a comparison of select historical water quality parameters at the infiltration gallery location with current water quality from the SRWA sampling program, which started in October 2016. These data cover a four-month period from October 31, 2016 to February 27, 2017; the majority of the sampling campaign will occur over a 12-month period ending in October 2017. It should be noted that when a series of "atmospheric river" precipitation events in the area began in January 2017, sample collection frequency for TOC, dissolved organic carbon (DOC), iron and manganese was increased from once per month to once every two weeks, in order to facilitate a better understanding of the nature and duration of storm-related impacts on these key parameters. Other key parameters that could influence process train selection (e.g., total coliform, *E. coli*, turbidity and pH) are already being monitored once every two weeks.

Table 1. Comparison of SRWA Tuolumne River Sampling Results with Historical Water Quality Data, for Select Parameters

Water Quality Parameter	Statistic	Waterford Road CEDEN (8/09 – 8/12) Upstream	Fox Grove CEDEN (8/09 – 8/12) Upstream	Infiltration Gallery TID (5/06 – 10/08)	Infiltration Gallery SRWA (10/16 - ongoing)	TID Pilot Study TID (9/06 – 4/07) Downstream
Alkalinity, mg/L as CaCO3[a]	Range	No data	No data	23 - 80	16 - 28	27 - 36
	Average			37	22	32
	Median			37	24	32
	N[b]			40	6	--
Bromide, µg/L	Range	No data	No data	<0.1 - <0.1[c]	7.3 – 8.8	No data
	Average			<0.1	8.2	
	Median			<0.1	8.4	
	N			30	3	
Dissolved Oxygen, mg/L, Field	Range	7.05 – 7.27	7.09 – 17.60	7.93 – 14.49	9.3 – 11.7	7.40 – 18.50
	Average	7.16	9.42	10.60	10.5	10.33
	Median	7.16	7.85	10.53	10.7	7.71
	N	2	7	66	9	4
Organic Carbon, Dissolved, mg/L[a]	Range	No data	No data	1.3 – 4.0	1.9 – 3.9	1.5 – 2.3
	Average			2.5	2.8	
	Median			2.4	2.4	Not reported
	N			47	6	Not reported
Organic Carbon, Total, mg/L[a]	Range	No data	No data	1.4 – 6.5	1.9 – 7.3	1.5 – 2.3
	Average Average[d]			3.3	3.66 2.81[d]	1.8
	Median			3.0	2.6[C]	Not reported
	N			47	6	Not reported
Specific Conductance, µmho/cm, Lab	Range	30 - 60	30 - 190	33 - 201	52 - 76	No data
	Average	43	88	90	66	
	Median	40	75	77	68	
	N	5	10	67	4	
Specific Conductance, µmho/cm, Field	Range				47.8 – 68.2	
	Average				59.3	
	Median				61.1	
	N				9	
SUVA, L/mg-m[a]	Range	Not reported	Not reported	Not reported	2.5 – 3.0	Not reported
	Average				2.8	
	Median				2.8	
	N				6	

Table 1. Comparison of SRWA Tuolumne River Sampling Results with Historical Water Quality Data, for Select Parameters

Water Quality Parameter	Statistic	Waterford Road CEDEN (8/09 – 8/12) Upstream	Fox Grove CEDEN (8/09 – 8/12) Upstream	Infiltration Gallery TID (5/06 – 10/08)	Infiltration Gallery SRWA (10/16 - ongoing)	TID Pilot Study TID (9/06 – 4/07) Downstream
Turbidity, NTU, Lab[(a)]	Range	0.89 – 1.08	1.33 – 3.56	0.62 – 7.32	0.65 - 12	0.75 – 8.70
	Average	0.96	2.33	2.25	3.9	2.8
	Median	0.96	1.62	2.25	1.3	Not reported
	N	3	7	72	9	Not reported
Turbidity, NTU, Field	Range				0.59 – 15.43	
	Average				6.1	
	Median				2.4	
	N				9	
Ammonia, mg/L	Range	No data	No data	<0.1[(c)]	<0.05 – 0.059[(c)]	No data
	Average			<0.1	<0.05	
	Median			<0.1	--	
	N			11	3	
Nitrate, mg/L as N	Range	No data	No data	0.3 – 0.9	0.17 – 0.49	No data
	Average			0.5	0.323	
	Median			0.4	0.315	
	N			19	4	
Iron, Dissolved, mg/L	Range	No data	No data	No data	0.021 – 0.098	No data
	Average				0.067	
	Median				0.073	
	N				5	
Iron, Total, mg/L	Range	No data	No data	<0.05 – 6.5[(c)]	0.14 – 0.67	0.11 – 0.35
	Average			0.188	0.398	0.17
	Median			<0.10	0.4	Not reported
	N			94	5	Not reported
Manganese, Dissolved, mg/L	Range	No data	No data	No data	<0.002 – 0.0044[(c)]	No data
	Average				<0.002	
	Median				<0.002	
	N				5	
Manganese, Total, mg/L	Range	No data	No data	<0.01 – 0.850[(c)]	0.013 – 0.028	0.014 – 0.085
	Average			0.0294	0.018	0.04
	Median			0.017	0.015	Not reported
	N			95	5	Not reported

Table 1. Comparison of SRWA Tuolumne River Sampling Results with Historical Water Quality Data, for Select Parameters

Water Quality Parameter	Statistic	Waterford Road CEDEN (8/09 – 8/12) Upstream	Fox Grove CEDEN (8/09 – 8/12) Upstream	Infiltration Gallery TID (5/06 – 10/08)	Infiltration Gallery SRWA (10/16 - ongoing)	TID Pilot Study TID (9/06 – 4/07) Downstream
E. coli, MPN/100 mL	Range	12.1 – 172.3	3 – 461.1	0 - 160	6.3 - 460	No data
	Average	60.8	75.9	24.0	108	
	Median	26.2	29.0	12.7	41	
	Average				108	
	N	5	10	24	9	
Total Coliform, MPN/100 mL	Range	866 - >2420	816 – >2420	4 - >1600	820 - >2420	No data
	Average	1728.4	1876.8	282	1851	
	Median	1732.9	1986.3	130	1700	
	N	5	8	73	9	
Cryptosporidium, oocysts/L	Range	0	0 – 0.258	0 - 09	0 - 1	No data
	Average		0.052	0	0.0025	
	Median		0	0	0	
	N	1	5	24	4	
Giardia, cysts/L	Range	0.195	0 – 0.129	0 – 2.00	0.1 – 0.4	No data
	Average		0.026	0.33	0.225	
	Median		0	0	0.2	
	N	1	5	12	4	

(a) Eurofins and Trussell Tech (TT) data were merged into one dataset when analysis frequency was increased for this Project. When samples for a specific collection date were analyzed by both Eurofins and TT, only Eurofins data was included in dataset.

(b) "N" = number of samples

(c) When the dataset included measurements below the detection limit, the detection limit was used in calculating the average and median.

(d) The TOC measured by Eurofins on Feb 13, 2017 was 7.3 mg/L. The DOC measured for this same sample was 2.8 mg/L. For all prior samples, the DOC was > 94% of the TOC. Additionally, the TOC of water collected this same day for bench testing was 3.07 mg/L. Therefore, the TOC measurement of 7.3 mg/L is considered an outlier and was excluded from the indicated statistics.

Most parameters in this sampling campaign are analyzed by the State-certified laboratory, Eurofins. Dissolved oxygen, conductivity, pH, temperature, and turbidity are also measured in the field at the time of sample collection. TOC, DOC, ultraviolet (UV)-254[1], pH, turbidity and alkalinity are also measured in the Trussell laboratory when river water samples are received for bench testing. Measurements from all three sources are included in Table 1.

Statements about how these recently collected data compare with historic data, along with preliminary implications for treatment train selection, are discussed below.

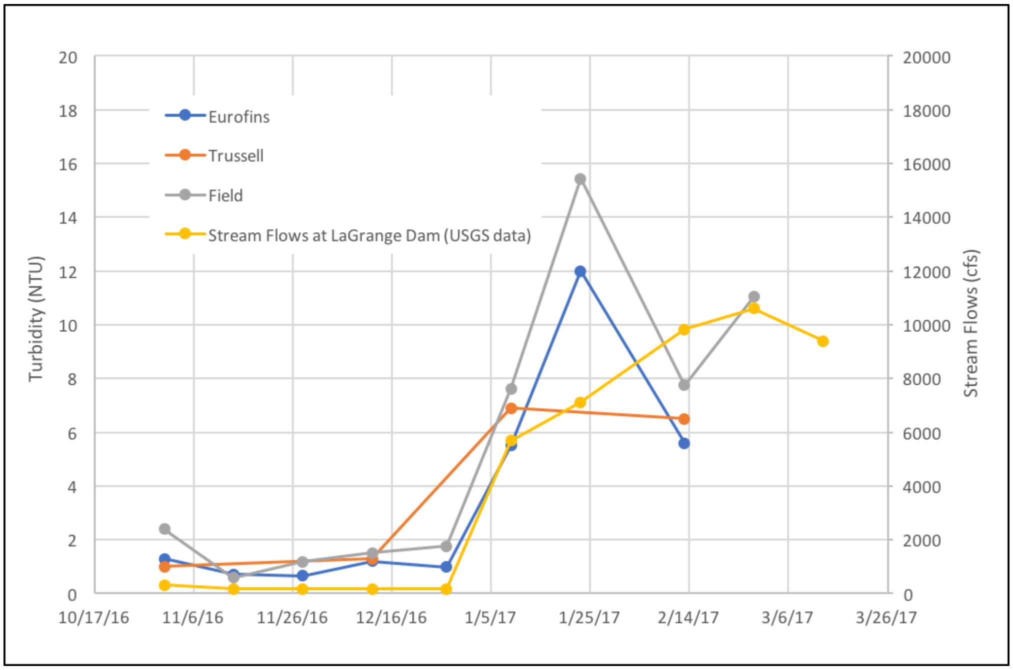
3.1.1 General Water Quality Parameters

General water quality parameters include alkalinity, color, pH, turbidity, sodium, chloride, conductivity, dissolved oxygen, temperature, calcium, and magnesium. Noteworthy observations are summarized below:

- **Alkalinity** ranged from 16-28 milligrams per liter (mg/L) as $CaCO_3$, which is a slightly lower than nearby historical measurements.
- **Turbidity** measured in the lab ranged from 0.65-12 nephelometric turbidity units (NTU), while field turbidity ranged from 0.59-15.43 NTU. These numbers are in line with the historical data, but the maximum measured during this monitoring program is slightly higher than the maximum historical measurements. As shown on Figure 1 turbidity increased in relation to the winter storm events and higher releases from Don Pedro Reservoir. The infiltration gallery intake will likely dampen the storm related turbidity “spikes.” Even without accounting for the assumed turbidity reduction provided by the infiltration gallery, these raw water turbidity values do not preclude the use of direct filtration or membrane filtration (which generally requires that raw water turbidity is consistently less than 10 NTU).

[1] UV-254: The amount of UV light that is absorbed by the sample at a wavelength of 254 nanometers (nm).

Figure 1. Turbidity Levels in the Tuolumne River at the Infiltration Gallery Location in Relation to Releases from Don Pedro Reservoir



3.1.2 Nutrients

The parameters considered in the nutrient category are ammonia, nitrite, nitrate, and phosphorus[2]. Noteworthy observations are summarized below:

- **Ammonia** was below the minimum reporting limit (MRL) of 0.05 mg/L in three out of four samples. The one time it was detected the concentration was 0.059 mg/L, just slightly above the MRL.
- **Nitrite** was never detected.
- **Nitrate** concentrations were lower than the historical data, with a maximum measured concentration of 0.49 mg/L as N and an average concentration of 0.32 mg/L as N. The average nitrate concentration from the historical data was 0.5 mg/L as N. Nitrate concentrations measured during the on-going monitoring program decreased in relation to the Dec-Feb storm events and large releases from Don Pedro Reservoir, likely due to dilution.

[2] To date, phosphorus test results have not been received from the laboratory. We are following up with the lab to locate the missing data.

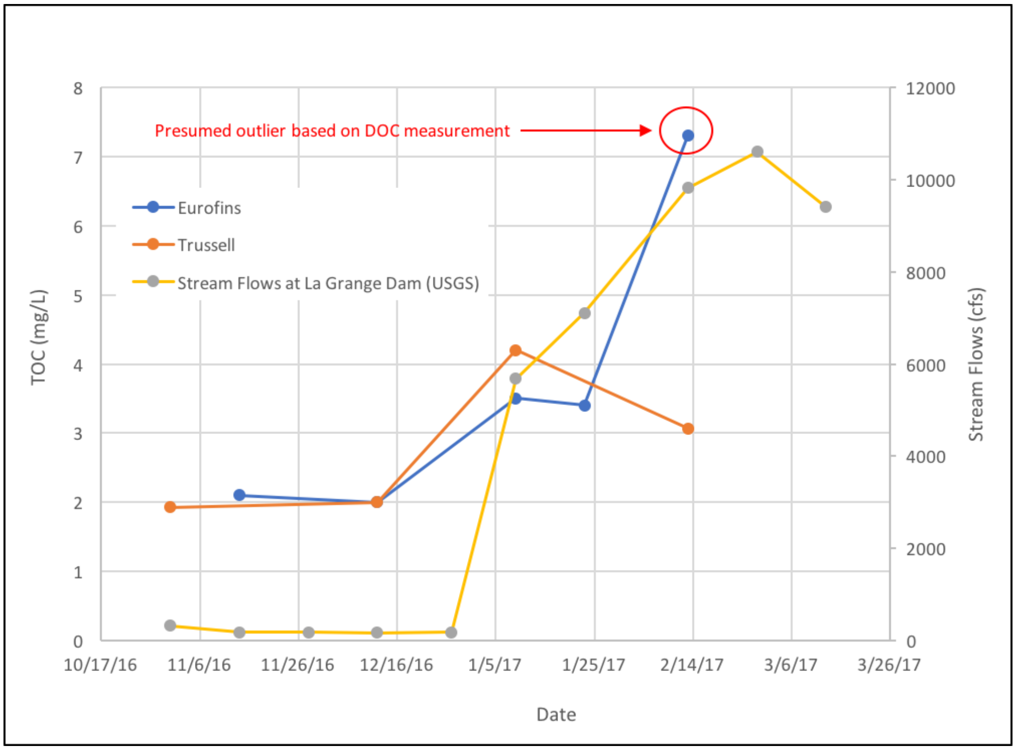
3.1.3 Disinfection By-Product Related Parameters

Water quality parameters that fall into the DBP-related category include TOC, DOC, UV-254, specific ultraviolet absorbance (SUVA), and bromide. Noteworthy observations are summarized below:

- **Bromide** concentrations remained very low, with a maximum concentration of 0.0088 mg/L. Bromate can form during ozonation when bromide concentrations are high enough (typically at concentrations greater than 0.10 mg/L (Song, et al., 1997 in USEPA, April 1999)). The maximum contaminant level (MCL) for bromate is 0.010 mg/L. Based on experience, the bromide limit for exceeding the bromate MCL with ozone is typically 0.1 to 0.3 mg/L, more than an order of magnitude higher than measured concentrations. Thus, bromate formation during ozonation of this source water should not be a concern.
- **Natural organic matter (NOM)** in the water is the precursor material for the chlorination DBPs. TOC concentrations (a measure of NOM) measured to date as part of this SRWA monitoring program have been consistent with historical concentrations. The average TOC concentration measured between 2006 and 2008 at the infiltration gallery location was 3.3 mg/L, and the average from current monitoring is 2.8 mg/L (excluding a presumed outlier[3] of 7.3 mg/L).
- **TOC** concentrations in the Tuolumne River increased in relation to winter storm events and higher stream flows (see Figure 2).
- As discussed in the Section 3.2 of this TM, the TOC concentrations of this source water are expected to be high enough at times that DBP formation will exceed regulatory limits with free chlorine as a final disinfectant, unless sufficient TOC is removed during treatment or chloramines are used for final disinfection.
- **DOC** concentrations are consistently > 94 percent of the TOC concentrations, meaning that most of the organic carbon is dissolved rather than particulate.

[3] This reported TOC concentration is considered an outlier and disregarded because (a) for the same sample the DOC was measured by the laboratory to be 2.8 mg/L, (b) the DOC has consistently been between 94 percent and 112 percent of the TOC and if the TOC was truly 7.3 mg/L then the DOC would have been only 38 percent of the TOC, and (c) Trussell Tech measured the TOC of a different sample, but collected the same day, to be 3.07 mg/L.

Figure 2. TOC in the Tuolumne River at the Infiltration Gallery Location in Relation to Releases from Don Pedro Reservoir



3.1.4 Iron and Manganese

As part of the on-going monitoring program, both total and dissolved iron and manganese have been measured. The historical dataset includes only total iron and manganese concentrations. Recent SRWA monitoring data indicates manganese is present in the Tuolumne River at the infiltration gallery location, at total manganese concentrations ranging from 14 to 28 micrograms per liter (µg/L). In four of seven samples to date, the dissolved manganese concentration was below 2 µg/L, which is the method reporting limit. These data indicate that dissolved manganese from the Tuolumne River (as Mn^{2+}) may not be a concern for this WTP unless there is another source of Mn^{2+} or ozone produces a manganese colloid that is not effectively removed. Also, it is good to keep in mind that we are only partway through the sampling campaign, so there may be additional raw water samples in the future with Mn^{2+}. Based on experience with infiltration galleries (and other types of sub-surface collectors like Ranney collectors, etc.) and water treatment plant design, manganese can show up when the full-scale facility starts up or has been operating some time, even if it is not measured in the Tuolumne River samples (Trussell and Snoeyink, 2017). Ideally, the WTP design will be flexible enough to address manganese removal if needed. The finished water goal for total manganese should be ≤ 10 µg/L to avoid potential aesthetic issues related to manganese that may pass through the treatment plant and into the distribution system.

Iron and manganese are important because of the potential for aesthetically unpleasant colored water in the distribution system, as well as potential health impacts. Currently, both iron and manganese have a secondary MCL but neither has a primary MCL. Manganese has been included on the latest Contaminant Candidate List (CCL4) and Unregulated Contaminant Monitoring Rule (UCMR4) lists because of potential neurological effects in children and infants. Therefore, a pMCL may be forthcoming in the future for manganese.

3.1.5 Microbiological

Microbiological parameters that were measured during this on-going sampling program include *E. coli*, total coliform, *Giardia* and *Cryptosporidium*. Noteworthy observations are summarized below:

- **Total coliform** numbers measured during this sampling program are in line with those reported for the upstream Waterford Road and Fox Grove locations, as well as the downstream historical sampling locations. However, the numbers are higher than measured by Turlock Irrigation District at the infiltration gallery location between 2006 and 2008 as part of the Watershed Sanitary Survey.
- On average, the ***E. coli*** numbers measured during the ongoing sampling campaign are higher than the historical data.
- As discussed in Section 4.2 of this TM, the total coliform and *E. coli* levels may lead DDW to require higher-than-minimum pathogen treatment for *Giardia* and viruses (minimum treatment requires 3-log and 4-log reduction, respectively).
- ***Cryptosporidium*** samples analyzed to date (four out of the 24 required samples) indicate this source water falls in Bin 1, requiring only 2-log removal per regulations. DDW, however, may require 3-log removal based on total coliform and *E. coli* results.

3.1.6 Pesticides and other Synthetic Organic Chemicals (SOCs)

The pesticides and SOCs included in this sampling program include the following:

- Constituents with a primary or secondary maximum contaminant level (pMCL or sMCL).
- Constituents detected above the analytical detection limit in the available historical data.
- Constituents with high application rates (>5,000 lbs/yr or applied to >10,000 acres) in the watershed.

Of the 189 parameters analyzed, only two were detected: diuron and simazine. Diuron has a Health Advisory level of 1 mg/L and was measured at 66 nanograms per liter (ng/L), or 0.000066 mg/L, which is roughly 4 orders of magnitude less than the Health Advisory Level. Simazine has a pMCL of 0.004 mg/L and was measured at a concentration of 93 ng/L (or 0.000093 mg/L), or roughly two orders of magnitude below the pMCL. Neither of these are on the list of high-use pesticides for the Lower Tuolumne River watershed. However, both pesticides were previously detected in historical sampling between La Grange Dam and Modesto.

3.2 Bench Test Results

To help answer questions regarding the treatability of the source water, and to aid in the development of preliminary design doses for certain treatment chemicals, a series of bench tests are being conducted as part of a year-long monitoring program (November 2016 through October 2017). The bench tests conducted to date, and the questions they have attempted to answer, are summarized below:

- **Coagulation jar tests** were conducted to evaluate TOC removal with three commonly used coagulants as a function of coagulant dose and pH. In conjunction with these jar tests, DBP formation with free chlorine and chloramines has been evaluated as a function of contact time, using the simulated distribution system disinfection by-product (SDSDBP) test procedure.
- **Ozone demand tests** were conducted to evaluate the ozone dose required for ozonation of both raw water (i.e., pre-ozonation) and coagulated/settled water (i.e., intermediate ozonation). Bromate formation, a regulated ozonation by-product, was determined as a function of ozone dose. Ozone demand tests are being conducted monthly to evaluate seasonal changes in ozone demand and to accurately select a design dose.
- **Manganese removal jar tests** were conducted to evaluate whether reduced manganese (Mn^{2+}) could be effectively removed if ozone were included in the treatment train. Mn^{2+} concentrations measured thus far in this source water have been very low, with only three of seven samples having a measurable concentration above the laboratory's method reporting limit. There are other potential sources of manganese for SRWA's treatment plant, however: (a) manganese as a component of a ferric chloride coagulant (if used); (b) reduction of particulate manganese through the infiltration gallery or an unanticipated contribution by groundwater to infiltration gallery influent; and (c) dissolved manganese in the decant stream from sludge storage basins and drying beds. Experience indicates that reduced manganese can show up in the influent to the WTP even if it was not measured during the source water characterization program, and the WTP design should be flexible to accommodate manganese removal if needed (Trussell and Snoeyink, 2017). Ineffective removal of Mn^{2+} can result in colored water that is aesthetically unappealing to consumers. In addition, a pMCL is being considered for manganese because of potential neurological effects in children and infants.

Key preliminary findings of these bench tests are summarized in the subsections below. The discussion is organized in terms of the questions each bench test was intended to answer. A separate, standalone report will be prepared to provide detailed discussion of all bench test results; this report is expected to be published in April 2017.

3.2.1 Enhanced Coagulation and DBP Formation

The Disinfectants and Disinfection Byproducts (D/DBP) Rule requires a specified percentage of raw water TOC to be removed through a process known as "enhanced coagulation[4]", depending on raw water TOC concentration and alkalinity. The TOC removal requirements are summarized in Table 2. Per the regulations, enhanced coagulation requirements apply to conventional treatment, while direct filtration and membrane filtration treatment trains are exempt. The reason is because a low coagulant dose (e.g., $\leq$ 5 mg/L) is used in direct filtration and membrane filtration, which typically provides little or no TOC removal. So, the regulations do not force a direct filtration plant to add sedimentation to accommodate the higher required coagulant dose, but they still require that the plant is compliant with the DBP standards for drinking water. Therefore, regardless of whether enhanced coagulation is required, the finished water must meet the total trihalomethanes (TTHM) and haloacetic acids (HAA5) MCLs of 80 µg/L and 60 µg/L, respectively, as measured in the distribution system.

Table 2. TOC Removal Requirements as Specified by the D/DBP Rule

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	0-60	>60-120	>120
>2.0 – 4.0	35%	25%	15%
>4.0 – 8.0	45%	35%	25%
>8.0	50%	40%	30%

Because DBP formation is largely a function of DBP precursor concentration (i.e., TOC), the D/DBP Rule includes "Alternative Compliance Criteria" which are alternate means of complying with this Rule. In brief, the Alternative Compliance Criteria applicable to the Tuolumne River state that the specified TOC removals do not have to be met if (1) raw water TOC is <2.0 mg/L, (2) treated water TOC is <2.0 mg/L, (3) raw water SUVA is < 2.0 L/mg-m, or (4) treated water SUVA is <2.0 L/mg-m.

Three coagulants were tested to compare their effectiveness for both TOC removal and turbidity removal: ferric chloride (ferric), aluminum sulfate (alum), and polyaluminum chloride (PACl). These are conventional coagulants used widely in water treatment. Aluminum chlorohydrate ($Al_nCl_{(3n-m)}(OH)_m$) or ACH, another long-chain aluminum-based coagulant, was not tested as part of this study. ACH and PACl are similar chemicals; neither reduces pH or consuming as much alkalinity as alum.

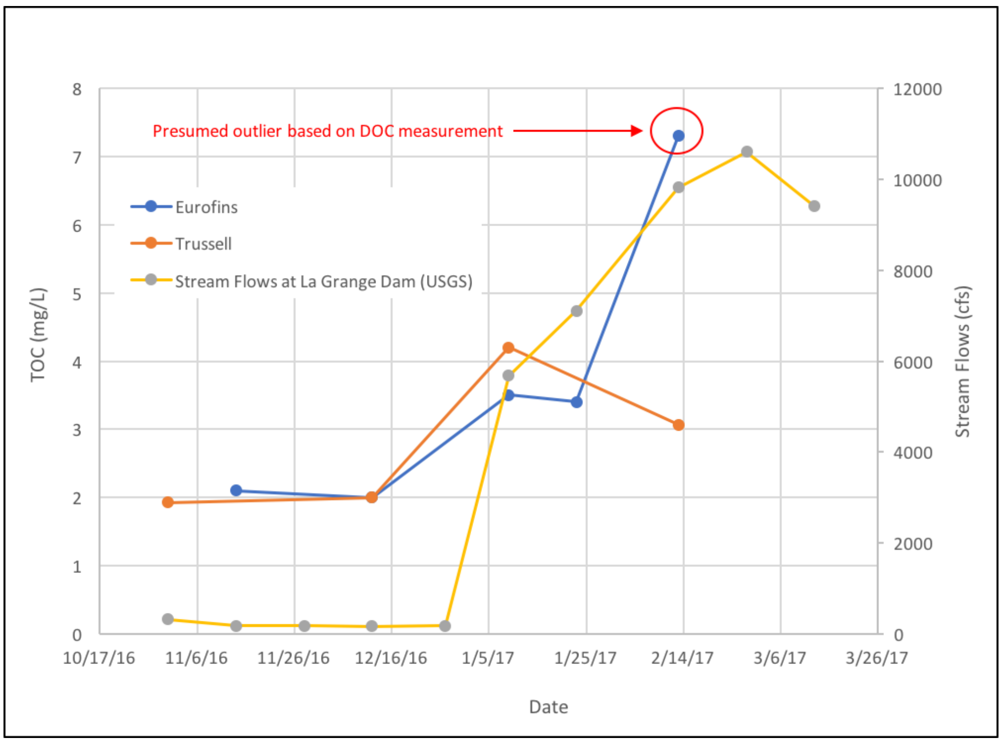
Results from these enhanced coagulation jar tests are discussed below in terms of key questions the tests were designed to answer.

[4] Enhanced coagulation typically entails the precipitation of humic compounds present in raw water by coagulation, flocculation and settling.

3.2.1.1 Will Enhanced Coagulation be required for this source water, or will one of the Alternative Compliance Criteria be applicable?

The raw water TOC has been variable since monitoring began at the end of October, with concentrations ranging from 1.9 mg/L to 4.2 mg/L (the max TOC of 7.3 mg/L was excluded as an outlier). The TOC was ≤ 2.1 mg/L from the start of the sampling campaign through mid-December when the "atmospheric river" storm events began, such that only a small coagulant dose would be required to reduce the TOC below 2.0 mg/L. From mid-December 2016 to early March 2017, TOC levels have been well above 2.0 mg/L such that enhanced coagulation would be required for conventional treatment. This variability in raw water TOC is shown on Figure 2 (and repeated below as Figure 3 for ease of reference) in relation to stream flows.

Figure 3. Raw Water TOC Concentrations Over Time and as a Function of Stream Flows



The SUVA for this source water has consistently been above 2.0 L/mg-m, ranging from 2.5 to 3.0 L/mg-m. SUVA is an indicator of the humic content of the water. Humic organic material is more amenable to removal through coagulation than non-humic organic material. SUVA is calculated by dividing the UV-254 measurement by the DOC concentration. Waters with a low SUVA contain primarily non-humic organic material which are not amenable to enhanced coagulation. Waters with a high SUVA are generally amenable to enhanced coagulation. Thus, the raw water for this treatment plant should be amenable to effective TOC removal through enhanced coagulation.

ANSWER: For a conventional treatment facility, enhanced coagulation (i.e., use of a higher coagulant dose to meet regulated TOC removal) will be required some portion of the year. A conventional treatment facility is designed with sedimentation, which can handle the changing coagulant doses without impacting treatment. As such, there is no reduction in treatment capacity and no more frequent backwashing associated with an enhanced coagulation process. However, the periods of time when a higher coagulant dose is required will experience higher chemical usage and greater sludge production. A direct filtration plant or a membrane filtration plant, however, does not have the option of meeting the DBP regulations by increasing the coagulant dose to provide greater TOC removal. So, although the regulations do not require enhanced coagulation for a direct filtration facility or a membrane filtration facility, significant TOC removal will be required to meet the DBP MCLs if free chlorine is used for final disinfection. Without sufficient TOC removal, chloramines will be required to meet DBP limits.

3.2.1.2 How do the coagulants tested compare in terms of their effectiveness for both TOC removal and turbidity removal?

Jar tests evaluating turbidity and TOC removal were performed on Tuolumne River water samples collected in November 2016 and January 2017. The November water was representative of what seems to be “dry weather” conditions: low streamflow, low turbidity (≤ 2 NTU), and low TOC (≤ 2 mg/L). The January water was collected shortly after a series of major storms affected the region, and was representative of “wet weather” high streamflow conditions with higher turbidity (5 – 10 NTU) and higher TOC (4.0 – 4.5 mg/L).

Settled water turbidity as a function of coagulant dose (mg/L) is shown on Figure 4. Alum and PACl consistently performed the same during both the November and January enhanced coagulation tests. Ferric chloride performed similar to the aluminum-based coagulants, but promoted particle settling at a slightly lower dose. All three coagulants were able to effectively destabilize and settle particulates.

Settled water TOC as a function of coagulant dose (mg/L) is shown on Figure 5. For both the November and January jar tests, alum and PACl performed the same while ferric provided better TOC removal at a lower dose. However, as discussed later in this TM, Mn^{2+} (a reduced form of manganese) is a common contaminant in ferric chloride coagulant, and could be a drawback of this coagulant in terms of finished water aesthetics.

ANSWER: Alum and PACl performed almost identically for both turbidity and TOC removal. Ferric chloride was able to provide comparable turbidity removal to alum and PACl; ferric provided greater TOC removal at comparable doses (mg/L). As discussed, though, the greater TOC removal provided by ferric does not justify the risk of adding Mn^{2+} to the water.

Figure 4. Comparison of Coagulants for Turbidity Removal in Coagulant Dose in Units of mg/L
(Nov. test on left; Jan. test on right)

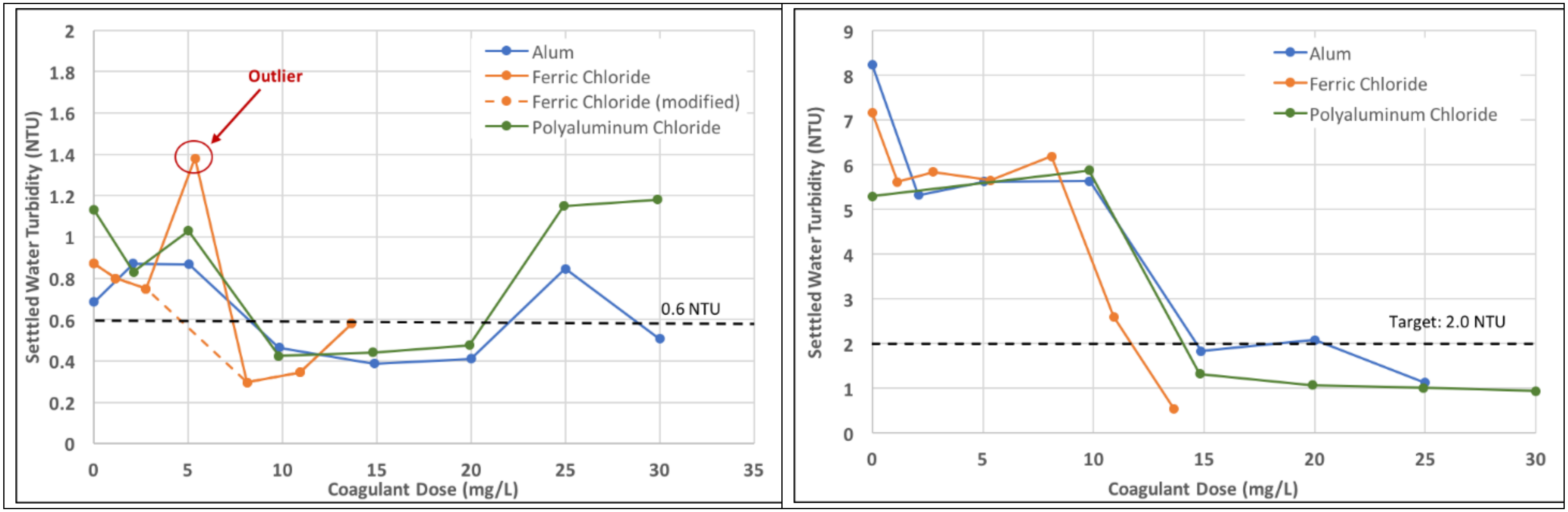
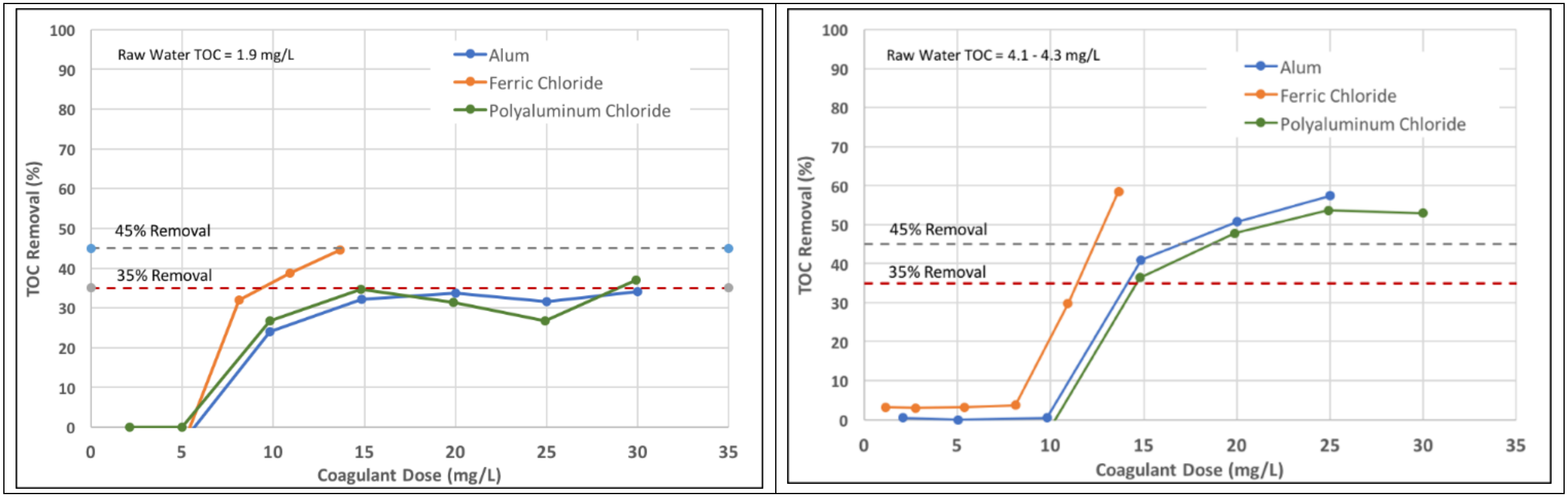


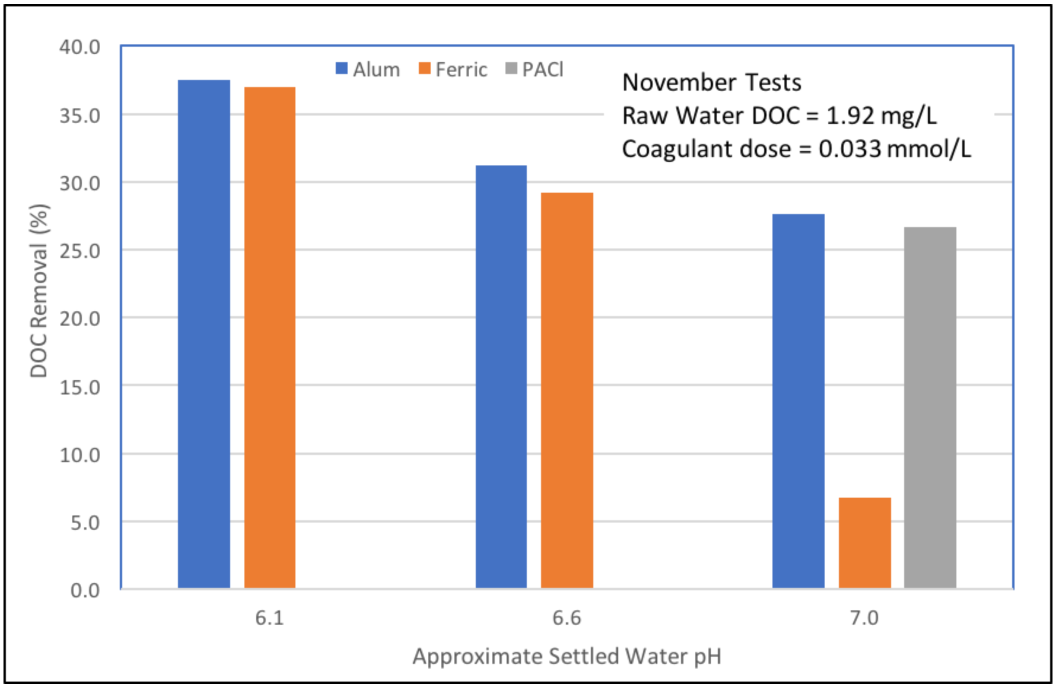
Figure 5. Comparison of Coagulants for TOC Removal with Coagulant Dose in Units of mg/L (Nov. test on left; Jan. test on right)



3.2.1.3 Will pH reduction be required for effective TOC removal?

Figure 6 shows that greater TOC removals are achieved at lower pHs. This is consistent with the USEPA's Enhanced Coagulation Guidance Manual (USEPA, May 1999). However, for a water with a low alkalinity like SRWA's source water, if the pH is reduced for coagulation it will have to be raised at the end of the treatment train to produce a stable, non-corrosive water for the distribution system. The preceding section comparing coagulants for TOC removal showed that all three coagulants are able to achieve 35 percent TOC removal when the raw water TOC is between 2.0 and 4.0 mg/L, and 45 percent removal when the source water TOC is above 4.0 mg/L, as required by the regulations. Reasons to consider lowering the coagulation pH are (1) lower sludge production at lower coagulant doses, and (2) potential chemical cost savings depending on the unit cost of each bulk chemical and the chemicals chosen for post-treatment stabilization (e.g., lime versus caustic).

Figure 6. TOC Removal as a Function of Coagulation pH



ANSWER: pH reduction during coagulation does improve TOC removal, but it is not required for effective TOC removal (per the D/DBP Rule) from this source water.

3.2.1.4 Are the chlorination DBPs (i.e., TTHMS and HAA5) a concern for this source water?

SDSDBP tests have been conducted twice: once in November when the raw water was representative of "dry weather" conditions with a low turbidity (≤ 2 NTU) and low TOC concentration (≤ 2 mg/L); and once in February when the raw water was representative of "wet weather" conditions with a higher turbidity (5 – 10 NTU) and higher TOC (4.0 – 4.5 mg/L). The coagulant dose used to prepare coagulated/settled (CS) water for both the November and February SDSDBP tests was selected to achieved a target 35 percent TOC removal consistent with the

Enhanced Coagulation guidelines. Ferric was used in November at a dose of 7.9 mg/L and achieved an average 40 percent TOC removal. Alum at a dose of 9.8 mg/L was used to prepare the CS water for the February SDSDBP tests, and the average DOC removal was 26.5 percent (DOC removal is reported because TOC numbers were considered erroneous due to poor floc settling). Also during the February tests, a low alum dose of only 5 mg/L, representative of a dose for direct filtration, was used to prepare water for the SDSDBP tests.

Final disinfection with both free chlorine and combined chlorine was tested. The sample holding times were 1-hour, 48-hours and 96-hours. The 1-hour holding time is representative of a chlorine contact basin. The 96-hour holding time is representative of the estimated time in the finished water pipeline and Turlock's largest distribution system water age. Finally, the 48-hour holding time was selected to provide an additional data point for the development of trends.

The November SDSDBP test results are shown on Figure 7. The February low coagulant dose SDSDBP results are on Figure 8, and the February conventional coagulant dose is shown on Figure 9. The tabulated results are provided in Table 3. SDSDBP Formation with Free Chlorine & Combined Chlorine. Key conclusions that can be drawn are the following:

- With conventional coagulation treatment, and when the raw water TOC is 2.0 mg/L or less, the resultant TTHMs and HAAs should be well below regulatory limits.
- With direct filtration, when the coagulant dose is < 5 mg/L and the raw water TOC is elevated (i.e., ≥ 2.5 to 3 mg/L), the treatment facility will likely exceed both TTHM and HAA MCLs. With little or no TOC removal, chloramines will definitely be required for secondary disinfection.
- HAA formation is a greater concern for this water than are the TTHMs.
- Even with conventional treatment, there is potential to exceed the HAA MCLs when the raw TOC is elevated, such that the clarified/settled water TOC is greater than roughly 2.6 mg/L (Figure 9). Presumably, a higher coagulant dose can be used if needed for higher TOC removal. Or ozone with BAC filtration can be used to provide even greater TOC removal. Note that regulatory compliance is based on locational running annual average DBP concentrations.
- Ozonation of the coagulated/settled water resulted in lower DBP formation—both for TTHMs and HAA5.

ANSWER: With direct filtration treatment, which provides little or no TOC removal, DBPs are likely to exceed their MCLs with free chlorine for final disinfection. TOC removal, as required by the Enhanced Coagulation portion of the D/DBP Rule, will be required if the Cities choose to use free chlorine for final disinfection. This may preclude using direct filtration or membrane filtration treatment with free chlorine for secondary disinfection, or may require using chloramines for final disinfection rather than free chlorine. Sufficient TOC removal should be attainable with a conventional treatment train. Ozonation of the coagulated/settled water seems to result in lower levels of DBPs.

Table 3. SDSDBP Formation with Free Chlorine and Combined Chlorine (i.e., Chloramines)

Month/Sample	Raw Water TOC, mg/L	Disinfectant	Dose, mg/L as Cl_2	TTHM 1-hr, µg/L	HAA5 1-hr, µg/L	TTHM 48-hr, µg/L	HAA5 48-hr, µg/L	Disinfectant Residual, 48 hrs	TTHM 96 hr, µg/L	HAA5 96-hr, µg/L	Disinfectant Residual, 96 hrs
Nov/CS (7.9 mg/L ferric)	1.21	Free chlorine	2.0	11	8.3	31	24	0.60	Not tested	Not tested	Not tested
Nov/CS-O_3 (7.9 mg/L ferric)	1.21	Free chlorine	2.0	3.1	ND	27	15	0.54	Not tested	Not tested	Not tested
Nov/CS (7.9 mg/L ferric)	1.21	Chloramines	3.25	11	8.3	16	11	2.24	Not tested	Not tested	Not tested
Nov/CS-O_3 (7.9 mg/L ferric)	1.21	Chloramines	3.25	3.1	ND	7.1	3.6	2.22	Not tested	Not tested	Not tested
Feb/CS (5.1 mg/L alum)	3.35	Free chlorine	2.75	28	38	90	114	0.42	79	90	0.14
Feb/CS (5.1 mg/L alum)	3.35	Chloramines	3.25	30	33	40	46	1.85	37	47	1.83
Feb/CS (9.8 mg/L alum)	2.67	Free chlorine	2.5	16	15	55	47	1.05	49	52	0.83
Feb/CS-O_3 (9.8 mg/L alum)	2.67	Free chlorine	2.5	10	12	41	37	0.91	49	53	0.63
Feb/CS (9.8 mg/L alum)	2.67	Chloramines	3.0			22	18	2.12	20	20	1.94
Feb/CS-O_3 (9.8 mg/L alum)	2.67	Chloramines	3.0			15	12	2.04	14	13	1.78

Notes:
Target free chlorine residual was 0.4 mg/L after 48 hours. Target chloramine dose was 2.0 mg/L after 48 hours. A phosphate buffer was used to maintain a constant pH of 7.7 – 8.0 during SDSDBP tests.
An O_3:TOC ratio of 1.0 was used to prepare the CS-O_3 water.

Figure 7. November SDSDBP Test Results Representing Enhanced Coagulation with Low TOC Raw Water Quality

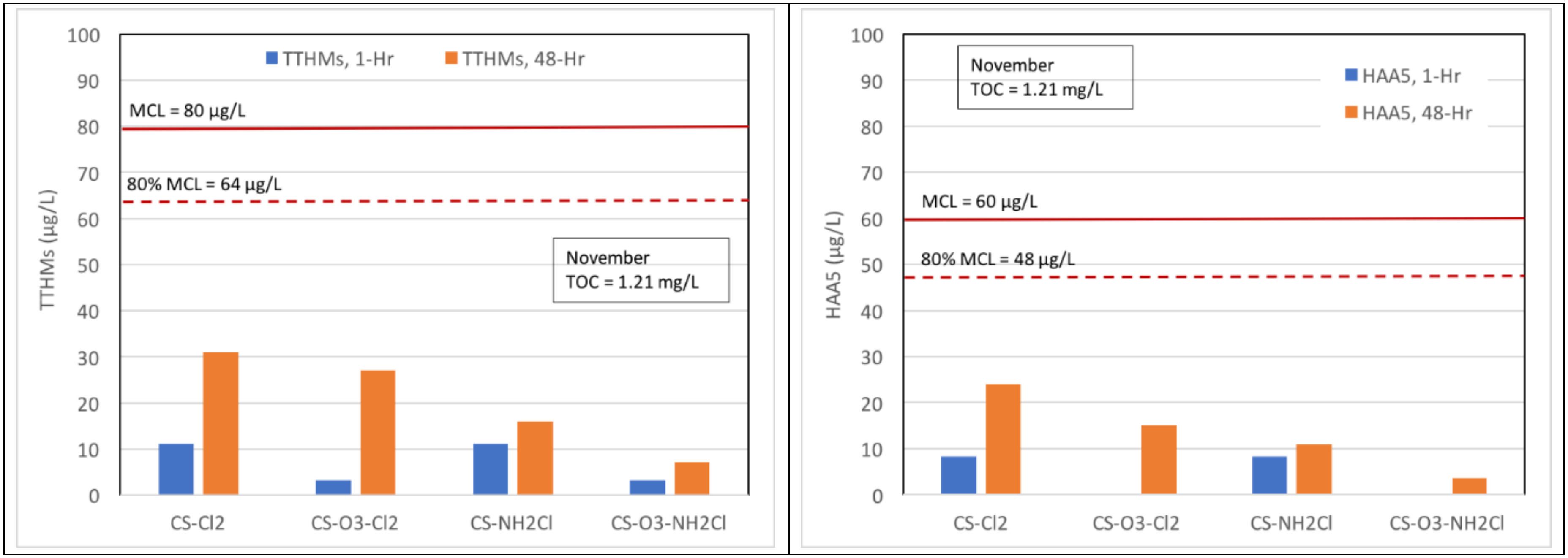
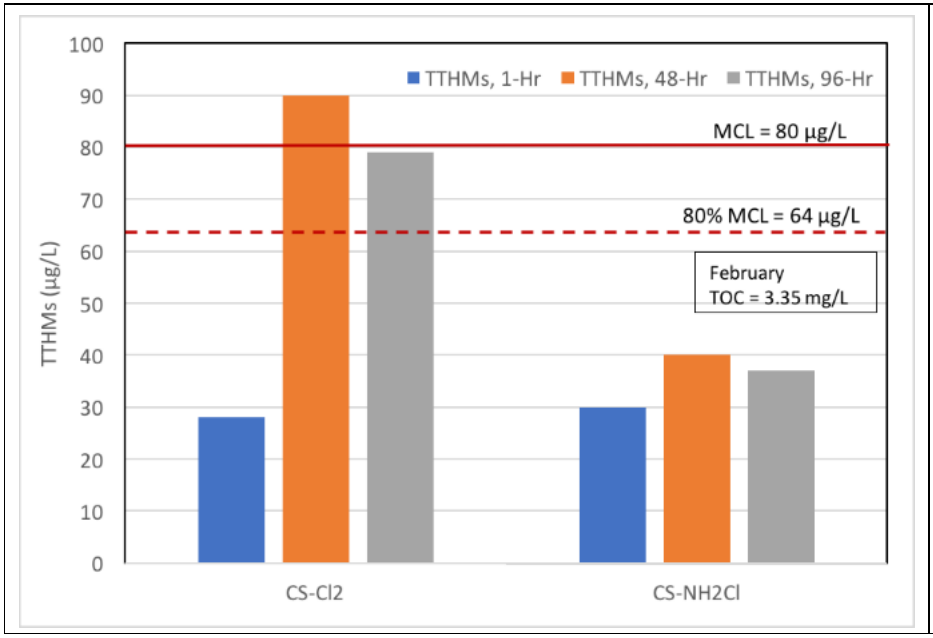


Figure 8. February SDSDBP Test Results Representing Direct Filtration Equivalent Low Coagulant Dose with High TOC Raw Water Quality



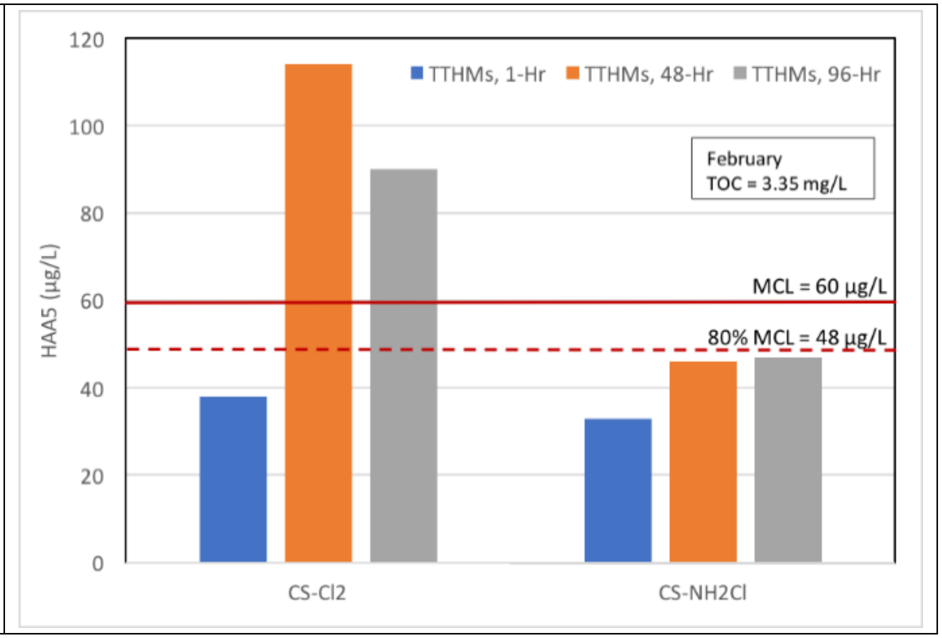
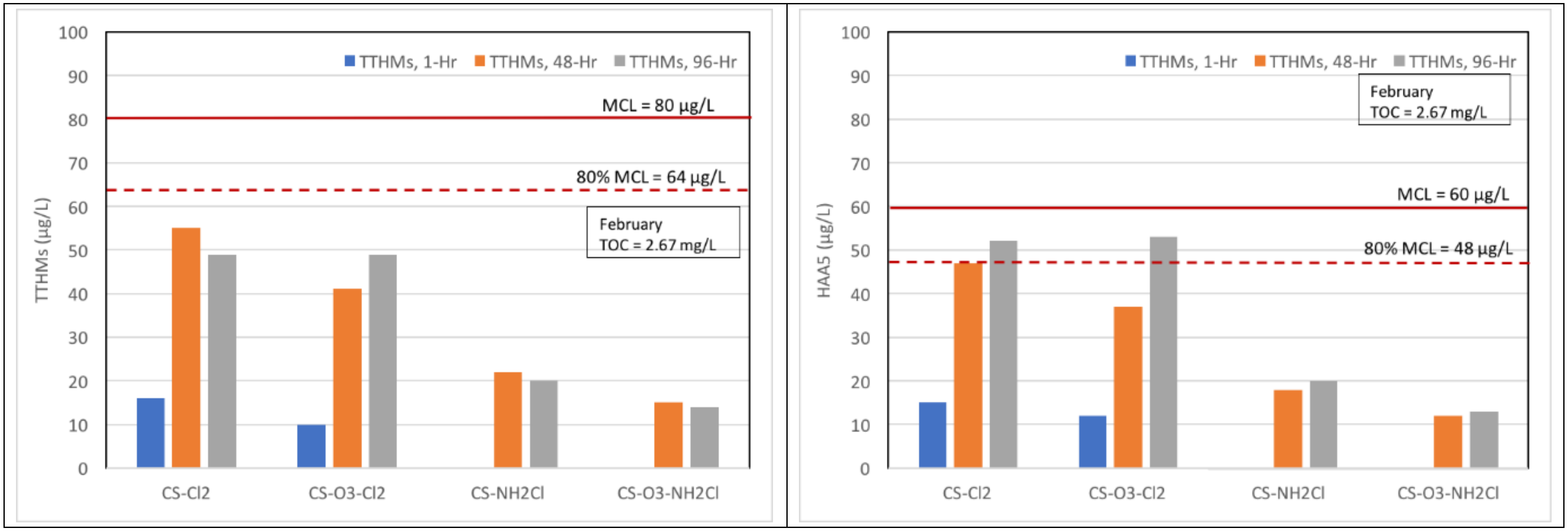


Figure 9. February SDSDBP Test Results Representing Enhanced Coagulation with High TOC Raw Water Quality



3.2.2 Ozone Demand and Bromate Formation

Bromate is an ozonation by-product that forms during ozonation when bromide is present at high enough concentrations. The bromate MCL is 10 µg/L. Bromate was analyzed in the raw water and in the CS water, for O_3:TOC ratios of 0.6 and 1.0, as part of the monthly ozone demand bench tests. As shown in Table 4, bromate concentrations were consistently below the detection limit. Therefore, bromate formation is not a concern for this water.

Table 4. Bromate Formation During Ozonation of Raw and Coagulated/Settled (CS) Water

Month	Bromate, µg/L			
	Raw, 0.6 O_3:TOC	Raw, 1.0 O_3:TOC	CS, 0.6 O_3:TOC	CS, 1.0 O_3:TOC
November 2016	ND (1)	1.0	ND (1)	ND (1)
December 2016	ND (1)	ND (1)	ND (1)	ND (1)
January 2017	ND (1)	ND (1)	ND (1)	ND (1)

There are multiple purposes for including ozone in the treatment train: primary disinfection for *Giardia* and viruses; treatment for pesticides and other SOCs; and taste and odor (T&O) control. A benefit of pre-ozonation experienced by Modesto Irrigation District (MID) at the Modesto Regional Water Treatment Plant was killing of Asian Clams (*Corbicula fluminea*) and preventing their shells from moving past the ozone contactor. As shown in the preceding section, ozonation resulted in lower TTHM and HAA formation; it is expected that ozone with BAC filtration would result in even lower DBP formation due to biodegradation of the DBP precursor material through the filters.

In a conventional treatment train, ozone can be located at the front of the treatment train prior to coagulant addition (pre-ozonation) or between clarification and filtration (intermediate ozonation). Pre-ozonation would require a higher ozone dose than intermediate ozonation because the ozone demand of the water would be greater prior to TOC removal (i.e., through clarification). Based on the preliminary ozone demand bench test results, an appropriate design ozone dose for pre-ozonation of the raw water is 2.5 mg/L (see Figure 10). For intermediate ozonation (see Figure 11), an appropriate design ozone dose is 1.5 mg/L.

In order to receive disinfection credit with ozone, the ozone demand of the water must be met and then an ozone residual must be provided in order to achieve the required CT for disinfection credit. The simplest way to achieve ozone disinfection credit is to meet the ozone demand of the water and then maintain an ozone residual out of the first chamber of the ozone contactor above 0.3 mg/L. When this condition is maintained, the SWTR regulations allow 0.5-log *Giardia* inactivation credit and 1-log virus inactivation credit. Additional CT credit is achieved by monitoring ozone residual throughout the remainder of the ozone contactor.

Figure 10. Ozone Demand as a Function of Ozone Dose in Raw Water

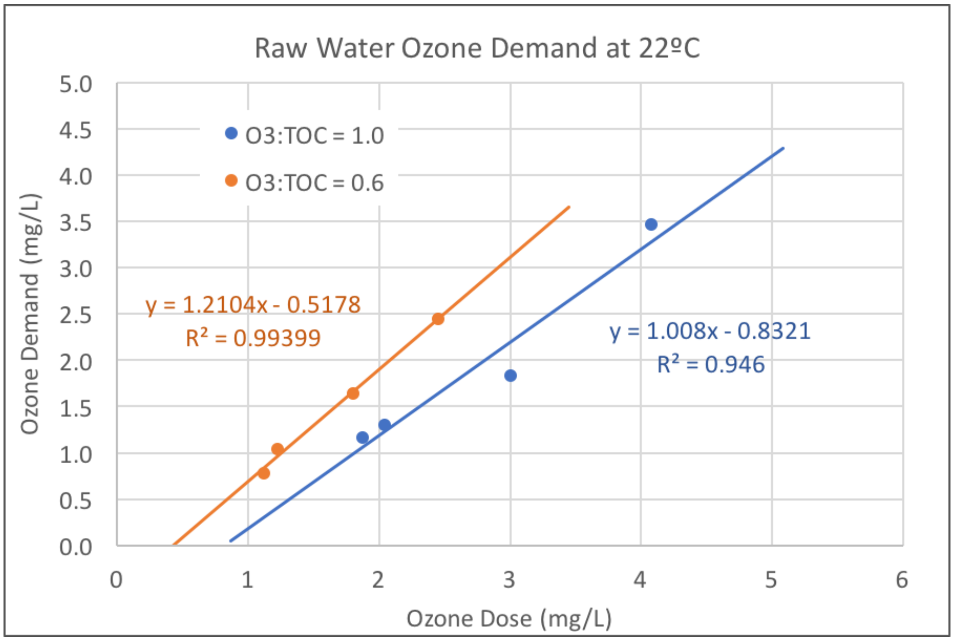
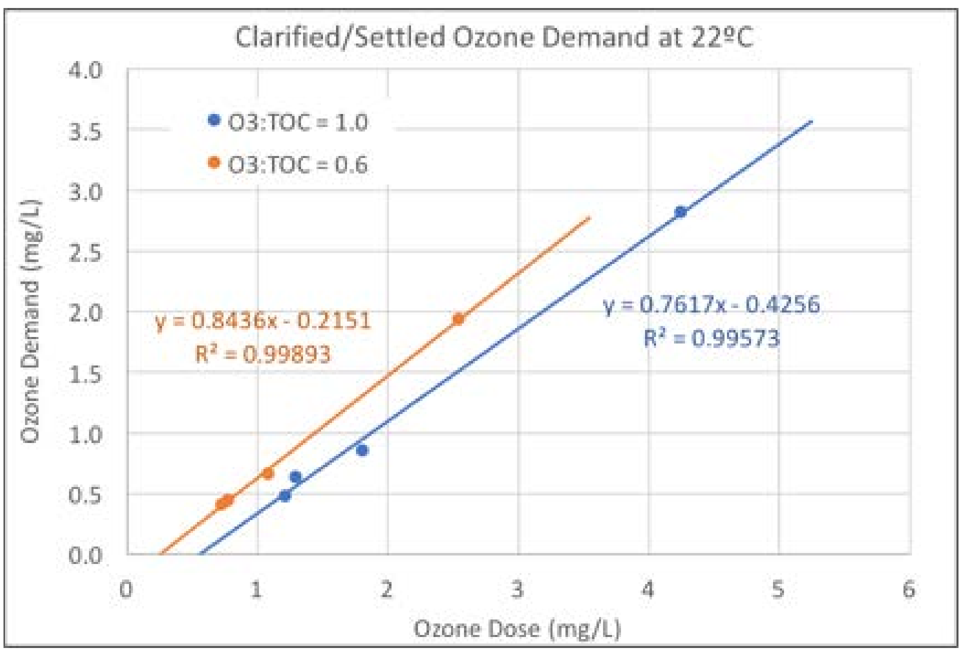


Figure 11. Ozone Demand as a Function of Ozone Dose in Clarified/Settled Water



3.2.3 Manganese Removal

If reduced Mn^{2+} is present in the water, ozonation must be carefully managed so that colloidal MnO_2 is not formed and allowed to pass through to the distribution system where it can present aesthetic issues. The Tuolumne River at the infiltration gallery location seems to have mostly particulate manganese that has already been oxidized (i.e., to MnO_2). It is unknown whether this infiltration gallery, which is embedded within a layer of coarse pea gravel and should allow fairly rapid flow, will promote reduction of particulate manganese or will draw more groundwater than anticipated, but planned construction of the raw water pump station wet well will allow SRWA to test this possibility. As discussed previously, though, experience indicates that reduce manganese can show up in the influent to the WTP even if it was not measured during the source water characterization program, and the WTP design should be flexible to accommodate manganese removal if needed (Trussell and Snoeyink, 2017).

A second round of manganese removal bench tests are currently underway. These tests are evaluating (1) the potential for ozonation to form colloidal MnO_2 which passes through treatment, (2) the effectiveness of potassium permanganate for oxidizing Mn^{2+} to MnO_2 and subsequent removal through clarification, (3) the importance of reaction time for permanganate oxidation, and (4) the preferred location for ozonation—pre- or intermediate—for particulate and colloidal MnO_2 removal. For the first round of manganese removal bench tests conducted in December, the raw water was spiked with 0.3 mg/L Mn^{2+}. Aside from one outlier in the historical data set, the maximum total manganese concentration measured at the infiltration gallery or nearby was 0.11 mg/L. For this second round of manganese tests, the raw water was spiked with a lower Mn^{2+} concentration of 0.1 mg/L. No results from this second round of testing are available at this time.

From the December tests, we learned the following that may impact treatment:

- The stock ferric chloride used in the tests contained dissolved Mn^{2+} at undesirable concentrations. Mn^{2+} is a common contaminant in ferric chloride, a result of the manufacturing processes. Different grades of ferric chloride can be purchased resulting in varying amounts of manganese contamination. The ferric chloride used for these jar tests was a sample provided by Kemira. The stock chemical was analyzed by Eurofins for both iron and manganese; lab results showed that every 5 mg/L of ferric chloride adds 0.02 mg/L Mn^{2+} ions to the raw water.
- Contact time is important for $KMnO_4$ oxidation of Mn^{2+}; one minute and five minutes were tested. A 56-minute contact time, which represents travel time from the raw water pump station to the WTP influent, is being tested this round.
- Higher manganese removals were observed at higher ozone doses.

3.3 High River Flows and Raw Water Quality

This section provides a discussion of the significant Tuolumne River flows observed during the winter of 2017 and their impacts on the raw water quality for the SRWA Project.

3.3.1 Winter 2017 and Historical Stream Flows

January and February 2017 witnessed extended periods of significant precipitation in the watershed of the lower Tuolumne River, and have contributed to an extended period of unusually high flows in the Tuolumne River below Don Pedro Reservoir. For example, the highest daily average flow measured below LaGrange Dam during the month of February 2017 was 13,900 cfs, versus an average daily flow for February over the previous ten years (2007 to 2016) of 506 cfs[5]. Because the recent high flow periods have coincided with reductions in raw water quality for several key parameters, an effort has been made to place this period into proper historical context and help predict how frequently similar high flow periods might occur in the future. To this end, historical stream flows on the Tuolumne River below La Grange Dam and at Modesto since 1970 (when construction of Don Pedro Reservoir was completed) are shown on Figure 12; a zoomed in plot, from 1980 to present, is shown on Figure 13). As indicated, there have been numerous extended periods of high stream flows since 1970. Table 5 provides a summary of stream flow statistics of interest since 1970. Since January 1, 2005 there have been nine extended periods (defined as periods greater than seven days) when stream flows were consistently above 5,000 cfs. This flow represents the 95th percentile flow below LaGrange Dam since 1970, and represents a significant increase over the median value over the same period. The dates and duration of each of these extended high flow periods were:

- Mar 25, 2005 to Apr 7, 2005 — 14 days
- May 19, 2005 to May 31, 2005 — 13 days
- Jan 4, 2006 to Jan 14, 2006 — 11 days
- Mar 27, 2006 to May 30, 2006 — 65 days
- Jun 20, 2006 to Jun 26, 2006 — 7 days
- Dec 17, 2010 to Jan 7, 2011 — 22 days
- Mar 20, 2011 to Apr 28, 2011 — 40 days
- Jun 3, 2011 to Jun 19, 2011 — 17 days
- Jan 4, 2017 to Mar 13, 2017 ongoing — (69+ days)

[5] USGS Station ID 11289650 (Tuolumne River Below La Grange Dam Near La Grange, CA) and USGS Station ID 11290000 (Tuolumne River at Modesto, CA).

Figure 12. Historical Stream Flows on the Tuolumne River Upstream and Downstream of the Infiltration Gallery, 1970 to Present

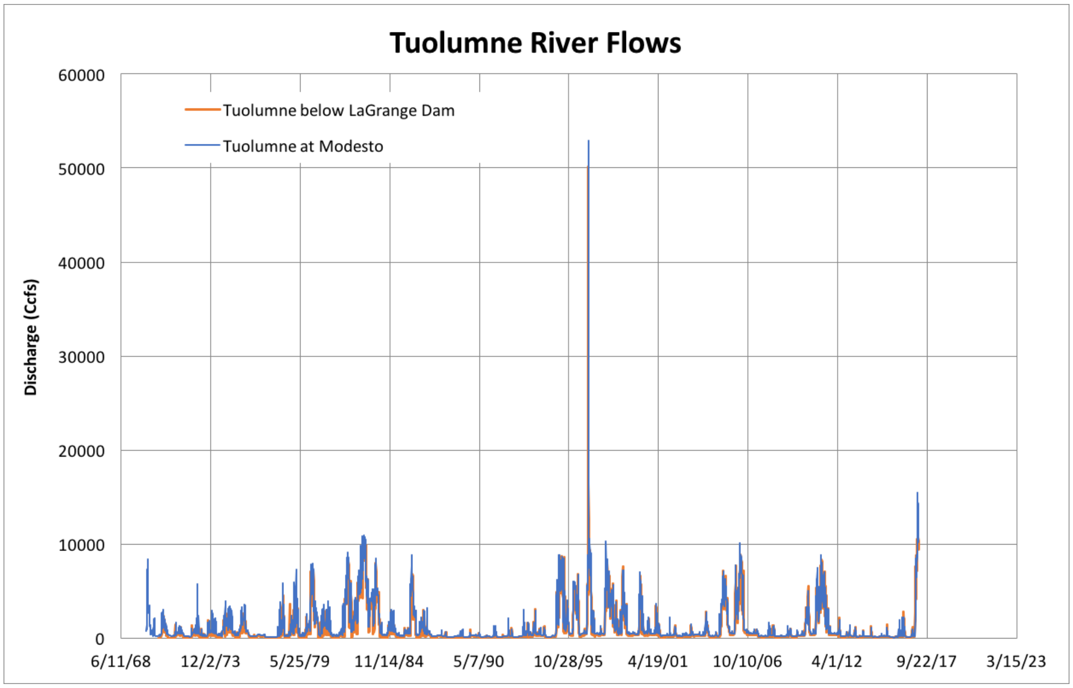
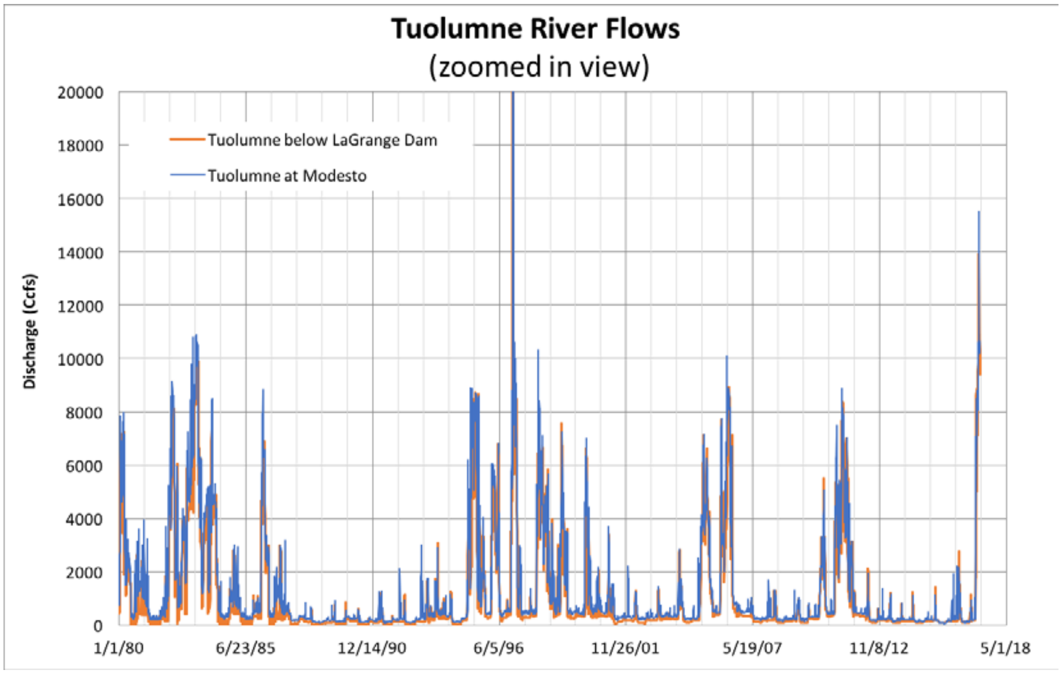


Figure 13. Historical Stream Flows on the Tuolumne River Upstream and Downstream of the Infiltration Gallery, 1980 to Present



3.3.2 Impacts of Recent High River Flows on TOC and Turbidity

The response of TOC and turbidity to recent storm events and high stream flows are shown on Figure 14 and Figure 15. If a treatment train were in place and shutdown or reduced production resulting from elevated raw water TOC or turbidity was required, SRWA would potentially not have finished water from this WTP for extended periods of time every 21 months, or at least once every other year. Additionally, with direct filtration or membrane filtration, and degraded raw water quality, little or no TOC removal would be achieved (due to the low coagulant dose), which would require that chloramines be used for secondary disinfection in order to comply with DBP regulatory limits. As discussed in Section 3.2.1.4 (and shown on Figure 8), when the raw water TOC is elevated, a low coagulant dose is used (e.g., representative of direct filtration or membrane filtration), and chloramines are used for secondary disinfection, little or no TOC removal is achieved and the SDS[6] HAA5 concentrations approach 80 percent of the MCL concentration (or 48 µg/L). SDS THM concentrations with chloramines, on the other hand, are well below 80 percent of the MCL level (or 64 µg/L). These initial SDS tests indicate this water forms higher concentrations of HAAs than THMs. Even when chloramines are used for secondary disinfection, there should be a brief period (e.g., 60 minutes) of free chlorine contact to attain virus and *Giardia* inactivation (per the multi-barrier requirement of the regulations) and to eliminate the potential for elevated levels of Heterotrophic Plate Count (HPC) and ammonia oxidizing bacteria (AOBs) in the finished water—making a more biologically stable water for the distribution system. The detention time and size of this chlorine contact basin will be the same for either the free chlorine or the chloramine secondary disinfection scenarios; the only difference is that the chloramine scenario requires ammonia addition and mixing before the water is sent to the distribution system.

Table 5. Summary Statistics of Stream Flows at La Grange Dam since 1970[(a)]

Category	Value
All Data	
Average Flow	982 cfs
99th Percentile Flow	8,470 cfs
95th Percentile Flow	5,040 cfs
90th Percentile Flow	3,210 cfs
50th Percentile (Median) Flow	229 cfs
10th Percentile Flow	19 cfs
High Flow Events[(b)]	
No. Events	27
Max Event Duration	105 days
Average recurrence interval	21 months
Longest streak without events	8 years (1987-1994)
Longest streak with events	6 years (1995-2000)
No. events lasting ≥ 4 weeks	12
No. events lasting ≥ 8 weeks	4

(a) Raw data source: USGS Station ID 11289650 (Tuolumne River Below La Grange Dam Near La Grange, CA. Data through March 13, 2017.
(b) Defined as periods with flow ≥ 5,000 cfs for ≥ 7 days.

[6] SDS: Simulated distribution system

Figure 14[7]. Raw Water TOC in Relation to High Stream Flows on the Tuolumne River from Recent Winter Rain Events

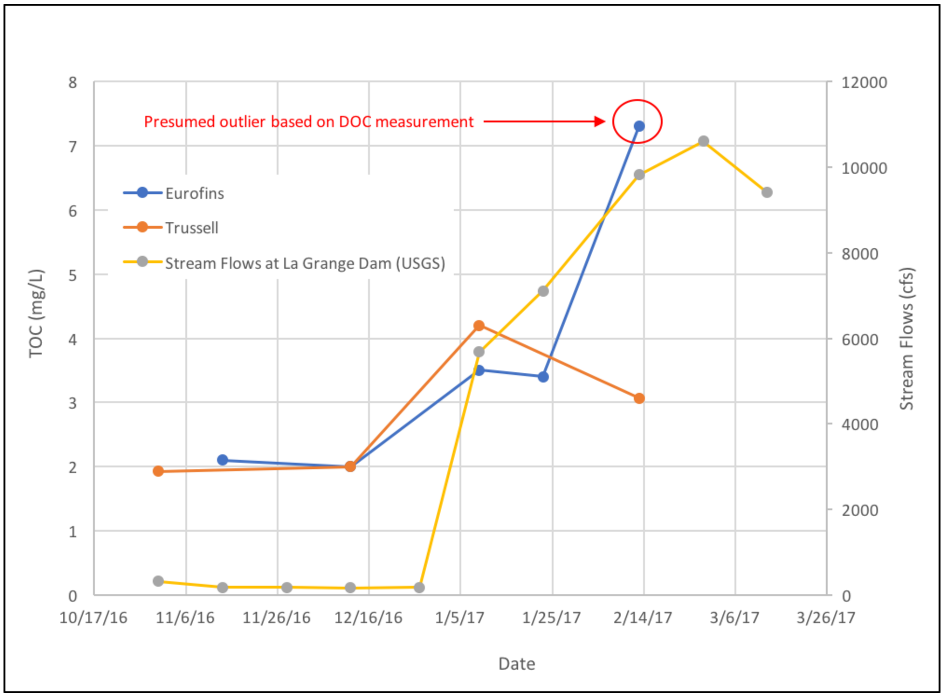
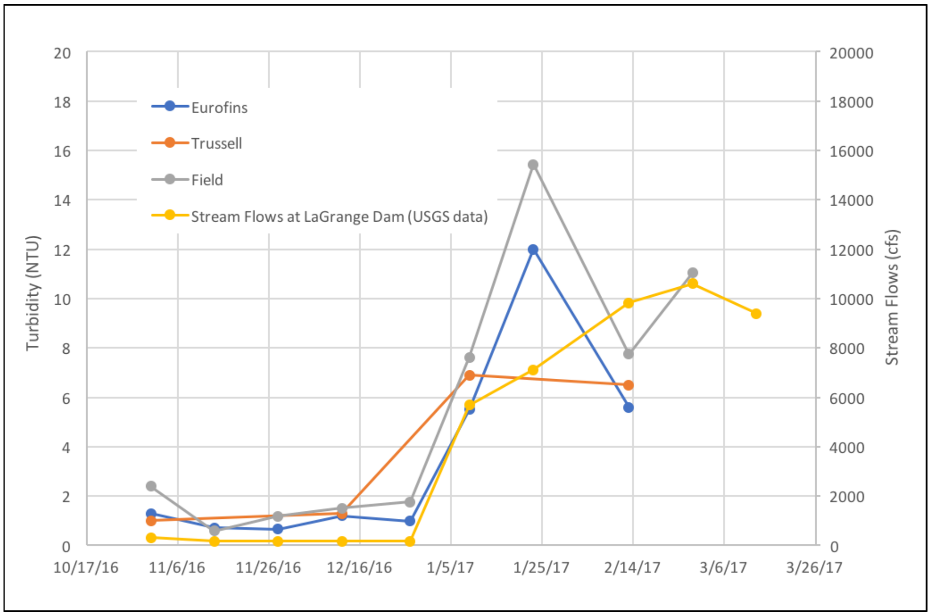


Figure 15. Raw Water Turbidity in Relation to High Stream Flows on the Tuolumne River from Recent Winter Rain Events



[7] Duplicate of Figure 3. Repeated for ease of reference.

4.0 DEVELOPMENT OF REFINED TREATMENT TRAIN ALTERNATIVES

This section describes the process by which an updated and refined set of available treatment train alternatives was developed. This evaluation was made possible by the additional source water quality and bench testing results, and was conducted in accordance with the feedback provided by the TAC at a January 2017 workshop and in discussions at subsequent TAC correspondence.

4.1 Treatment Train Discussion at the January 12, 2017 TAC Workshop

At the TAC workshop on January 12, 2017, the PM Team led a discussion of available unit processes within the context of three treatment trains. These trains (defined below) were used as the basis for discussion based on available source water quality data at the time, and the performance goals previously developed and adopted by the TAC and Board. The three trains discussed during the January TAC meeting were comprised of the following unit processes:

- **Train A**: Direct Filtration – Ozone Treatment – Biologically Active Filters
- **Train B**: Conventional Pretreatment – Ozone Treatment – Biologically Active Filters
- **Train C**: Membrane Filtration – Ozone Treatment – Biologically Active Filters

The principle differences between these three trains were the methods of pretreatment (direct filtration versus conventional coagulation, flocculation and sedimentation) and the primary methods of filtration (membrane filtration versus media filtration). Each of these trains included ozone treatment and biologically active filters (BAF), followed by the use of free chlorine for secondary disinfection.

Discussion at the January 12, 2017 TAC workshop included the following important topics and related direction for further evaluation:

- **Need for comparative cost and benefit information**. In general, the TAC emphasized the need to better understand the costs and benefits associated with the various unit processes under consideration before selecting a treatment train.
- **Costs vs. benefits of ozone treatment**. Despite consensus among the TAC and PM Team that ozone treatment would provide a variety of benefits consistent with the adopted treatment performance goals, the TAC requested that the cost and benefit information alluded to above be evaluated before confirming whether ozone should be included in the treatment train.
- **Willingness to consider use of chloramines**. The TAC indicated they preferred not using chloramines for final disinfection, but they would leave it open as an option until they were able to review the cost/benefit analysis provided in this TM.
- **Amenability to periodic, short-term WTP shutdowns**. Prior to the January 12, 2017 workshop, all but one of the six source water samples analyzed to date had indicated that a treatment train that relied on enhanced coagulation (e.g., a direct filtration process) or the use of chloramines could be used without jeopardizing compliance with DBP limits. However, TOC data from the January 9, 2017 sampling event indicated that such a treatment train would be unlikely to meet DBP limits, and would be subject to periodic shutdowns or capacity reductions when similar

raw water conditions prevailed. Based on the assumption that such high river flow and corresponding high TOC level events would be rare (i.e., once every 10 to 20 years), relatively short in duration (i.e., a few weeks at a time), and coincident with low treated water demand periods (i.e., during the winter months), the TAC indicated a willingness to consider periodic, short-term shutdowns or reductions in treatment capacity to accommodate a potentially less expensive direct filtration or membrane filtration treatment train.

Considering the above feedback, as well as the additional source water quality and bench test results collected since October 2016, the treatment trains previously presented in TM No. 1 have been reorganized to include updated combinations of unit processes. Because the inclusion or omission of certain treatment processes (e.g., primary disinfection with ozone) impacts a train's ability to meet minimum regulatory requirements for the treatment of pathogens, pathogen treatment requirements have been used herein as a framework for re-assembling and comparing the updated list of feasible treatment trains. **A discussion of this procedure and the resulting updated treatment trains is provided below**. Qualitative descriptions and comparison of individual unit processes that comprise the trains resulting from this procedure are provided in Section 5 of this TM.

4.2 Pathogen Treatment Requirements and the Development of Updated Treatment Train Alternatives

There have been a series of four federally mandated Rules that have been promulgated with the intent of preventing waterborne diseases caused by pathogenic microorganisms, starting with the Surface Water Treatment Rule (SWTR). These Rules established treatment techniques to remove and/or inactivate microbial contaminants through effective filtration and disinfection. The following is a summary of the requirements of these Rules as applicable to SRWA process train selection. The unit processes making up each alternative treatment train is dictated in many ways by the need to meet pathogen treatment.

- The SWTR, promulgated in 1989, requires 4-log (99.99 percent) removal/inactivation of viruses and 3-log (99.9 percent) removal/inactivation of *Giardia lamblia*.
- The Interim Enhanced Surface Water Treatment Rule (IESWTR), promulgated in 1998, requires 2-log removal of *Cryptosporidium* by meeting the combined filter effluent turbidity standards to 0.3 NTU.

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), promulgated in 2006, requires additional *Cryptosporidium* treatment depending on the source water's "Bin" classification. Bin classification is summarized below in Table 6.

Table 6. Bin Classification for Filtered Public Water Systems Indicating the Cryptosporidium Removal Required Under the LT2ESWTR

Bin	Average Cryptosporidium Concentration, oocysts/L	Treatment Requirements for Conventional Filtration	Treatment Requirements for Direct Filtration
1	<0.075	No additional treatment	No additional treatment
2	0.075 to <1.0	1-log	1.5-log
3	1.0 to <3.0	2-log	2.5-log
4	≥3.0	2.5-log	2-log

In addition to stipulating the overall requirements, these rules require a multi-barrier treatment approach (i.e., removal and disinfection) to ensure effective microbial treatment.

DDW has stated it plans to follow the DDW Surface Water Treatment Rule (SWTR) guidance document[8] with regard to log treatment requirements for *Giardia* and viruses:

Total coliform (monthly median):

- If <1000 /100 mL, then 3-log or 4-log treatment requirements for Giardia and viruses, respectively.
- If >1000 /100 mL, then 4-log or 5-log treatment requirements for Giardia and viruses, respectively.

E. coli (monthly median):

- If <200 /100 mL, then 3-log or 4-log treatment requirements for *Giardia* and viruses, respectively.
- If >200 /100 mL, then 4-log or 5-log treatment requirements for *Giardia* and viruses, respectively.

Initial data from the source water monitoring program (Nov 2016 to Feb 2017 only) indicate the Tuolumne River at the infiltration gallery location will fall into Bin 1 for *Cryptosporidium*. As discussed in Section 3.1.5, the overall median total coliform concentration (thus far) for the SRWA monitoring program is 1,700 MPN/100 mL, which is above the threshold for requiring 1-log higher treatment for both *Giardia* and viruses. The *E. coli* median concentration for the SRWA monitoring program is 41 MPN/100 mL, which is below the threshold for requiring additional treatment, even though some individual samples exceeded the 200 MPN/100 mL threshold. Therefore, based on total coliform and *E. coli* data, DDW may opt to require 4-log *Giardia* treatment and 5-log virus treatment. Even though the SRWA monitoring results to date indicate Bin 1 for *Cryptosporidium*, DDW may decide to require 1-log additional treatment for *Cryptosporidium* to follow suit with the additional treatment for *Giardia* and viruses. A conservative estimate of the overall pathogen removal requirements for SRWA's new WTP is

[8] "Appendix B, Guidelines for Determining when Surface Waters will Require More than the Minimum Levels of Treatment Defined in the Surface Water Treatment Regulations".

assumed for the discussion and cost estimates presented in this TM. DDW's interpretation of these data in relation to the required level of treatment should be discussed with DDW staff.

Table 7. Overall Regulatory Pathogen Removal/Inactivation Requirements

Pathogen	DDW Standard Removal/Inactivation for Non-Impaired Source Water	Assumed DDW Removal/Inactivation Requirements based on SRWA Data
Cryptosporidium	2-log	3-log
Giardia	3-log	4-log
Viruses	4-log	5-log

Greater *Giardia* and *Cryptosporidium* removal credit is awarded for membrane filtration than for direct filtration with GMF, as summarized in Table 8 below. The additional required treatment credit, for multi-barrier treatment, is achieved through disinfection.

Table 8. Pathogen Removal Credit for Conventional Filtration (with GMF) and Direct Filtration (GMF vs. MF)

Pathogen	Assumed DDW Treatment Requirements	Credit for Conventional Treatment with GMF	Credit for Direct Filtration	
			With GMF	With MF
Cryptosporidium	3-log	2-log	2-log	4-log
Giardia	4-log	2.5-log	2-log	4-log
Viruses	5-log	2-log	1-log	--

The different alternative treatment trains will achieve pathogen treatment requirements in different ways depending on the filtration process, whether ozone is included, and whether sufficient DBP precursor (i.e., TOC) is removed to allow primary disinfection with free chlorine. The following key points must be considered in deciding how each train can best achieve pathogen treatment.

- Little or no TOC removal is achieved with the coagulant doses used for direct filtration and membrane filtration. This means free chlorine contact time should be limited to an hour or less and chloramines should be used for secondary disinfection to control DBP formation for meeting regulatory DBP limits.
- The SWTR regulations require 2-log *Cryptosporidium* removal through filtration. If additional *Cryptosporidium* treatment is required, options include (1) achieving individual filter effluent (IFE) turbidity and combined filter effluent (CFE) turbidity $\leq$ 0.15 NTU 95 percent of the time with conventional or direct filtration treatment or (2) disinfection with ozone or UV. *Cryptosporidium* are resistant to chlorine disinfection so chlorine disinfection is not a good choice. A high ozone dose is required for 1-log Crypto inactivation compared to *Giardia* and virus inactivation. The most effective disinfectant for *Cryptosporidium* (and *Giardia*) is UV.

- Per the SWTR regulations, 0.5-log *Giardia* credit and 1-log virus credit is awarded for maintaining an ozone residual out of the first chamber of the ozone contactor.

Table 9 shows an updated list of feasible treatment trains and summarizes the probable approach for pathogen inactivation for each.

5.0 NON-COST COMPARISON OF UNIT PROCESSES

This section provides descriptions and non-costs comparisons of individual unit processes that comprise the updated treatment trains presented in Table 9. In general, the comparisons below are made between processes that provide similar core treatment functions (e.g., disinfection and filtration). Presentation and comparison of planning-level construction costs for the individual unit processes in included in Section 6 of this TM.

5.1 Ozone vs. Chlorine for Primary Disinfection

Disinfection in water treatment is typically provided in two treatment steps, often referred to as primary disinfection (for inactivation of microorganisms) and secondary disinfection (for maintenance of a disinfectant residual in the distribution system). Primary disinfection methods reflected in Table 8 include combinations of ozone, free chlorine and UV light. Secondary disinfection methods reflected in Table 9 are free chlorine and chloramines[9]. A brief overview of ozone and chlorine processes is provided below, followed by a summary of the relative advantages and disadvantages of each process.

5.1.1 Ozone Treatment

Ozone is a very powerful disinfectant and oxidant in water treatment. It can be applied in the treatment train ahead of clarification as pre-ozonation, or between clarification and filtration as intermediate ozonation. Because ozone breaks down large molecular weight natural organic matter (NOM) into smaller, more easily biodegraded organic pieces, it is preferable to include biologically active filtration (typically with a combination of Granular Activated Carbon (GAC) and sand media) at some point after ozonation to reduce the potential for biological regrowth and loss of disinfectant residual in the distribution system.

When disinfection is the objective, pre-ozonation generally requires a higher dose than intermediate ozonation because the NOM has not yet been reduced and exerts a greater ozone demand. To obtain disinfection credit, the dose must meet the demand of the water plus additional ozone for CT (i.e., residual concentration x contact time = CT) disinfection credit. Based on ozone demand testing completed to date, an ozone dose of 2.5 mg/L is estimated for pre-ozonation of this source water, and a dose of 1.5 mg/L is estimated for intermediate ozonation.

[9] Even when chloramines are used for secondary disinfection, there is a relatively brief period of free chlorine contact (i.e., 30 to 60 minutes) for primary disinfection prior to ammonia addition to form chloramines.

Table 9. Approach to Pathogen Treatment for each Alternative Treatment Train

Train No.	Treatment Train	Pathogen Treatment Per Unit Process (Log Removal)							Total Pathogen Treatment Achieved	Assumed Pathogen Treatment Requirements
1	**Conventional w/ Pre-O_3**	Pre Ozonation	Coagulation	Flocculation / Sedimentation		GAC/Sand Filters		Free Chlorine		
	Cryptosporidium					3			**3**	**3**
	Giardia	1				2.5		0.5	**4**	**4**
	Viruses	2				2		4	**8**	**5**
2	**Conventional w/ Intermediate-O_3**		Coagulation.	Flocculation / Sedimentation	Interim Ozonation	GAC/Sand Filters		Free Chlorine		
	Cryptosporidium					3			**3**	**3**
	Giardia				1	2.5		0.5	**4**	**4**
	Viruses				2	2		4	**8**	**5**
3	**Conventional w/o O_3**		Coagulation.	Flocculation / Sedimentation		GAC/Sand Filters	UV	Free Chlorine		
	Cryptosporidium					3	1		**4**	**3**
	Giardia					2.5	1	0.5	**4**	**4**
	Viruses					2		4	**6**	**5**
4	**Direct Filtration w/ O_3**	Pre Ozonation	Coagulation	Flocculation		GAC/Sand Filters	UV	Chloramines		
	Cryptosporidium					3	1		**4**	**3**
	Giardia	0.5				2	1	0.5	**4**	**4**
	Viruses	1				1		4	**6**	**5**
5	**Direct Filtration w/o O_3**		Coagulation	Flocculation		GAC/Sand Filters	UV	Chloramines		
	Cryptosporidium					3	1.5		**4.5**	**3**
	Giardia					2	1.5	0.5	**4**	**4**
	Viruses					1		4	**5**	**5**
6	**Membrane Filtration w/ O_3**		Coagulation	Membrane Filters	Interim Ozonation	GAC/Sand Filters		Chloramines		
	Cryptosporidium			4					**4**	**3**
	Giardia			4	0.5			0.5	**5**	**4**
	Viruses				1			4	**5**	**5**
7	**Membrane Filtration w/o O_3**		Coagulation	Membrane Filters			UV	Chloramines		
	Cryptosporidium			4			4		**8**	**3**
	Giardia			4			4	0.5	**8**	**4**
	Viruses						1	4	**5**	**5**

A conventional ozone contactor is an enclosed, baffled contactor with a hydraulic detention time of four to six minutes. Ozone gas is generated in an ozone generator, producing an ozone stream that is 10 to 12 percent ozone by weight. Liquid oxygen (LOX) is more commonly used than air as the feed gas for ozone generation. Ozone can be introduced into the water through side-stream injection or bubble diffusion with diffusers on the bottom of the first cell of the ozone contactor. Components of an ozone system include: ozone contactors, LOX storage, vaporizers (to convert LOX to gaseous oxygen), ozone generators, a nitrogen boost system, a cooling water system, ozone injection and associated pumps as needed, power supply, ozone destruct system, associated particle filters and desiccant dryers, oxygen monitors, ozone gas monitors, and ozone residual monitors.

5.1.2 Chlorine Disinfection

A relative comparison of the effectiveness of free chlorine, ozone and UV for primary disinfection is shown in Table 10.

Table 10. Relative Comparison of Primary Disinfectant Effectiveness

Microorganism	Free Chlorine	Ozone	UV
Bacteria	Excellent	Excellent	Good
Viruses	Excellent	Excellent	Fair
Giardia	Fair	Good	Excellent
Cryptosporidium	Poor	Good	Excellent

As a primary disinfectant, chlorine can be added at the beginning of the treatment train prior to coagulation and sedimentation, or after clarification, depending on the TOC concentration and DBP formation potential of the water. Chlorine generally is not added immediately prior to a GAC filter since the GAC removes chlorine, which therefore would not be providing any pathogen inactivation. Often, chlorine is added after clarification and filtration, in a chlorine contact basin (or pipeline) to achieve the required CT.

Chlorine disinfection typically requires an open, baffled chlorine contact basin, a chlorine feed solution (typically a 12.5 percent solution of sodium hypochlorite) and associated chemical storage tanks, chemical metering pumps and residual chlorine monitors. The hydraulic detention time (HDT) for the chlorine contact basin will depend on how much CT credit is needed and whether on-site storage is needed for other purposes. For discussion purposes, though, if free chlorine is used for both primary and secondary disinfection, the contact basin may have a HDT of one to two hours. If chloramines are used for secondary disinfection, 30 minutes to one hour of free chlorine contact may be provided prior to ammonia addition to achieve the required virus and *Giardia* inactivation. Based on chlorine decay curves developed during the SDSDBP bench tests in November 2016 and February 2017, a chlorine dose of 2 mg/L is appropriate for a free chlorine system, and a chlorine dose of 3 mg/L followed by ammonia addition at a 4:1 Cl_2:NH_3-N weight ratio is appropriate to for a chloramination system. Chloramines are a less effective disinfectant compared to free chlorine, so a higher chloramine concentration is generally maintained in the distribution system compared to free chlorine.

5.1.3 Advantages and Disadvantages

Ozone is a very powerful oxidant and provides additional benefits beyond disinfection, including: treatment of taste and odor compounds; breakdown and removal of pesticides and other contaminants of emerging concern (CECs) when combined with biologically active carbon (BAC) filtration; enhanced clarification and filtration performance; and a more stable finished water, with respect to organics, for the distribution system. Advantages and disadvantages of chlorine versus ozone for primary disinfection is summarized in Table 11.

Table 11. Advantages and Disadvantages of Ozone vs. Chlorine for Primary Disinfection

Treatment Process	Advantages	Disadvantages
Ozone	• Provides treatment for pesticides, CECs, and algal toxins. • Provides taste and odor treatment. • SDSDBP bench tests showed lower DBP formation with ozone. • Ozone with BAC filter can provide up to 40 percent DOC removal (Crittenden, et al., 2012). For SRWA's source water, the DOC is consistently 94 percent to 96 percent of the TOC. • The ozonation by-product, bromate, is not an issue for this source water. • Shorter contact time is required compared to free chlorine.	• Ozone must be generated on-site. • Can contribute to manganese passing through treatment train (depending on form of manganese). Refer to Section 3.2.3 for discussion. • Safety concerns requires ozone gas phase monitoring and alarms.
Free Chlorine	• Least expensive disinfection option. • Effective disinfectant for viruses and Giardia.	• Forms TTHMs and HAAs at high levels, depending on TOC concentration. MCLs may be exceeded in the distribution system. • Chloramines may be preferred over free chlorine for secondary disinfection in the distribution system, depending on DBP concentrations formed.

5.2 Direct Filtration Treatment vs. Conventional Filtration

Filtration in water treatment is generally preceded by a combination of several pretreatment processes. In a treatment train featuring conventional filtration, the filters are preceded by coagulation, flocculation and sedimentation. In a direct filtration treatment train, the sedimentation process is omitted. A schematic comparing a conventional filtration train with a direct filtration train is provided on Figure 16.

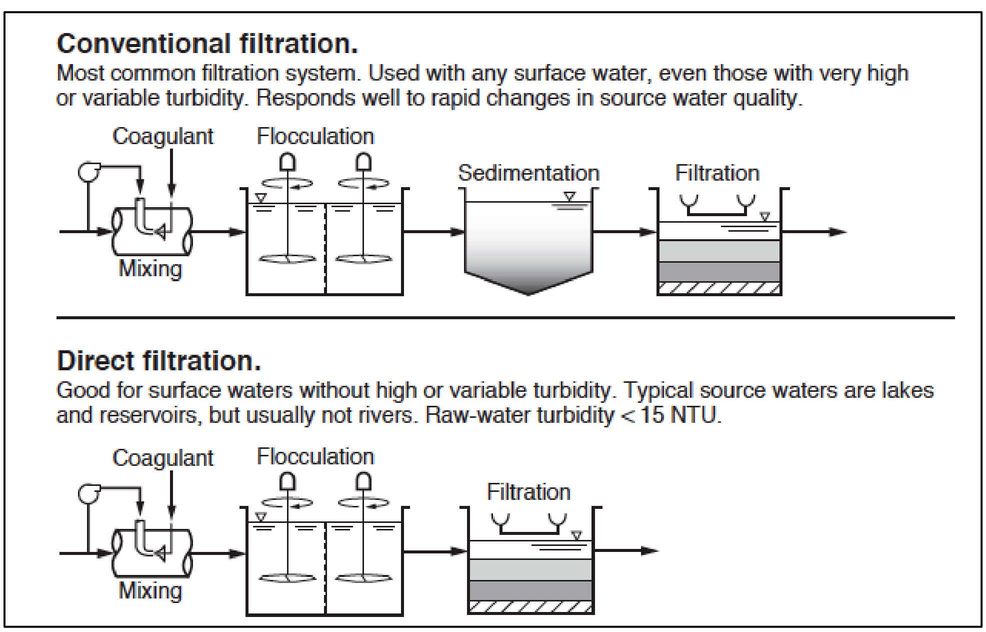
Of the seven treatment trains depicted in Table 8, three would be considered conventional filtration trains (Trains 1, 2 and 3) and two would be considered direct filtration trains (Trains 4 and 5). Membrane filtration (Trains 6 and 7) is generally not classified as a "direct filtration" process, even though it can include coagulation and typically does not include sedimentation. Membrane filtration is discussed separately in the next section.

A brief overview of each process is provided below, followed by a summary of the relative advantages and disadvantages of each.

5.2.1 Direct Filtration

As shown on Figure 16, a direct filtration train includes coagulant addition, flocculation, and filtration. Three main differences between a direct filtration train and a conventional treatment train are (1) the sedimentation basin, which is not included with direct filtration, (2) chemical conditioning, and (3) the detention time of flocculation step. Direct filtration is an appropriate technology if the influent turbidity is consistently less than 10 NTU, with occasional brief turbidity spikes of no more than 20 NTU. Coagulant doses used in direct filtration are typically only 1-5 mg/L, significantly lower than those used in conventional treatment (often 15-30 mg/L). Cationic polymer (e.g., Polydiallyldimethylammonium chloride [polyDADMAC]) is also commonly used with direct filtration at doses ranging from 0.5 to 2.5 mg/L. Cationic polymers can also be used in conventional treatment to aid in floc formation, but the dose is typically lower, on the order of 0.5 to 1 mg/L. The objective of chemical conditioning in direct filtration is to destabilize the particles which allows them to be removed through the filter bed (i.e., depth filtration) rather than forming a sweep floc that will settle. A disadvantage of using cationic polymer such as polyDADMAC is that it contains precursor material that can form *N*-Nitrosodimethylamine (NDMA) when reacted with chloramines. NDMA is one of several nitrosamines considered potential carcinogens. It forms as a by-product of some water treatment practices. NDMA and other nitrosamines are on EPA's CCL4. In California, it is regulated with a Notification Level (NL) of 10 ng/L, and is considered a good candidate for future regulation with a MCL.

Figure 16. Comparison of a Conventional Treatment Train with a Direct Filtration Treatment Train (Crittenden, et al., 2012)



Unit processes and equipment associated with direct filtration treatment include: flash mixing facilities for rapid mixing of the coagulant with raw water; flocculation basin(s) and mechanical mixers; and dual or mono-media filters with a backwash and air-scour system. A flocculation time of 10 to 20 minutes is typical for direct filtration, while 30 to 45 minutes of flocculation time is typical for conventional treatment. As such, the flocculation basin is generally smaller with direct filtration. Design parameters for the filters themselves, including filter loading rates, bed depths, and backwash systems, are very similar for both direct filtration and conventional treatment approaches. However, because effective treatment is so dependent on chemical conditioning and particle removal through the filter bed, at least six months of pilot testing is recommended for proper selection of media size, design of the filter bed, selection of design filtration rate, selection of appropriate chemicals and doses, and to demonstrate performance to DDW.

One significant difference between direct filtration treatment and conventional treatment is the inherent difficulty in responding to changing water quality conditions associated with "flashy" water (i.e., a source water prone to turbidity spikes) and/or seasonal storm events. Direct filtration is limited by the coagulant dose (generally no greater than 5 mg/L) and the coagulated particles' inability to settle. During the preparation of this TM, three large direct filtration treatment facilities were contacted about operational challenges they face, and detailed responses were received from two facilities. The facilities contacted were: (1) the Los Angeles Aqueduct Filtration Plant (LAAFP) in Los Angeles, CA (a 600-mgd direct filtration facility with pre-ozonation); (2) the Tolt Water Treatment Facility in Duvall, Washington; and (3) Metropolitan Water District of Southern California's (MWDSC) Skinner treatment facility that has both a conventional train and a direct filtration train. The operational experiences from LAAFP and Tolt are discussed in Attachment A to this TM, and general feedback provided by MWDSC is discussed here. The common response from all three facilities was that when influent water quality degrades, such as during storm events, treatment becomes challenging and there are four available options: increase coagulant dose; reduce filter run length; reduce plant flows; or reject the source water (i.e., switch sources or shut down). One or more of these options could be used to respond to the degradation of influent water quality.

5.2.2 Conventional Filtration

As discussed above, a conventional treatment facility differs from a direct filtration treatment facility in the following ways: conventional treatment typically uses higher coagulant doses and lower polymer doses; conventional treatment typically utilizes a longer flocculation time; and conventional treatment requires a sedimentation basin. A conventional treatment facility is more robust and able to effectively respond to changing water quality brought on my storm events. Importantly, conventional treatment can accommodate a sufficiently high coagulant dose for enhanced coagulation and subsequent removal of DBP precursor material (i.e., TOC).

Per California Title 22 CCR, both conventional treatment and direct filtration treatment filters are generally operated at a filtration rate of no more than 6.0 gallons per minute per square foot (gpm/ft^2), and should be designed to operate at this rate with one filter off-line for backwashing. After a period of operation, a utility may re-rate their filters to operate at higher filtration rate by submitting a demonstration report to DDW based on filter effluent turbidity performance at the higher rates. This approach presents an excellent opportunity to increase treatment capacity without incurring additional construction costs. Details of the re-rating process are discussed in Title 22 CCR.

5.2.3 Advantages and Disadvantages

Comparative advantages and disadvantages of direct filtration treatment and conventional filtration treatment are summarized in Table 12.

Table 12. Advantages and Disadvantages of Direct Filtration and Conventional Filtration Processes

Treatment Process	Advantages	Disadvantages
Direct Filtration	• Lower coagulant dose (lowers chemical costs). • Smaller footprint due to: — Lack of sedimentation basin — Shorter HDT through flocculation	• Higher polymer dose (increases chemical costs) • If a polyDADMAC cationic polymer is used, NDMA (NL = 10 ng/L) can form during final disinfection with chloramines[(a)] • Not a robust treatment for a "flashy" source water. For persistent turbidity spikes above 10-20 NTU, the WTP would likely have to shut down until the raw water turbidity subsided. • Six months of pilot testing required for proper design and chemical selection, and demonstration of performance to DDW. • Operations can be challenging when source water quality degrades. • May be difficult to find operators that understand how to operate a direct filtration facility. • DDW discourages the use of direct filtration.
Conventional Filtration	• Robust treatment for changing influent water quality • Amenable to enhanced coagulation for DBP control • Can accommodate use of powdered activated carbon if needed for T&O control.	• Larger footprint • Higher coagulant use

(a) Najm and Trussell, 2000; Wilczak, et al., 2003

5.3 Membrane Filtration vs. Media Filtration

Membrane filtration (MF), like media filtration, relies on particulate and pathogen removal for treatment. Just as for direct filtration (with media filters), membrane filtration is exempt from the enhanced coagulation requirements of the D/DBP Rule, but must still meet DBP MCLs.

Of the seven treatment trains depicted in Table 8, five rely strictly on media filtration (Trains 1 through 5), one places media filtration after membrane filtration (Train 6), and one relies strictly on membrane filtration (Train 7). A brief overview of each process is provided below, followed by a summary of the relative advantages and disadvantages of each process.

5.3.1 Membrane Filtration

In a membrane filtration treatment train, either microfiltration or ultrafiltration membranes can be used. Coagulation may or may not be needed for effective filtration, but is often included to aid in particulate removal. Flocculation, however, is not required for membrane filtration. When a coagulant is added, the dose is generally quite low (i.e., 1 to 5 mg/L); the coagulant is added to help reduce membrane fouling, increase the time between membrane cleanings, and possibly allow operation at a higher flux (i.e., the flow rate through the membrane). This low coagulant dose does not provide effective TOC removal. Polymers are typically not used in membrane filtration treatment. And just as for direct filtration (with media filters), membrane filtration treatment is most appropriate for raw waters with turbidities less than 10-15 NTU. Membrane filtration is more adept at handling infrequent and short-lived turbidity spikes than direct filtration, without compromising pathogen removal or filter effluent turbidity. Without sedimentation, a membrane treatment facility would have to either reduce production or shut-down for extended periods of turbidities exceeding 15 NTU. And just as for direct filtration, four to six months of pilot testing is recommended for membrane filtration to investigate the effect of coagulant on membrane performance, optimum coagulant type and dose, and demonstrate effective performance to DDW.

Operation of a membrane filtration system includes automatic reverse filtration/air scrubbing to remove accumulated particulate material from the membranes, a daily chemically enhanced backwash to disinfect the membranes and restore permeability, and less frequent, but periodic, clean-in-place (CIP) chemical cleaning sequences. CIP sequences typically use citric acid. Filter runs are typically 30 to 40 minutes between backwashes; the optimum backwash frequency would be determined through pilot testing.

Components of a membrane filtration system include feed water pumps, auto-backwashing strainers, membranes, compressed air for daily pressure decay testing of membrane integrity, potentially two CIP chemical storage tanks (i.e., one acid tank and one base tank), backwash pumps and an air scour system, and a filtrate tank. Membrane systems are typically housed within an enclosed, climate controlled building.

Membrane filtration is considered an “absolute barrier” to *Giardia* and *Cryptosporidium*. Generally, DDW will credit membrane filtration with 4-log *Giardia* and 4-log *Cryptosporidium* removal. The membrane manufacturer must conduct a “challenge test” using the specific membrane to be installed and DDW must approve the submitted challenge test report. This is a product-specific challenge test and not a water-specific test. Greater *Giardia* and *Cryptosporidium* removal credit is awarded for membrane filtration than for direct filtration with granular media filters. The additional required pathogen treatment credit (for multi-barrier treatment) is achieved through disinfection. Virus removal credit is awarded for direct filtration with media filters, but typically not for membrane filtration.

5.3.2 Media Filtration

Media filtration was discussed briefly in the preceding section. The components of a dual media filtration process include: open, reinforced concrete filter cells; filter media (either anthracite over sand or GAC over sand); backwash pumps and air scour equipment to assist cleaning the media during backwash; and underdrain and filtered water collection systems. For a dual-media filter, the filter bed would be approximately 5-6 feet of anthracite or GAC over 1-foot of sand. The head loss across each individual filter, individual filter effluent turbidities, and combined filter effluent turbidity would be monitored continuously. A granular media filter is not considered an "absolute barrier" to pathogens, and therefore receives less pathogen removal credit than a membrane filtration system. (This was discussed previously in Section 4.2.)

Title 22 CCR limits filtration rates at conventional filtration and direct filtration treatment facilities to a maximum of 6 gpm/ft^2, with one filter off-line for backwashing. Filter re-rating to a higher filtration rate is a viable option for future plant expansion. Filter re-rating requires a full-scale filtration performance study be performed. Re-rating to a filtration rate less than twice the original permitted rate can be based on filter effluent turbidity performance. Higher filtration rates require a study be conducted to demonstrate *Giardia* and virus removal.

5.3.3 Advantages and Disadvantages

Advantages and disadvantages of membrane filtration and media filtration are summarized in Table 13.

Table 13. Advantages and Disadvantages of Membrane Filtration and Media Filtration Processes

Treatment Process	Advantages	Disadvantages
Membrane Filtration	• Up to 4-log *Giardia* and *Cryptosporidium* treatment credit are offered for effective and compliant operation. • Modular system allows for relatively straightforward expansion, provided adequate space is available. • Can handle brief (e.g., hours) turbidity spikes while producing consistent filtrate water quality because of inherent straining and small pore size characteristics.	• Little or no TOC removal is achieved so chlorination DBPs will be an issue if free chlorine is used for final disinfection; SRWA would have to consider switching to chloramines for residual maintenance in the distribution systems. • Without ozone/BAC included in the process train, a membrane filtration facility cannot address T&O issues or CECs, pesticides and/or other SOCs. • At least 4-6 months of pilot testing would be required to satisfactorily demonstrate system performance and develop design criteria. • Membrane filtration treatment requires more chemical use and storage than a conventional or direct filtration treatment systems, because of the additional CIP chemicals. • Potential difficulties disposing of CIP waste chemicals. DDW has clearly stated that CIP chemicals cannot be returned to the head of the plant for blending with raw water. • Mixed reviews for membrane facilities in the region indicate a potential for unanticipated performance and/or reliability issues
Media Filtration	• Filter re-rating is a viable, cost-effective means of plant expansion after a period of full-scale performance data has been gathered at design filtration rates of 6 gpm/ft^2. • Proven technology	• Less pathogen treatment credit is awarded for media filtration than for MF

6.0 CONSTRUCTION COST COMPARISON OF UNIT PROCESSES AND TREATMENT TRAINS

This section provides a summary of planning-level construction cost estimates for the variety of unit processes and treatment trains discussed in Sections 4 and 5 of this TM. The methodologies used to develop the cost information presented herein are described in a TM titled *Methodology for Developing Planning Level Construction Cost Information for SRWA Surface Water Treatment Unit Processes* (West Yost, March 2017), which is included as Attachment B to this TM.

A summary of the unit process cost estimates presented in Attachment B is included in Table 14. Costs shown in Table 15 reflect the combinations of unit processes associated with the treatment train alternatives in Table 9. In instances where cost data were available from more than one reference facility, the capacity-adjusted reference costs from the more recently constructed facility are used. Percentage adders are then applied for a variety of categories (sitework, yard piping, electrical & instrumentation and mobilization) to capture a more complete picture of potential WTP construction costs. Finally, an overall estimating contingency of 25 percent is applied.

Section 7 of this TM presents planning-level operation and maintenance (O&M) cost information for the treatment trains identified by the TAC and PM Team for further evaluation at the conclusion of the March 30, 2017 workshop.

Table 14. Summary of Planning-Level Unit Process Construction Costs[a]

Unit Process	Reference Facility Information			Adjusted Facility Information		
	Source of Reference Costs	Process Capacity	Reference Facility Midpoint of Construction	Inflated to Midpoint of SRWA WTP Construction (June 2020), dollars	SRWA Target Capacity	Adjusted to SRWA WTP Target Capacity, dollars
Flash Mixing	WDCWA Plant	30 mgd	Jan 2015	602,000	15 mgd	397,000
Coagulation, Flocculation and Sedimentation	Vineyard Plant	50 mgd	Aug 2009	17,297,000	15 mgd	8,399,000
	WDCWA Plant	30 mgd	Jan 2015	6,731,000	15 mgd	4,441,000
Coagulation and Flocculation Only (No Sedimentation)	Vineyard Plant	50 mgd	Aug 2009	7,310,000	15 mgd	3,550,000
Granular Media Filtration	WDCWA Plant	30 mgd	Jan 2015	14,929,000	15 mgd	9,849,000
Membrane Filters	MID Plant	30 mgd	Jun 2008	30,438,000	15 mgd	20,082,000
	Lodi Plant	8 mgd	May 2012	7,268,000	15 mgd	10,598,000
Ozone Treatment	MID Plant	30 mgd	Jun 2008	12,599,000	15 mgd	8,312,000
	WDCWA Plant	30 mgd	Jan 2015	6,577,000	15 mgd	4,339,000
Chlorine Contact Basin (Free Chlor. and Chloramines)	WDCWA Benchmark WTP	212,000 gal	Jul 2011	684,000	625,000 gal	1,309,000
UV Disinfection	Vendor Proposal/Conceptual Layout	15 mgd	Mar 2017	748,000	15 mgd	748,000
Chemical Building	WDCWA Plant	30 mgd	Jan 2015	5,546,000	15 mgd	5,546,000
Operations & Administration Building	WDCWA Plant	30 mgd	Jan 2015	4,075,000	15 mgd	4,075,000
Maintenance Building	WDCWA Plant	30 mgd	Jan 2015	1,588,000	15 mgd	1,588,000
In-Plant Pump Station	WDCWA Plant	30 mgd	Jan 2015	1,935,000	15 mgd	1,277,000
Finished Water Clearwell	WDCWA Plant	5.75 MG	Jan 2015	7,487,000	2.375 MG	4,432,000
Backwash Supply / Finished Water Pump Station	WDCWA Plant	30 mgd	Jan 2015	6,541,000	15 mgd	4,315,000
Backwash Equalization Basin	WDCWA Plant	30 mgd	Jan 2015	2,838,000	15 mgd	1,872,000
Gravity Thickeners	WDCWA Plant	30 mgd	Jan 2015	2,533,000	15 mgd	1,671,000
Drying Beds	WDCWA Plant	30 mgd	Jan 2015	2,691,000	15 mgd	1,775,000

[a] Does not include electrical and instrumentation costs. These costs are more appropriately captured as a percentage of the overall treatment process.

Table 15. Summary of Planning-Level Construction Costs for Available Treatment Trains for 15-mgd Surface Water Treatment Plant

Process/Facility	Treatment Train No.						
	1 Conventional with Pre-O_3, dollars	2 Conventional with Interim O_3, dollars	3 Conventional without O_3, dollars	4 Direct Filtration with O_3, dollars	5 Direct Filtration without O_3, dollars	6 Membrane Filtration with O_3, dollars	7 Membrane Filtration without O_3, dollars
Unit Processes Associated with Specific Treatment Trains							
Pre-Ozonation	4,339,000			4,339,000			
Coagulation and Flocculation				3,947,000	3,947,000	3,947,000	3,947,000
Coagulation, Flocculation and Sedimentation	4,838,000	4,838,000	4,838,000				
Intermediate Ozonation		4,339,000				4,339,000	
Granular Media Filters	9,849,000	9,849,000	9,849,000	9,849,000	9,849,000		
Membrane Filters						10,598,000	10,598,000
Backwash Equalization Basin	1,872,000	1,872,000	1,872,000	1,872,000	1,872,000		
UV Disinfection			700,000	748,000	748,000		748,000
Chlorine Contact Basin - Free Chlorine and Chloramines[a]	1,309,000	1,309,000	1,309,000				
Subtotal	22,207,000	22,207,000	18,568,000	22,016,000	17,677,000	20,193,000	16,554,000
Unit Processes and Facilities Common to all Treatment Trains							
Flash Mixing	397,000	397,000	397,000	397,000	397,000	397,000	397,000
In-Plant Pump Station	1,277,000	1,277,000	1,277,000	1,277,000	1,277,000	1,277,000	1,277,000
Clearwell	4,432,000	4,432,000	4,432,000	4,432,000	4,432,000	4,432,000	4,432,000
Backwash Supply / Finished Water Pump Station	4,315,000	4,315,000	4,315,000	4,315,000	4,315,000	4,315,000	4,315,000
Gravity Thickeners	1,671,000	1,671,000	1,671,000	1,671,000	1,671,000	1,671,000	1,671,000
Drying Beds	1,775,000	1,775,000	1,775,000	1,775,000	1,775,000	1,775,000	1,775,000
Chemical Building	5,546,000	5,546,000	5,546,000	5,546,000	5,546,000	5,546,000	5,546,000
Administration & Operations Building	4,075,000	4,075,000	4,075,000	4,075,000	4,075,000	4,075,000	4,075,000
Maintenance Building	1,588,000	1,588,000	1,588,000	1,588,000	1,588,000	1,588,000	1,588,000
Subtotal	47,283,000	47,283,000	43,644,000	47,092,000	42,753,000	45,269,000	41,630,000
Sitework[b] 15%	7,092,000	7,092,000	6,547,000	7,064,000	6,413,000	6,790,000	6,245,000
Yard Piping[b] 13%	6,147,000	6,147,000	5,674,000	6,122,000	5,558,000	5,885,000	5,412,000
Electrical and Instrumentation[b] 21%	9,929,000	9,929,000	9,165,000	9,889,000	8,978,000	9,506,000	8,742,000
Subtotal	70,451,000	70,451,000	65,030,000	70,167,000	63,702,000	67,450,000	62,029,000
Mobilization / Demobilization[b] 3%	2,114,000	2,114,000	1,951,000	2,105,000	1,911,000	2,024,000	1,861,000
Subtotal	72,565,000	72,565,000	66,981,000	72,272,000	65,613,000	69,474,000	63,890,000
Estimating Contingency 25%	18,141,000	18,141,000	16,745,000	18,068,000	16,403,000	17,369,000	15,973,000
TOTAL ESTIMATED CONSTRUCTION COST	**$90,706,000**	**$90,706,000**	**$83,726,000**	**$90,340,000**	**$82,016,000**	**$86,843,000**	**$79,863,000**

[a] Does not include any costs for incorporation of chloramines at City groundwater wells.

[b] Percentage adders are based on the averages of such costs for the WDCWA and SCWA reference projects.

7.0 RISK ASSESSMENT, RECOMMENDATIONS AND SUPPLEMENTAL EVALUATION INFORMATION

This section summarizes potential risks and provides recommendations regarding the treatment train alternatives discussed above. The PM Team recommendations in Section 7.2 were intended to guide discussion at the TAC workshop on March 30, 2017; recommendations presented in Section 7.3 reflects discussion at the end of that workshop. Supplemental analyses requested by the TAC during the March 30th workshop are presented in Section 7.4. Finally, updated TAC recommendations are presented in Section 7.5, based on additional discussion at a subsequent workshop on May 17, 2017.

7.1 Risks Associated with Treatment Train Alternatives

Table 16 lists several categories of finished water quality risks that may face SRWA's new WTP, and provides the PM Team's assessment of the relative likelihood that each risk might be realized for each treatment train alternatives considered. To place the risk assessments into economic perspective, the table also includes the relative differences in construction cost between Train No. 1 (the most expensive alternative) and the other alternatives. In general, the alternatives with lower risk assessments are more expensive, while riskier alternatives offer greater potential cost savings.

7.2 PM Team Recommendations (Developed prior to March 30, 2017 Workshop)

- **Do not select a treatment train that will require shut-down or reduced finished water production**. The average historical recurrence interval of the extended periods of high stream flows (which are assumed to coincide with elevated TOC levels) is too short, and the averaged historical durations of the same periods too long, to consider shut-down as an option.
- **Include ozone in the treatment train**. In addition to disinfection, ozone will provide taste and odor removal, pesticide and CEC removal, reduced chlorinated DBP formation, and increase flexibility for water quality changes in the Tuolumne River.
- **Include BAC dual-media filtration after ozonation**. BAC following ozone will provide up to 40 percent more TOC removal, which will limit DBP formation. BAC filtration ensures effective removal of the CECs and pesticides that are broken apart by the ozone.
- **Do not allow ferric chloride for clarification**. Avoiding the use of ferric chloride will reduce the potential for manganese control issues, as Mn^{2+} is a typical contaminant found in bulk ferric chloride.

7.3 Preliminary TAC Recommendations (Developed during March 30, 2017 Workshop)

- **Include ozone in the treatment train**. Adopting this recommendation results in the elimination of Trains 3, 5 and 7. In the case of Trains 1 and 2, Train 1 is preferred by the TAC, due to the reduced likelihood of manganese control issues associated with pre-ozonation. However, Train 2 may still be a viable alternative depending on the outcome of additional manganese removal bench testing and future raw water quality sampling after construction of the raw water pump station wet well.

- **Do not utilize direct filtration**. Adopting this recommendation results in the elimination of Trains 4 and 5.
- **Use free chlorine for secondary disinfection**. In accordance with the descriptions of available treatment trains in Table 9, excluding chloramines from further consideration would result in the elimination of Trains 4, 5, 6 and 7. Among these trains, all but Train 6 are simultaneously eliminated from consideration on the basis of the above TAC recommendations (i.e., include ozone and exclude direct filtration). With respect to Train 6, the TAC acknowledged that while the risk of exceeding regulatory limits for DBPs for Train 6 was higher with free chlorine than with chloramines, the potential capital cost savings associated with Train 6 warranted its further consideration.
- **Preliminary preferred trains**, after adoption of the above TAC recommendations, are as follows:
  - Train 1: Conventional Filtration with Pre-Ozonation, Biologically Active Filters and Secondary Disinfection with Free Chlorine
  - Train 6: Membrane Filtration with Intermediate Ozonation, Biologically Active Filters and Secondary Disinfection with Free Chlorine

7.4 Supplemental Evaluation Information for Preferred Treatment Trains

Following the March 30, 2017 workshop, the TAC and PM Team identified the following topics for further evaluation of the two preferred trains:

- Additional desktop evaluation of DBP compliance risks
- Planning-level O&M costs
- Treatment facility expandability
- Disposal options for membrane chemical cleaning wastes

These items are presented below.

7.4.1 Additional Desktop Evaluation of DBP Compliance Risks

As discussed previously, a conventional treatment train (e.g., Train 1) relies primarily on enhanced coagulation for removal of DBP precursor material (i.e., TOC), augmented by removal through ozone and biofiltration. To assess the likely performance of Train 1, Trussell conducted bench-scale jar tests to measure DBP precursor removal through enhanced coagulation. Additionally, bench-scale simulated distribution system DBP tests (or SDSDBP tests) were conducted in November 2016 and February 2017 to assess the potential formation of regulated DBPs in the distribution system after exposure to free chlorine as a secondary disinfectant. The results of these tests (shown on Figure 7 and Figure 9) neglect the additional DBP-removal benefit of ozone and biofiltration in combination since biofiltration cannot be easily evaluated at the bench-scale, and so provide a somewhat conservative estimate of the likely performance of Train 1.

In contrast to Train 1, a membrane filtration treatment train (e.g., Train 6) is not amenable to enhanced coagulation, and thus must rely solely on ozone and biofiltration for DBP precursor removal. Ozonation serves to break larger organic molecules into smaller, more easily biodegradable material, and biodegradation occurs as the ozonated water passes among the microbial communities which develop over time on the filter media. Often, DBP precursor concentration correlates with the TOC concentration of a water, and TOC is an easily measurable parameter. The amount of TOC removal that occurs through ozonation and biofiltration is typically specific to the water source, and cannot be reliably tested at the bench scale. Even larger scale pilot testing of TOC removal with ozone and biofiltration and is challenging, as the adsorption capacity of virgin GAC must first be exhausted and biological activity must be established prior to observing performance indicative of long-term operations. As such, bench-scale test data are not available to estimate potential concentrations of DBPs after treatment using Train 6 that reflect the impact of ozone and biofiltration (Figure 8 showed SDSDBP test results reflective of a low coagulant dose that would be appropriate for Train 6, plus primary disinfection with free chlorine). To generate estimates for Train 6 that consider ozone and biofiltration, Trussell instead conducted a desktop evaluation relying on data from a combination of literature reported studies, SRWA's ongoing source sampling program and historical source water data from TID's 2006-2007 sampling program. The methodology and results of this desktop evaluation are described in the following paragraphs.

To estimate TOC removal through ozone and biofiltration, literature reported studies must be relied upon. A 2005 American Water Works Association's Research Foundation (AWWARF) study of nine full-scale water treatment plants employing ozone and biofiltration[10] provides an indication of TOC removal through these processes for a variety of surface water supplies around the country (Westerhoff, et al., 2005). A summary of TOC removals reported by Westerhoff, et al., is shown on Figure 17. In the study, full-scale TOC removal through ozone and biofiltration ranged from 13 percent to 64 percent, with an average removal of 27 percent and median removal of 19 percent. To estimate TOC removal through ozone and biofiltration for SRWA, a conservative TOC removal rate of 18 percent was assumed. It is also assumed that DBP precursor levels are reduced by the same percentage, which allows estimation of DBP concentrations in the distribution system based on the reduced TOC concentrations.

[10] Two of the utilities (#5 and #7) utilize anthracite/sand biofilters rather than GAC/sand biofilters used by the other utilities.

Figure 17. TOC Removal Measured in a Nationwide Survey of Full-Scale Water Treatment Facilities Employing Ozone and Biofiltration (Westerhoff, et al., 2005)

TOC removals in utilities

Utilities	2002 TOC Removal			2003 TOC Removal		
ID #	ozonation	biofiltration	Total	ozonation	biofiltration	Total
1	1 %	15 %	18 %	26 %	15 %	38 %
2	3 %	24 %	30 %		*No sampling*	
3				-	1 %	19 %
4		No sampling		1 %	31 %	31 %
5	-1 %	18 %	29 %	-29 %	16 %	13 %
6	-13 %	26 %	18 %	-14 %	16 %	14 %
7	-3 %	1 %	19 %	-23 %	17 %	19 %
8		*No sampling*			*No TOC data*	
9A	-4 %	21 %	18 %	12%	23%	52%
9B		*No sampling*		4%	23%	64%

By applying the assumed additional 18 percent TOC removal to the SDSDBP tests from November 2016 and February 2017 (i.e., those depicted previously on Figure 7 and Figure 9), a more representative assessment of DBPs in the distribution system can be estimated, as shown on Figure 18. Similarly, Figure 19 shows the estimated impact of ozone and biofiltration on distribution system DBPs for Train 6, based on SDSDBP results from February 2017[11] (i.e., those depicted previously on Figure 8).

Figure 18. Estimated DBP Concentrations with Conventional Treatment Plus Ozone and Biofiltration (Train #1) Relative to MCLs and Treatment Goals

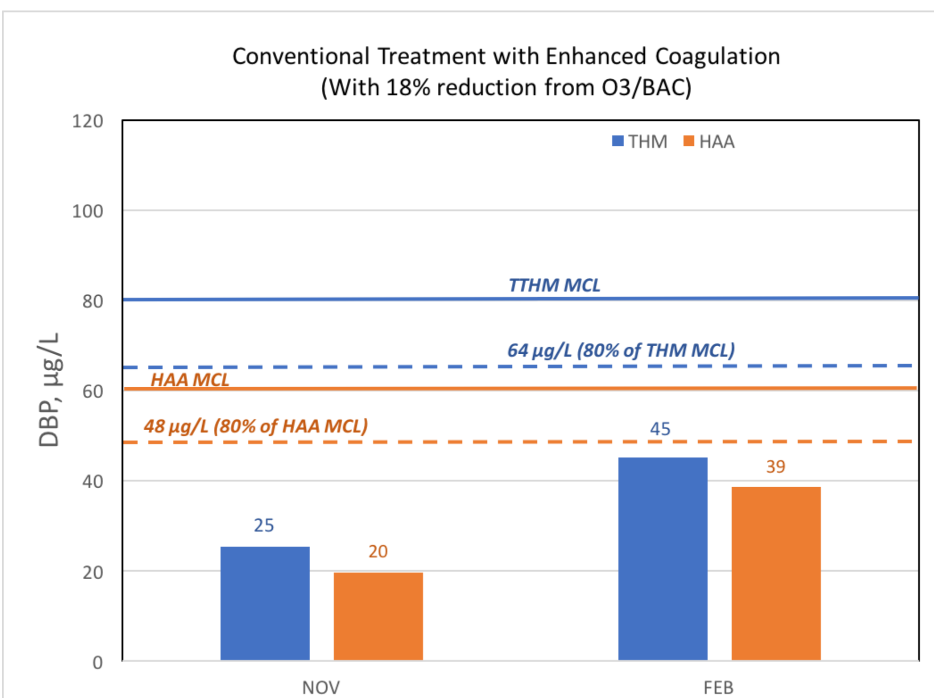
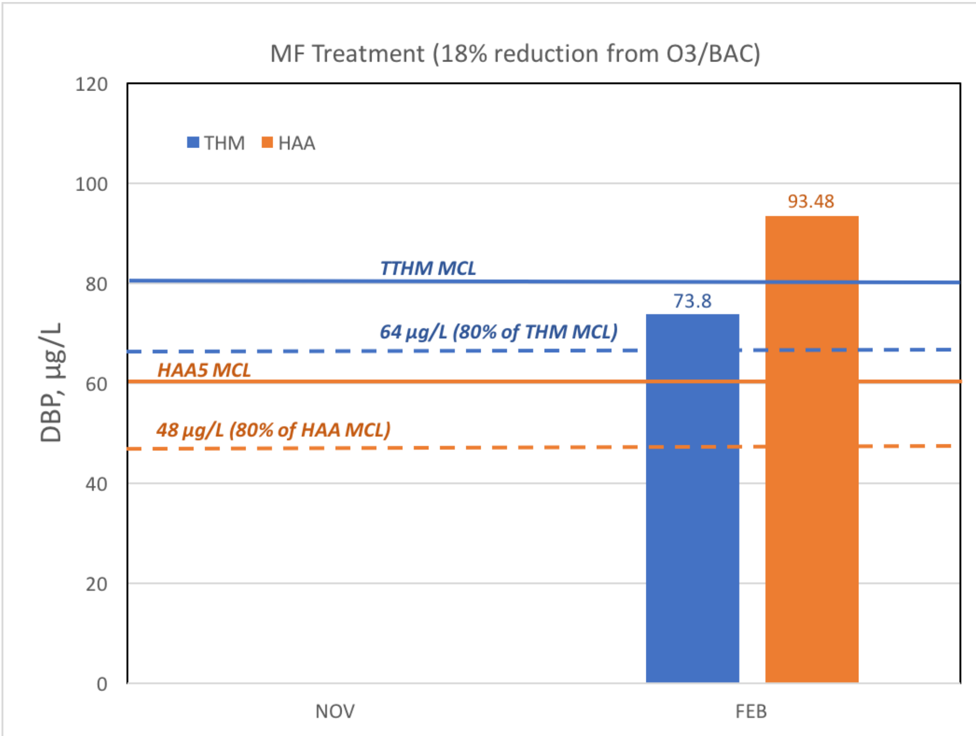


Figure 19. Estimated DBP Concentrations with Membrane Filtration Treatment Plus Ozone and Biofiltration (Train #6) Relative to MCLs and Treatment Goals



Conventional treatment with ozone and biofiltration (Figure 18) results in TTHM and HAA5 levels below both the MCLs and treatment goals (i.e., 80 percent of the MCL), under both dry- and wet-weather stream flow conditions. For membrane filtration treatment with ozone and biofiltration (Figure 19), the TTHMs were just slightly below the MCL but above the treatment goal, while the HAA5s were well above the MCL.

While the results shown on Figures 18 and 19 are instructive, they provide limited information about potential long-term trends for SRWA's source water, or of the locational running annual average (LRAA) DBP values which will be the basis for demonstrating DBP compliance in each City under the Stage 2 D/DBP Rule[12]. To estimate distribution system average DBP values for Trains 1 and 6, it was necessary to examine the potential TOC and DBP removal impacts of ozone and biofiltration on a larger set of raw water quality data, as described below.

---

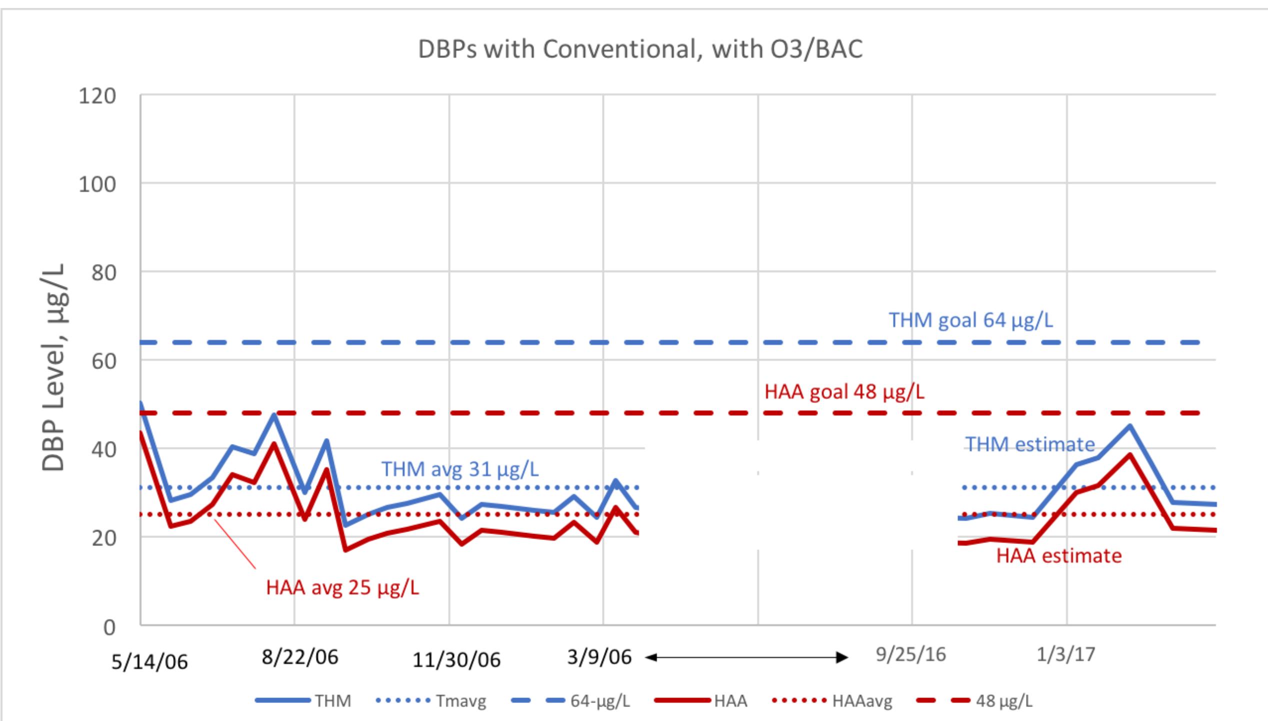
[11] No SDSDBP bench tests were conducted with a low coagulant dose during dry weather conditions (i.e., November).

[12] State and federal drinking water regulations for the Stage 2 D/DBP Rule require an Initial Distribution System Evaluation (IDSE) be conducted to identify locations in the distribution system where the highest DBP concentrations are likely to occur. These locations are then used for compliance monitoring. The Stage 2 D/DBP Rule requires that compliance with the TTHM and HAA5 MCLs be met at each compliance monitoring location based on calculated locational running annual average (LRAA), rather than a system-wide running annual average (RAA) as defined under the earlier Stage 1 D/DBP Rule. Compliance using LRAAs is more challenging and requires more conservatism than meeting the system-wide RAAs.

By comparing measured DBP concentrations from the November 2016 and February 2017 SDSDBP tests with measured raw water TOC concentrations from the same sampling events, correlations between raw water TOC and distribution system DBP concentrations were established. These correlations were then applied to historical TOC data collected at the Infiltration Gallery location during the TID pilot study (2006-2008) and the entirety of the recent TOC dataset collected as part of the SRWA sampling program to establish baseline estimated DBP concentrations for Train 1 and Train 6. By applying an additional 18 percent reduction in TOC concentrations, and thus DBP concentrations, via ozone and biofiltration treatment, DBP concentrations which more accurately reflect the performance of Trains 1 and 6 were estimated for all available raw water TOC measurements.

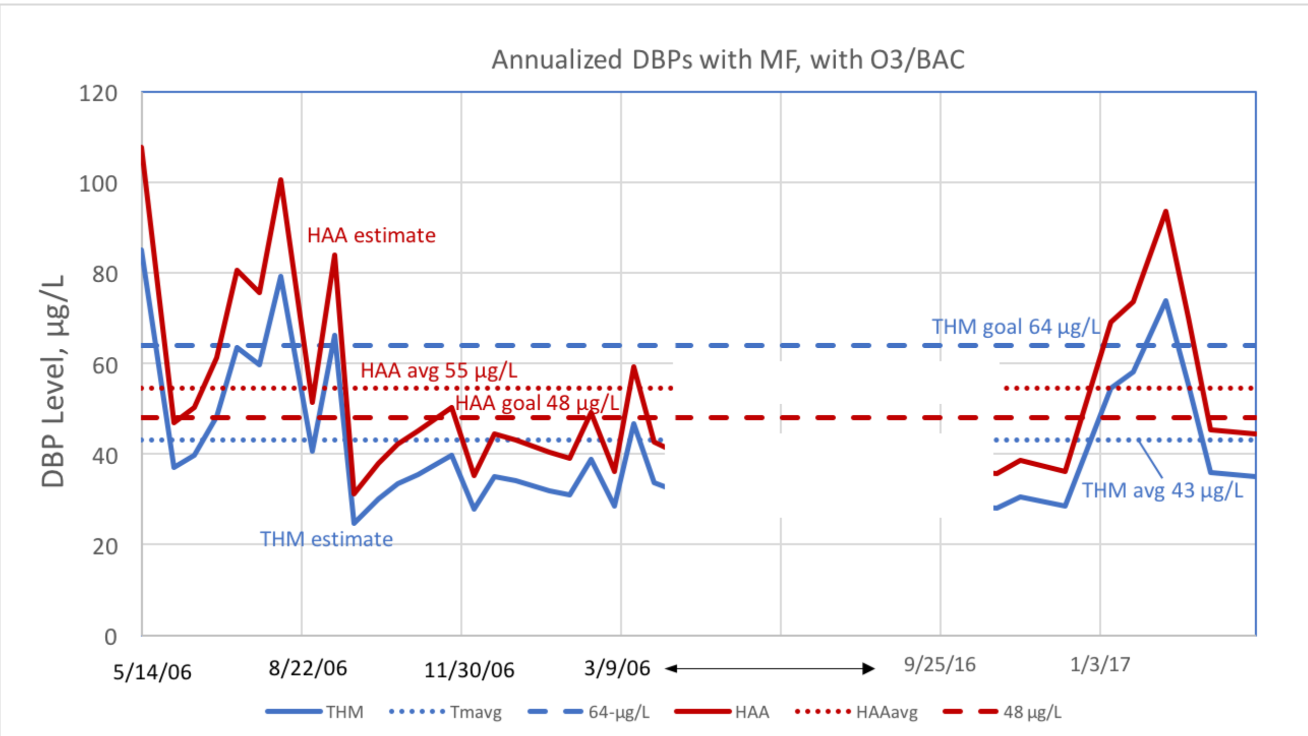
The resulting estimated DBP concentrations for conventional treatment with ozone and biofiltration (Train 1) and for membrane filtration treatment with ozone and biofiltration (Train 6) are shown on Figure 20 and Figure 21, respectively. For Train 1, estimated monthly TTHM and HAA concentrations are each consistently below their respective MCLs and treatment goals. The average TTHM concentration was estimated to be 31 µg/L and the average HAA5 concentration was estimated to be 25 µg/L. Thus, a conventional treatment train practicing enhanced coagulation that includes ozone and biofiltration plus free chlorine final disinfection (Train 1), is expected to result in TTHMs and HAA5s levels that meet DBP treatment goals and regulatory standards year-round.

Figure 20. Estimated Monthly and Average DBP Levels for Conventional Treatment Plus Ozone/BAC (Train #1) Relative to MCLs and Treatment Goals



For Train 6, monthly HAAs are estimated to exceed the MCL (60 µg/L) several times per year, and the estimated annual average concentration of 55 µg/L is above the treatment goal of 48 µg/L and only slightly below the MCL. Estimated monthly TTHM concentrations were predicted to occasionally exceed the MCL (80 µg/L) as well as the treatment goal of 64 µg/L. The estimated annual average TTHM concentration was 43 µg/L, which is below both the treatment goal and the MCL. Thus, even with ozone and biofiltration included in the treatment train, membrane filtration with free chlorine final disinfection (Train 6) is expected to result in DBP levels that exceed regulatory standards.

Figure 21. Estimated Monthly and Average DBP Levels for Membrane Filtration Treatment with Ozone/BAC (Train #6) Relative to MCLs and Treatment Goals



7.4.2 Planning-level O&M Costs

Planning-level O&M costs were developed for WTPs comprised of Trains 1 and 6. Because detailed design criteria have not yet been developed for either treatment train, the costs presented in this section rely heavily on industry expertise and recent cost information from similar facilities. In each case, O&M costs were estimated for the following categories:

- **Electrical power**: This category includes the raw water pump station, all WTP processes and the finished water pump stations. Raw water pump stations were included in either case because the treatment train is likely to influence the design hydraulic grade to which the raw water pump station must lift water to.
- **Chemicals**: This category includes all process chemicals, including coagulants, flocculants, disinfectants, membrane cleaning agents (specific to Train 6), pH adjustment, corrosion inhibitors, and so on.

- **Chemical disposal**: This category is unique to Train 6, and includes estimated costs for the offsite disposal of certain chemicals associated with the periodic cleaning of membrane filters.
- **Major equipment repair & replacement**: This category is intended to reflect annual SRWA contributions to an escrow account from which periodic major equipment repair, overhaul and replacement expenditures will be withdrawn. The estimated annual contributions are a function of the types, numbers, costs and estimated useful lives of the various major equipment items associated with each treatment train.
- **All other O&M costs**: This category includes all other typical O&M expenses not captured in the above categories (e.g., labor, routine maintenance activities, solids management, minor onsite utilities and contract services, and so on). Of these categories, labor comprises the largest portion of the estimated costs.

7.4.2.1 Train 1 O&M Cost Assumptions

Major assumptions used in the development of Train 1 O&M costs are summarized below. In each case, the basis for the Train 1 costs was recent cost information for a surface water treatment plant operated by the Woodland-Davis Clean Water Agency (which uses a treatment train that is essentially identical to Train 1), with as-needed adjustments to reflect characteristics specific to SRWA's project.

- **Power**: Power costs for Train 1 assume that the raw water pump station provides the necessary head to drive liquid stream flows through flash mixing, coagulation, flocculation, sedimentation, ozonation and media filtration. After the filters, it is assumed that an in-plant pump station lifts the filtered water to the clearwells. The finished water pump stations pump from the clearwells to either city.
- **Chemicals**: Chemical costs for Train 1 assume an average coagulant dose of 15 mg/L, reflective of bench-scale jar testing to simulate enhanced coagulation.
- **Chemical Disposal**: No chemical disposal costs are assumed for Train 1, as any over-dosed or spent chemicals will remain in the liquid stream or be returned to the head of the plant for treatment.
- **Major Equipment Repair & Replacement**: Repair and replacement costs for Train 1 generally reflect equipment rebuilds 5 to 10 years after installation, and equipment replacement 15 to 20 years after installation. Equipment requiring annual contributions to the repair and replacement escrow account of over $100,000 include: sedimentation basin scraper and internal components, ozone contactor diffusers, ozone generators, liquid oxygen storage tanks, filter underdrains, and granular filter media.
- **All Other O&M Costs**: Labor and other O&M costs not included above were assumed to be equivalent to such costs for the recently completed Woodland Davis Clean Water Agency surface water treatment plant.

7.4.2.2 Train 6 O&M Cost Assumptions

Major assumptions used in the development of Train 6 O&M costs are summarized below.

- **Power**: Power costs for Train 6 assume that the raw water pump station provides the necessary head to drive liquid stream flows through flash mixing, coagulation and flocculation, sedimentation, ozonation and media filtration. After the coagulation and flocculation facility, it is assumed that an in-plant membrane feed pump station provides sufficient head to drive the water across a pressurized membrane facility and then through ozonation, biological filters, and on to the clearwells. Similar to Train 1, the finished water pump stations pump from the clearwells to either city.
- **Chemicals**: Chemical costs for Train 6 assume an average coagulant dose of 5 mg/L, reflective of the typical maximum coagulant dose ahead of membrane filters. Additional costs are included for the chemicals necessary to conduct periodic membrane filter cleaning cycles.
- **Chemical Disposal**: For Train 6, it is assumed that spent citric acid solutions used during bi-monthly (i.e., six times per year) membrane clean-in-place (CIP) procedures are disposed of offsite at East Bay Municipal Utility District (EBMUD) facilities in Oakland, CA. This assumption is consistent with DDW feedback received by SRWA in June 2016 during a discussion of treatment processes which might be considered by SRWA; in that meeting, DDW staff indicated that return of spent CIP chemicals to the head of the plant, particularly citric acid, would not be allowed. The cost for disposal of chemicals from each CIP event are based on costs for similar disposal activities developed by MID. While the actual frequency for CIP events would not be known until after pilot testing, bi-monthly cleanings results in a conservative estimate. Other disposal options for membrane CIP waste are discussed in Section 7.4.3.
- **Major Equipment Repair & Replacement**: Repair and replacement costs for Train 6 are assumed to be similar to those of Train 1, except for the addition of annual contributions of $390,000 to reflect the replacement of all membrane modules after a seven-year period.
- **All Other O&M Costs**: Labor costs estimates for Train 6 reflect input from several facilities with membrane treatment systems, including MID's Modesto Regional Water Treatment Plant and San Diego County Water Agency's Twin Oaks Valley Water Treatment Plant. Coincidentally, the resulting estimate of labor costs was nearly identical to the labor estimate used for Train 1. As such, the total Train 6 costs for labor and other O&M activities not captured elsewhere was assumed to be equal to that of Train 1.

7.4.3 Treatment Facility Expandability

The following discussion on treatment facility expandability assumes an initial design capacity of 15 mgd, with a planned expansion to roughly double capacity. Expandability considerations are presented for each of the preferred treatment trains, Trains 1 and 6.

Train 1 – Conventional Treatment with Pre-Ozone and Biofiltration

Ozonation. The major components of the ozonation system include: ozone generators and power supply units, cooling water system, ozone contactors, liquid oxygen (LOX) storage tanks and vaporizers, and ozone destruct system. For the initial design phase for a 15 mgd treatment facility, the following design conditions might be considered. The exact design could be different depending on factors such as required turn down, variability in water quality, and desired degree of oversizing.

- Ozone Generators and Power Supply Units:
  - Initially sized for one duty, one standby (i.e., 1 + 1) redundancy. Each generator and power supply unit should be able to treat the full plant flow at the design ozone dose. Both generators should be run during operation to maintain dry conditions with a dry gas flow through the dielectrics (i.e., at 50 percent power).
  - Expand to 2 + 1 redundancy. When expanding the facility, add one additional ozone generator and power supply unit that has the same production capacity as the first two generators and power supply units, making it capable of treating the full additional flow. The initial redundant generator now serves as a redundant generator for both the initial facility flow and the expansion flow; the level of redundancy after expansion, though, is only 50 percent, whereas redundancy was 100 percent after initial construction. A second ozone generator and power supply unit could be added at expansion, rather than just one, if greater redundancy is desired.
- Cooling Water System
  - There will be one cooling water system for the two generators. The open loop and the closed loop will both have 1 duty + 1 standby pumps. Heat will be transferred between the open and closed loops by 1 duty + 1 standby heat exchangers.
  - For the expansion, the open loop cooling water pumps, closed loop cooling water pumps, and heat exchangers will each have 2 duty + 1 standby units.
- Ozone Contactors:
  - Assume traditional over/under water flow pattern through the contactor, with diffusers on the floor of the first contact chamber and countercurrent gas:water flow.
  - Assume 2 + 0 redundancy for the contactors, with each contactor sized to handle half the flow at a hydraulic detention time (HDT) of roughly 5 minutes. Redundancy is not needed since contactors rarely need to be taken out of service for maintenance or cleaning. If diffuser repair is required, scheduled down time can likely be planned.

  - Although each contactor would be designed to have a higher hydraulic capacity than the design flow rate (i.e., 150 percent of the design flow), to double the plant's capacity two additional equal sized ozone contactors should be constructed. Increasing the flow rate through each contactor is not a recommended expansion approach.
- LOX Storage Tank:
  - The initial design would require only one LOX tank, with one duty and one standby vaporizers (1+1). The vaporizers would cycle between each other, such that while one is in operation, the other is thawing.
  - The LOX storage tank is sized based on a typical 15 days of storage at the maximum ozone production rate. Typical oxygen boil off is 0.3 percent to 0.5 percent of the tank's capacity per day (Rakness, 2005).
  - For facility expansion, a second LOX tank should be added with the same capacity as the first one. An additional vaporizer will be added so there are 2 duty + 1 standby vaporizers.
- Ozone Destruct System:
  - The destruct system should be installed with the same redundancy as the generators. The initial design should have 1 duty + 1 standby destruct system, with each sized to accommodate the total gas flow.
  - For facility expansion, one additional destruct system should be added resulting in 2 duty + 1 standby destruct units.

Coagulation/Flocculation/Sedimentation. Major components of the Coagulation/Flocculation/Sedimentation system are the flash mix system for coagulant addition, flocculation basins with mixers, and sedimentation basin with sludge removal system. The flocculation/sedimentation facility could be any of a variety of designs, including conventional tapered flocculation with a traditional large sedimentation basin, conventional tapered flocculation with tube or plate settlers, or sand ballasted flocculation/sedimentation. Some thoughts on expandability of these components are as follows:

- Coagulant Addition:
  - Coagulant addition should be achieved through in-line pump flash mix system. Influent piping would likely be sized for the expanded plant capacity, with the flash mix system located in the influent piping.
  - The system should be designed with 1 duty + 1 standby flash mix systems.
  - Expansion of the treatment facility would not require any changes to the flash mix system except possibly increasing the capacity of the chemical metering pumps.
- Flocculation/Sedimentation:
  - The initial treatment facility should be designed with N+0 redundancy for the flocculation/sedimentation (floc/sed) system. Depending on how much plant capacity can be off-line for occasional maintenance, the facility can be designed with two or three parallel floc/sed trains.

— Each floc/sed train is designed for a "standard" surface loading rate (SLR), although the SLR of each type floc/sed system is different. Expansion will require duplication of the initial facility's floc/sed train(s) unless the units are intentionally under-designed (i.e., at a lower than "standard" SLR) when the initial plant is constructed. It is possible that the source water quality and full-scale operations experience will allow the system to be operated at a higher SLR than initially designed, which ultimately could affect sizing of the expansion floc/sed units but this is not something that can be planned for now.

GAC/Sand Filters (Biofilters). The major components of a dual media filtration process include: open, reinforced concrete filter cells; filter media (i.e., GAC over sand); backwash pumps and air scour equipment to assist cleaning the media during backwash; and underdrain and filtered water collection systems. The individual components do not need to be discussed separately with regards to expansion, since additional filter cells complete with media and a backwash system would be added during facilities expansion. However, unlike the other systems discussed for Train #1, some additional treatment capacity can be gained by re-rating the initial filters to operate at a higher filtration rate. When new filters are added during facility expansion, they should be designed at the higher filtration rate, assuming DDW approved the filter re-rating study. (Filter re-rating was discussed in Section 5.3.2 of this TM.)

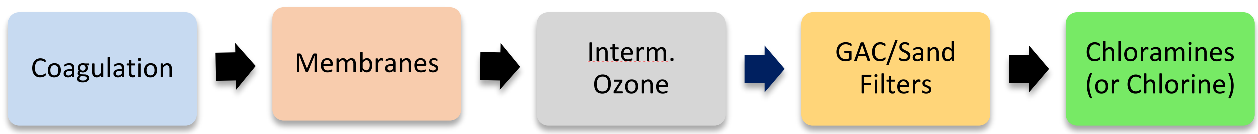
Some additional thoughts on initial filter design and future expandability are the following:

- The initial design should include N+2 redundancy to accommodate having one filter off-line for maintenance and one filter off-line for backwashing. Title 22 CCR limits filtration rates for conventional filtration facilities to a maximum of 6 gpm/ft^2, with one filter off-line for backwashing.
- Prior to facility expansion, consider re-rating existing filters to a higher filtration rate such as 8 gpm/ft^2. This would increase capacity by 33 percent more capacity without physical construction.
- Once the higher filtration rate has been approved by DDW, future filters that are added during facility expansion can be designed at the higher filtration rate. The new bank of filters should include N+0 redundancy, so the whole filtration system will retain the N+2 redundancy allowing the filters to operate at the approved filtration rate with one off-line for maintenance and one off-line for backwash.

Chlorine Contact Basin. The size of the chlorine contact basin will depend on the HDT needed for disinfection CT credit under worst-case temperature conditions and the on-site finished water storage capacity needed by SRWA. The basin should be baffled to provide a baffle factor (i.e., T10/T) of 0.6 or higher, improve disinfection efficiency and minimize short circuiting through the basin. A factor or redundancy is not required for the chlorine contact basin since there should be very little down-time for maintenance. But on the other hand, if the facility had two side-by-side chlorine contact basins, one basin could be taken off-line without having to shut-down the entire treatment facility.

For facility expansion, additional chlorine contact time would be required to meet regulatory disinfection requirements. The preferred expansion approach would likely be to add a second contact basin; otherwise, the whole treatment facility would need to be off-line while the existing basin was modified since disinfection is a critical component of treatment. Facility expansion would also be a good time for SRWA to reassess on-site finished water storage needs. Additional chemical storage for the chlorine (and other additional stabilization chemicals), as well as additional chemical metering pumps, would be needed when the chlorine contact basin is expanded.

7.4.3.1 Train 6 – Membrane Filtration with Ozone and BAC Filtration



The key difference in unit processes between Train 6 compared to Train 1 is the addition of membrane filtration and the elimination of the flocculation/sedimentation basins. Expandability considerations for the common unit processes are the same whether considering the conventional treatment train or the membrane filtration train. Therefore, the discussion of expandability for those processes included in Train 1 is not repeated here.

The main components of the MF system are the membrane rack, the backwash (with air scour) system, and the enhanced flux maintenance (EFM) and CIP systems which include chemical mixing tanks, pumps and chemical storage. Considerations for expansion of the MF system are the following:

- The initial design should have an N+2 redundancy on the number of membrane skids to accommodate one skid being backwashed and another being cleaned (i.e., CIP) or maintained (i.e., EFM) while not sacrificing production capacity.
- For expansion, consider modular expansion and universal racks to increase production. Depending on the number of MF racks or basins, redundancy should be increased to N+3 to accommodate more flexibility in backwash and EFM/CIP cleaning.
- The initial MF system design should leave space for the future equipment needed for expansion.
- Re-rating, or increasing the operating flux is generally not a viable approach for increased production.

7.4.4 Disposal Options for Membrane CIP and other WTP Wastes

As discussed in Section 7.4.3, the planning-level O&M costs for Train 6 assume that membrane CIP waste chemicals would be hauled from the WTP to a suitable disposal facility. In lieu of this approach, it may be possible to construct a sanitary sewer connection between the WTP and a nearby wastewater treatment plant (WWTP) such as the City of Hughson's WWTP. Regardless of the treatment train ultimately selected and constructed, the ability to send WTP waste streams (e.g., CIP wastes, treatment residuals, sanitary waste, and so on) to a WWTP instead of one or more on-site treatment systems may offer advantages to SRWA. The ability of one or more local WWTPs to accept such wastes, and the potential capital and operating costs associated with conveying such wastes by pipeline, will be evaluated by the PM Team in greater detail during the next phase of the Project.

Table 16. Treatment Train Risk Assessment

Risk/Issue	Train #1 Conventional w/ Pre-Ozonation	Train #2 Conventional w/ Intermediate Ozonation	Train #3 Conventional w/o Ozone	Train #4 Direct Filtration w/ Ozone	Train #5 Direct Filtration w/o Ozone	Train #6 Membrane Filtration w/ Ozone	Train #7 Membrane Filtration w/o Ozone
Exceedance of DBP MCLs	Low	Low	Low-CC[b] Med-FC[c]	Low-CC[b] Med-FC[c]	Low-CC[b] High-FC[c]	Low-CC[b] Med-FC[c]	Low-CC[c] High-FC[b]
Taste & Odor[a] Complaints and/or Inadequate Treatment of Algal Toxins[a]	Low	Low	High	Low	High	Low	High
Inadequate Treatment of Pesticides[a]	Low	Low	Med	Low	Med	Low	High
Inadequate Control of Manganese[a]	Low	Med	Low	Low	Med	Med	Med
Cost Difference Relative to Train No. 1, Rounded to Nearest $M	-- 0%	-- 0%	($7M) -8%	-- 0%	($9M) -10%	($4M) -4%	($11M) -12%

[a] If present
[b] CC = combined chlorine (i.e., chloramines)
[c] FC = free chlorine

Table 17 summarizes the planning-level O&M cost estimates for Trains 1 and 6. A summary of the assumptions used in the development of the costs for each train, particularly those that result in significant differences among the costs for the two trains, is included below.

Table 17. Planning-level WTP O&M Costs for Trains 1 and 6

O&M Cost Element	Train 1, dollars	Train 6, dollars
Power (1)	700,000	750,000
Chemicals (2)	550,000	470,000
Chemical Disposal (3)	N/A	600,000
Major Equipment Repair & Replacement (4)	410,000	800,000
All Other O&M Costs (5)	2,860,000	2,860,000
Total	$4,520,000	$5,480,000

Notes:
1) Includes raw and finished water pump station and all WTP loads. For Train 6, assumes pressurized membrane system.
2) Includes all process chemicals. Assumes coagulant doses. 5 mg/L for Train 1, and 5 mg/L dose for Train 6. Does not account for potentially-higher dose for "hybrid" Train 6.
3) Assumes offsite disposal of citric acid waste from MF system for six cleanings per year. Assumes disposal to EBMUD facilities.
4) Annual contributions to major equipment R&R escrow account. For MF system, assumes module replacement after 7 years.
5) Includes labor, maintenance, routine R&R, solids management, and onsite utilities.

7.5 Updated TAC Recommendations

The information presented in Section 7.4 was summarized and presented to the TAC on May 16, 2017. At the conclusion of the presentation, the TAC and PM Team agreed that Train 6 should be eliminated from further consideration by SRWA due that train's increased risks associated with DBP formation and regulatory compliance, as well as the likelihood that O&M costs for Train 6 may exceed those for Train 1. To foster innovation and cost competition among design-build proposers, it was agreed that opportunities for allowing flexibility in the manner in which design-build proposers are able to satisfy performance requirements will be explored.

8.0 NEXT STEPS

During the next phase of the Project, which is set to begin in approximately July 2017, the TAC and PM Team will advance the definition of treatment process requirements in advance of issuing a request for design-build proposals in late 2019. The following activities critical to the evaluation, definition, design, construction and eventual operation of the treatment plant will be conducted during this upcoming phase:

- Continued collection and analysis of source water samples, with a potentially abbreviated sampling program following the first year of sample collection
- Completion of remaining bench testing activities (ozone demand and manganese removal)

- Preparation of preliminary design information for the preferred treatment train, including:
  - Development of preliminary design criteria
  - Development of preliminary site plan(s)
  - Development of a preliminary instrumentation and control systems design
  - Development of refined construction and O&M cost estimates
- Development of treatment process performance and design-build acceptance test requirements

9.0 REFERENCES

Brandhuber, P., Clark, S., Knocke, W., Tobiason, J. 2013. Guidance for the Treatment of Manganese. Water Research Foundation.

Najm, I and Trussell, R.R. 2001. NDMA Formation in Water and Wastewater. *JAWWA*, 93:2:92.

Rakness, K.L. 2005. Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization, American Water Works Association, Denver, CO.

Song, R., et al. 1997. Bromate Minimization During Ozonation, *JAWWA* 89:2:69.

Trussell, R. and Snoeyink, V. 2017. Personal Communication.

USEPA. April 1999. Alternative Disinfectants and Oxidants Guidance Manual.

USEPA, May 1999. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual.

Westerhoff, P., Summers, R.S., Chowdhury, Z., Kommineni, S. 2005. Ozone-Enhanced Biofiltration for Geosmin and MIB Removal. American Water Works Association Research Foundation.

Wilczak, A., et al., 2003. Formation of NDMA in Chloraminated Water Coagulated with DADMAC Cationic Polymer. *JAWWA*, 95:9:94-106.

Yamamura, H., Kimura, K., Higuchi, K., Watanabe, Y., Ding, Q., Hafuka, A. 2015. Tracking Inorganic Foulants Irreversibly Accumulated on Low-Pressure Membranes for Treating Surface Water. Water Research 87:218-224.

ATTACHMENT A

Direct Filtration Operational TM

TECHNICAL MEMORANDUM

prepared for Stanislaus Regional Water Authority

Date: March 23, 2017

Authors: Fred W. Gerringer, D. Env., P.E., BCEE

Reviewers: R. Rhodes Trussell, Ph.D., P.E., BCEE
Elaine W. Howe, P.E.

Job Number: 69.014

Subject: Operational Experience of Large Direct Filtration Water Treatment Plants

Trussell Technologies contacted three direct filtration (DF) water treatment plants to gather information about their operating experiences, such as some of the challenges they face and how they respond to changing source water quality. The information received from two of the DF plants; the Los Angeles Aqueduct Filtration Plant (LAAFP) in Los Angeles, California and the Tolt Water Treatment Facility (TWTF) in Seattle, Washington; are discussed in this technical memorandum.

Los Angeles Aqueduct Filtration Plant, Los Angeles, CA

The LAAFP in Los Angeles, California was originally designed to treat 600 million gallons per day (MGD) of imported water from the Los Angeles Aqueduct and was later approved to treat water from the State Water Project. The water from the Los Angeles Aqueduct was served to the city with only chlorination treatment from 1913 until 1986 when the LAAFP came on line[1]. The quality of both source waters is typically stable and are blended together to produce average influent turbidity and TOC levels of 3.8 NTU and 1.6 mg/L, respectively. The treatment train includes fluoridation, ozonation, rapid mixing, flocculation, media filtration, disinfection with ultraviolet light, and chloramination (Figure 1). Ozone dose ranges from 1 to 1.5 mg/L, and coagulant dose ranges are 1 to 1.5 mg/L for ferric

[1] Coagulants were sometimes added to the aqueduct in the late 1970s and 1980s. The LA aqueduct passes through several reservoirs on its way to Los Angeles.

chloride and 1 to 5 mg/L for cationic polymer. The filters consist of 5 feet of 1.5 mm anthracite mono-media and are designed to operate with a loading rate of 13 gpm/ft^2, and filter run lengths vary from 8 to 24 hours, depending on the water quality conditions and the filtration rate. Approval for this high filtration rate required extensive (> 2 years) pilot and full-scale testing[2].

Operation of the facility has been more challenging in the winter of 2017 because runoff from heavy rainfall has carried fine glacial till, or "rock flour", to LAAFP. Despite this challenge, the facility continues to satisfy regulatory requirements. When encountering difficult raw water quality, LAAFP has four primary options: reject the water source, increase the coagulant dose, reduce filter run lengths, or reduce flows. The decision of how to respond depends on factors such as the status of treated water storage, the duration of the poor water quality event, and water demands. One challenge associated with operating a DF plant is the availability of fewer tools for addressing challenging water quality compared to a conventional treatment plant. The effective operation of a DF plant like LAAFP requires staff to diligently perform routine maintenance and to ensure sufficient chemical is stored to respond to water quality that is difficult to treat. Because LAAFP does not use free chlorine for primary disinfection and uses chloramines for secondary disinfection, chlorinated DBPs are well below regulatory limits. However, the ozone dose needs to be managed to control bromate formation, as bromide is present in water from the State Project.

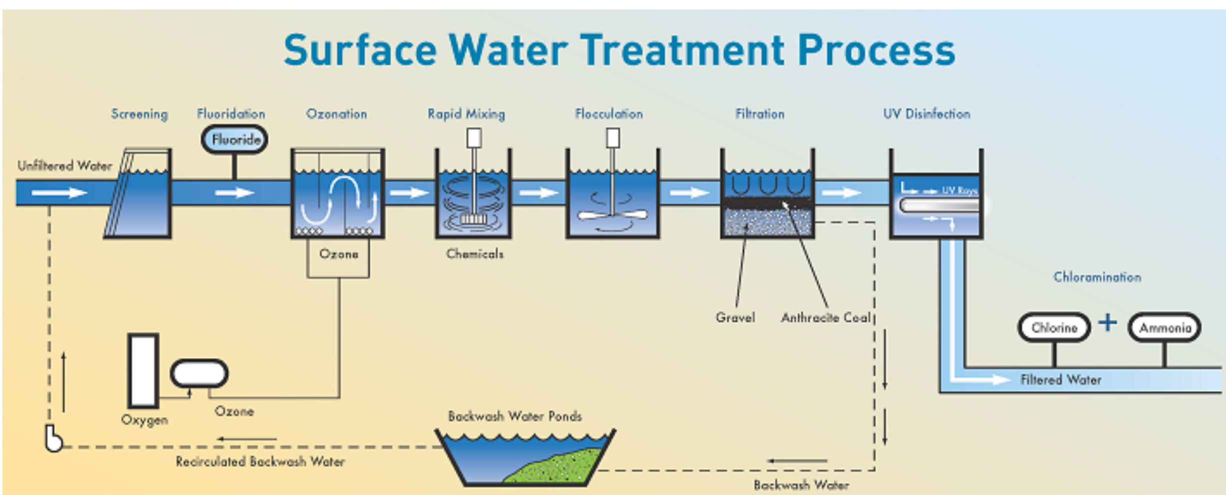


Figure 1. Los Angeles Aqueduct Filtration Plant Process Flow Diagram (https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-w-wqreport-wtrtmntprocess)

[2] Filter re-rating must be done after the full-scale facility has been constructed and operated. The re-rating study required by DDW is based on full-scale demonstration testing. This high of a filtration rate may not get DDW approval today based on the current regulatory climate.

Tolt Water Treatment Facility, Duvall, WA

The TWTF in Seattle, Washington has a capacity of 120 MGD and treats water from the Tolt Reservoir, which was created by a dam on the South Fork Tolt River. Seattle originally served this water with only chlorination and, eventually, pH adjustment until the promulgation of the Surface Water Treatment Rule required that it be filtered. Water quality is usually stable because the reservoir minimizes water quality fluctuations. Turbidity typically ranges from 0.2 to 0.5 NTU and generally does not exceed 5 NTU. The normal range for TOC is 1.1 to 1.5 mg/L, although it has occasionally reached 2.0 mg/L. The treatment train includes ozonation, coagulation/flocculation, lime addition, media filtration, carbon dioxide, chlorination, and fluoridation (Figure 2). The normal range of the coagulant doses are 0.4 to 0.7 mg/L for both ferric chloride and cationic polymer, although polymer is only used for about 6 months every year. The media filters contain 6 ft of anthracite coal and have a design loading rate of 12 gpm/ft^2. Just as for the LAAFP, extensive pilot and full-scale demonstration testing was required to get the approval of state regulators for this high filtration rate. Filter run lengths usually range from 24 to more than 48 hours, but have dropped below 24 hours in rare circumstances.

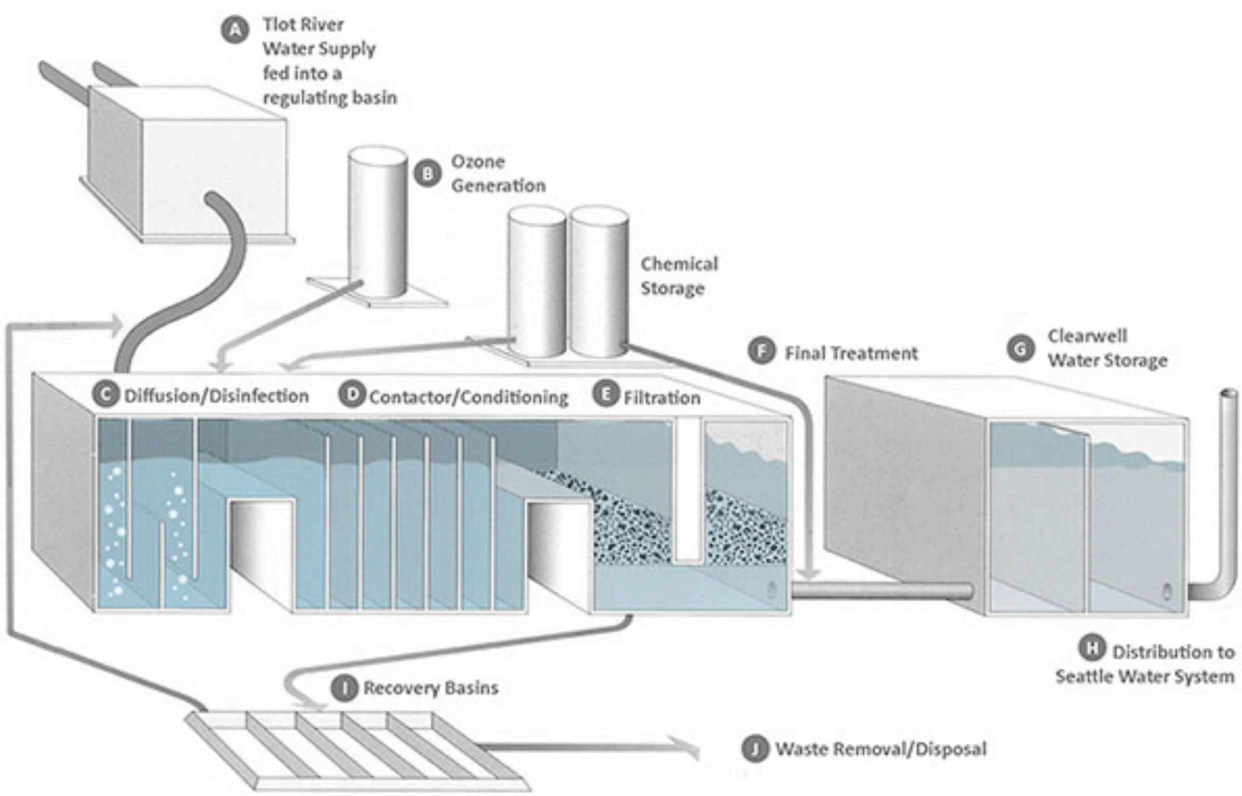


Figure 2. Tolt Water Filtration Plant process flow diagram (http://www.seattle.gov/util/MyServices/Water/AbouttheWaterSystem/WaterSystemOverview/ToltTreatmentFacility/index.htm)

One of the challenges with operating this plant comes from the short detention time from the plant influent to the filter effluent (approximately 30 minutes), which limits the amount of time available to respond to rapid changes in water quality or equipment failure. Another challenge is when high turbidity occurs with cold water temperatures, which makes it difficult to manage filter effluent turbidity[3]. Removing one of the two treatment trains for maintenance when the water is cold makes operation more difficult because the coagulation/flocculation time is reduced by 50%.

[3] Temperature affects reaction kinetics of the coagulation process—colder temperatures slow reaction kinetics. Headloss is also greater through a filter in cold temperatures because the viscosity of the water increases.

ATTACHMENT B

Methodology for Developing Planning Level Construction Cost Information for SRWA Surface Water Treatment Unit Processes (West Yost, March 2017)

TECHNICAL MEMORANDUM

DATE:	March 28, 2017	Project No.: 693-20-16-01 SENT VIA: EMAIL
TO:	SRWA Technical Advisory Committee	
FROM:	Andy Smith, RCE #C74673	
REVIEWED BY:	Gerry Nakano, RCE #C29524 Lindsay Smith, RCE #C72996 Rhodes Trussell, Trussell Technologies, RCE #C25107 Fred Gerringer, Trussell Technologies, RCE #C67467	
SUBJECT:	Methodology for Developing Planning-Level Construction Cost Information for SRWA Surface Water Treatment Plant Unit Processes	

INTRODUCTION

The Stanislaus Regional Water Authority (SRWA) is planning to construct a new surface water treatment plant (WTP) to provide a new, supplemental drinking water supply to the cities of Ceres and Turlock. As part of the SRWA Technical Advisory Committee's (TAC) evaluation of alternative treatment processes for the new WTP, planning-level construction cost information has been developed for the unit treatment processes that comprise the available treatment train alternatives.

The purpose of this Technical Memorandum (TM) is to describe the methodology used for developing these planning-level construction cost estimates. This TM is organized as follows:

- Introduction
- Background
- Classification and Intended Use of Cost Estimates
- Construction Cost Estimating Approaches
- Sources of Reference Costs
- Summary of Estimated Construction Costs

BACKGROUND

The first cost information related to the WTP provided to the TAC was developed in September 2016 as part of a request by the TAC to provide preliminary cost information to support a preliminary evaluation of the potential monthly cost impact to existing water customer bills. At that time, there was limited definition of the treatment processes to be included in the future WTP. As such, the costs presented in September 2016 were developed by making coarse cost adjustments to a surface WTP recently constructed for the Woodland-Davis Clean Water Agency (WDWCA) in Woodland, California. The adjustments made included the following:

- Elimination of costs for facilities or processes anticipated to be absent for the SRWA project,
- Coarse scaling of costs for facilities or processes anticipated to be smaller or larger and/or more or less robust than the WDCWA project, and
- Inflation adjustments.

The resulting estimate was intended as a placeholder amount until more detailed source water quality information was available, and a more thorough and comparative evaluation of treatment trains could be made.

CLASSIFICATION AND INTENDED USE OF COST ESTIMATES

The updated cost information presented herein is considered by West Yost Associates (West Yost) to be compatible with Class 5 estimates, per the Association for the Advancement of Cost Engineering (AACE). AACE's cost estimate classification matrix is shown in Table 1. The intended use of these estimates is to help facilitate the TAC's selection of one or more preferred treatment trains for further analyses and refinement. It is assumed that refined cost estimates for the TAC's preferred treatment train will be developed in conjunction with ongoing pre-design efforts, including the development of preliminary design criteria, site layout and a hydraulic profile for the selected treatment train. A cost estimating contingency of 25 percent has been applied to all cost estimates, in accordance with the "low" end of the expected accuracy range for Class 5 estimates.

Table 1. AACE Cost Estimate Classification Matrix[a]

Estimate Class	Primary Characteristics	Secondary Characteristic		
	Maturity Level of Project Definition Deliverables	End Usage	Methodology	Expected Accuracy Range
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgement or analogy	Low: -20% to -50% High: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	Low: -15% to -30% High: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	Low: -10% to -20% High: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit costs with forced detailed take-off	Low: -5% to -15% High: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit costs with forced detailed take-off	Low: -3% to -10% High: +3% to +15%

a) Source: AACE International Recommended Practice No. 18R-97, revised March 1, 2016

CONSTRUCTION COST ESTIMATING APPROACHES

Currently, because specific treatment train processes have not yet been decided upon by the TAC and Board, preliminary design details for the specific capacities and processes under consideration cannot be developed. However, several simplified approaches have been utilized for developing unit process construction cost estimates, as described below.

Unit process cost estimates have been developed primarily by adapting known construction costs from similar facilities to conform to the size and characteristics currently known for the SRWA project. Under this approach, the most detailed cost information available for the processes in question were obtained from one or more reference facilities. The available cost information was then adjusted as follows:

- Costs were screened to remove or adjust sub-elements that are not directly applicable to the SRWA project and/or treatment process.
- Costs were further screened to remove electrical and instrumentation costs, which are more appropriately captured at the planning level as a percentage of the overall treatment process construction costs.

- Costs were adjusted (i.e., inflated) to bring the reference costs to the midpoint of construction anticipated for the SRWA project, which is projected to be around June 2020.
- Costs were further adjusted to reflect differences in capacity between the reference facility and the anticipated capacity for the first phase of the SRWA project, which is currently assumed to be 15 million gallons per day (mgd). Additional discussion of this capacity-based adjustment is provided below.

Capacity-based Cost Adjustments

Capacity-based construction cost adjustments were made using the power law, a simple approach used to estimate costs of facilities based on a known cost and capacity of a similar (i.e., reference) facility. A simplified form of the power law for comparing similar facilities is the "six tenths rule". Because the facilities compared herein are assumed to be identical except for capacity, the six tenths rule is appropriate for these planning-level cost estimates (AWWA and ASCE, Water Treatment Plant Design 26.6). The equation used to determine the estimated cost is as follows:

$$C_B = C_A \left(\frac{S_B}{S_A} \right)^x$$

Where:

C_B = Estimated cost of facility having capacity S_B

C_A = Known cost of facility having capacity S_A

$\frac{S_B}{S_A}$ = Ratio of capacities

x = Correlating exponent, $0 < x < 1$ ($x = 0.6$ in the six tenths rule)

For the costs presented herein, the known costs are those associated with the reference facilities described below.

Other Cost Estimating Methodologies

For the ultraviolet (UV) disinfection facilities envisioned for several of the treatment train alternatives under consideration, applicable reference facility costs could not be obtained by West Yost. The methodology for developing costs for these facilities is described below.

- Solicitation of budgetary equipment cost information based on required equipment capacity, quantity and UV dose. The assumed equipment type is closed vessel reactors.

- Development of a conceptual facility layout to facilitate preparation of quantity take-offs for estimating concrete foundations, exposed piping, canopies and other ancillary items.
- Preparation of construction cost estimates using unit costs from recent treatment plant construction projects and the quantity take-offs described above.

SOURCES OF REFERENCE COSTS

This section provides a brief overview of the projects from which reference cost information was obtained and adapted. In some instances, cost information from more than one process at a given reference facility was utilized for this exercise. In instances where cost information for a given process was available from more than one reference facility, the more costs from the more recently constructed facility were used in the evaluation of available SRWA treatment trains.

Modesto Irrigation District Modesto Regional Water Treatment Plant

The Modesto Irrigation District (MID) Regional Water Treatment Plant (MID Plant) is a 60-mgd facility owned and operated by MID. The facility treats surface water from the Modesto Reservoir, and features two independent 30-mgd treatment trains, one using a conventional treatment process, and one using membranes. The conventional treatment train was constructed in 1994. Construction of the membrane process was completed in 2016[1]. Reference costs for the SRWA Project were obtained for the following processes, each of which is part of the newer membrane treatment train:

- Ozone treatment
- Membrane filters

City of Lodi Surface Water Treatment Facility

The Lodi Surface Water Treatment Plant (Lodi Plant) is an 8-mgd facility owned and operated by the City of Lodi. The facility treats surface water from the Mokelumne River (via Lodi Lake). Construction of the facility was completed in 2013. Reference costs for the SRWA Project were obtained for the following processes:

- Membrane filters

WDCWA Regional Water Treatment Facility

The WDCWA Regional Water Treatment Facility (WDCWA Plant) is a 30-mgd facility owned and operated by WDCWA. The facility treats surface water from the Sacramento River, upstream of the confluence with the American River. Construction of the facility was completed in 2016. Reference costs for the SRWA Project were obtained for the following processes:

[1] The original construction of the membrane process was completed in 2009. Due to operational issues, however, additional construction efforts were undertaken and eventually completed in 2016. The cost information obtained for this analysis is from the work that was completed in 2009.

- Flash mixing
- Coagulation, flocculation and sedimentation basins[2]
- Ozone treatment
- Granular media filters
- Chlorine contactor[3]
- In-plant pump station
- Finished water clearwell
- Backwash supply & finished water pump station
- Backwash equalization basin
- Gravity thickeners
- Solids drying beds

In addition, reference costs for several typical ancillary buildings were obtained from available WDCWA cost data:

- Chemical building
- Operations & administration building
- Maintenance building

Sacramento County Water Agency Vineyard Surface Water Treatment Plant

The Sacramento County Water Agency (SCWA) Vineyard Surface Water Treatment Plant (Vineyard Plant) is a 50-mgd facility owned and operated by SCWA. The facility treats surface water from the Sacramento River, downstream of the confluence with the American River. Construction of the facility was completed in 2010. Reference costs for the SRWA Project were obtained for the following processes:

- Coagulation, flocculation and sedimentation basins

SUMMARY OF ESTIMATED CONSTRUCTION COSTS

Table 2 summarizes the results of the cost estimating procedures described above. Additional details for each listed process and reference facility can be found in Attachment 1.

[2] The WDCWA Plant uses a system referred to as “Sand Ballasted Clarification”, better known by its trade name Actiflo®.
[3] The completed WDCWA Plant does not include a true chlorine contactor, as free chlorine is injected at a pump station ahead of the finished water clearwells. In this case, the reference facility cost information comes from a detailed estimate developed for the “benchmark” WTP, which was defined by WDCWA prior to final design of their WTP. The benchmark WTP for WDCWA included a standalone chlorine contactor.

Table 1. Summary of Planning-Level Unit Process Construction Costs[(a)]

Unit Process	Reference Facility Information				Adjusted Facility Information	
	Source of Reference Costs	Process Capacity	Reference Facility Midpoint of Construction	Inflated to Midpoint of SRWA WTP Construction (June 2020), dollars	SRWA Target Capacity	Adjusted to SRWA WTP Target Capacity, dollars
Flash Mixing	WDCWA Plant	30 mgd	Jan 2015	602,000	15 mgd	397,000
Coagulation, Flocculation and Sedimentation	Vineyard Plant	50 mgd	Aug 2009	17,297,000	15 mgd	8,399,000
	WDCWA Plant	30 mgd	Jan 2015	6,731,000	15 mgd	4,441,000
Coagulation and Flocculation Only (No Sedimentation)	Vineyard Plant	50 mgd	Aug 2009	7,310,000	15 mgd	3,550,000
Granular Media Filtration	WDCWA Plant	30 mgd	Jan 2015	14,929,000	15 mgd	9,849,000
Membrane Filters	MID Plant	30 mgd	Jun 2008	30,438,000	15 mgd	20,082,000
	Lodi Plant	8 mgd	May 2012	7,268,000	15 mgd	10,598,000
Ozone Treatment	MID Plant	30 mgd	Jun 2008	12,599,000	15 mgd	8,312,000
	WDCWA Plant	30 mgd	Jan 2015	6,577,000	15 mgd	4,339,000
Chlorine Contact Basin (Free Chlorine and Chloramines)	WDCWA Benchmark WTP	212,000 gal	Jul 2011	684,000	625,000 gal	1,309,000
UV Disinfection	Vendor Proposal/ Conceptual Layout	15 mgd	Mar 2017	748,000	15 mgd	748,000
Chemical Building	WDCWA Plant	30 mgd	Jan 2015	5,546,000	15 mgd	5,546,000
Operations & Administration Building	WDCWA Plant	30 mgd	Jan 2015	4,075,000	15 mgd	4,075,000
Maintenance Building	WDCWA Plant	30 mgd	Jan 2015	1,588,000	15 mgd	1,588,000
In-Plant Pump Station	WDCWA Plant	30 mgd	Jan 2015	1,935,000	15 mgd	1,277,000
Finished Water Clearwell	WDCWA Plant	5.75 MG	Jan 2015	7,487,000	2.375 MG	4,432,000
Backwash Supply/Finished Water Pump Station	WDCWA Plant	30 mgd	Jan 2015	6,541,000	15 mgd	4,315,000
Backwash Equalization Basin	WDCWA Plant	30 mgd	Jan 2015	2,838,000	15 mgd	1,872,000
Gravity Thickeners	WDCWA Plant	30 mgd	Jan 2015	2,533,000	15 mgd	1,671,000
Drying Beds	WDCWA Plant	30 mgd	Jan 2015	2,691,000	15 mgd	1,775,000

a) Does not include electrical and instrumentation costs. These costs are more appropriately captured as a percentage of the overall treatment process.

ATTACHMENT 1

Project Cost Breakdown for Ozone Facility at the WDCWA Regional Water Treatment Facility

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Ozonation Cost Derivation

COST ANALYSIS

Develop base cost for ozone from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Ozone Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Excavate/Backfill to Bottom of Foundation Slab	30,000	30,000	
Over-Excavate/Backfill to Bottom of Foundation Slab Ozone Generation an	56,269	56,269	
Final Backfill Ozone	28,756	28,756	
Form/Rebar/Pour - Foundation Slab for Ozone Contactor	155,024	155,024	
Form/Rebar/Pour - Wall Pour 1 - Ozone Contactor	194,226	194,226	
Form/Rebar/Pour - Wall Pour 2 - Ozone Contactor	194,227	194,227	
Form/Rebar/Pour - Wall Pour 3 - Ozone Contactor	194,227	194,227	
Shoring - Deck for Ozone Disp Contract	20,000	20,000	
Form/Rebar/Pour - Deck for Ozone Contactor	135,402	135,402	
Remove Shoring - Deck for Ozone Contactor	10,000	10,000	
Water Leak Test - Ozone Contactor	7,189	7,189	
Form/Rebar/Pour - Foundation Slab for Ozone Generator	279,079	279,079	
Form/Rebar/Pour - Foundation Slab for LOX System Slab	28,756	28,756	
Form/Rebar/Pour - Equipment Pedestals at Ozone Generator	9,189	9,189	
Form/Rebar/Pour - Foundation Slab for HVAC Unit	2,000	2,000	
Erect Rigid-Frame Steel, Girts and Purlins - Ozone Generation Building	110,000	110,000	
Erect Insulated Metal Panels - Roof/Siding - Ozone Generation Building	111,292	111,292	
Install Interior Framed Walls and Panels - Ozone Generation Building	78,756	78,756	
Install Walk Doors and Overhead Doors - Ozone Generation Building	20,024	20,024	
Install Underslab Piping - Ozone Generation Building	45,000	45,000	
Install Underslab Piping - Ozone Generation Slab	12,512	12,512	
Install Above Ground Piping - Ozone Contactor	192,698	192,698	
Install Ozone Dispersion Systems - Ozone Contactor	192,697	192,697	
Install Ozone Destructor Skids - Ozone Generation	50,000	50,000	
Install Ozone Cooling Water Skids - Ozone Generation	50,000	50,000	
Install Nitrogen Booster Skid - Ozone Generation	50,000	50,000	
Install Ozone Generator Skids	50,000	50,000	
Install LOX Tank	17,560	17,560	
Install Vaporizers	20,000	20,000	
Install A/G Pipe - Ozone Generation and LOX Area	530,742	530,742	
Test/Flush Piping - Ozone Generation and LOX Area	50,000	50,000	
Set HVAC Unit and Bring Duct Work to Inside Building	100,725	100,725	
Install Interior HVAC Ductwork - Ozone Generation Building	79,000	79,000	
Install Underslab Electrical - Ozone Contact Slab	5,000	-	[1]
Install Underslab Electrical - Ozone Generation Slab	38,804	-	[1]
Install In-Slab Electrical - Ozone Generation Slab	18,804	-	[1]
Rough-in Above Ground Electrical - Ozone Generation Slab	129,069	-	[1]
Install Electrical and I&C Equipment - Ozoner Generation Building	142,825	-	[1]
Pull/Terminate from Electrical Room to XFMR - Ozone Generation Building	20,078	-	[1]
Install and Fitup Light Fixtures	53,804	53,804	
Rough-in/Fitup - Ozone Equipment Skids and LOX Area	96,000	96,000	
Rough-in/Fitup - Instrumentation - Ozone Facility	90,021	-	[1]
Pull/Terminate/Test - Electrical and Instrument Circuits - Ozone Facility (Inc	124,940	-	[1]
Energize Electrical and Test - Ozone Facility	16,174	-	[1]
Paint A/G Pipe and Equipment - Ozone Facility	40,000	40,000	
Touch Up Walls and Doors - Ozone Generation Building	25,000	25,000	
LOX Equipment	182,401	182,401	
Ozone Supply System Equipment	2,034,784	2,034,784	
HEAT XCHR CARRIER WATER PUMPS	30,000	30,000	
WATER CONTROL GATES	63,560	31,780	[2]
Totals	6,216,614	5,599,119	
Cost per System	6,216,614	5,599,119	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Factored by 0.5 to reflect that 4 of 8 control gates for the project are associated with this facility.

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 — Date: 3/28/2017
Calc. By:	W. Sandelin — Chkd. By: A. Smith
Subject:	Ozonation Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		5,912,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		6,577,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	2,245,000
10	3,402,000
15	4,339,000
20	5,157,000
25	5,895,000
30	6,577,000
34	7,090,000
40	7,816,000
45	8,388,000

	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date: 3/28/2017	
	Calc. By: W. Sandelin	Chkd. By: A. Smith	
	Subject: Ozonation Cost Derivation		

COST ANALYSIS

Develop base cost for ozone from actual costs obtained for similar work at the MID Regional Water Treatment Plant.

Project Cost Breakdown for Ozone Facility at the MID Regional Water Treatment Plant

Work Element	SOV	Use	Notes
Ozone Contactor			
Structural			
Earthwork - Shoring at Ozone Structure	427,037	427,037	
Earthwork - Excavation	720,674	720,674	
Earthwork - Aggregate Base	16,144	16,144	
Earthwork - Backfill	288,872	288,872	
Concrete - Ozone Slabs	426,403	426,403	
Concrete - Injection & Destruct Slabs	16,943	16,943	
Concrete - Walls	560,163	560,163	
Concrete - Decks	343,964	343,964	
Concrete - Baffles	3,056	3,056	
Metals - Stairs, Handrail, & Grating	41,882	41,882	
Dampproofing - Walls Below Grade	7,617	7,617	
Test - Leak Test Structure	8,910	8,910	
Mechanical			
Protective Coatings	78,947	78,947	
Equipment - Ozone Destruct Units ODU-04-01, 02	6,873	6,873	
Equipment - Ozone Inject Skid SSP-04-01, 02, 03	36,364	36,364	
Equipment - Sump Pumps 201, 202 & Piping	23,664	23,664	
Piping - 60" TW (Interior)	31,288	31,288	
Piping - 8" Water Piping to Injection Skid	10,123	10,123	
Piping - 6" Ozone Off-Gas (Buried)	3,942	3,942	
Piping - 6" Ozone Off-Gas (Exposed)	14,078	14,078	
Piping - 6" OZW Piping (Buried)	8,460	8,460	
Piping - 6" & 3" Injection Piping (Exposed)	4,303	4,303	
Piping - 6" Perforated Drain	17,448	17,448	
Piping - Sample Piping Within Contactor	19,736	19,736	
Piping - Sample Piping & Sample Pumps at Ozone Gallery	81,771	81,771	
Piping - CATS & NOCL Chemical Systems	8,342	8,342	
Test - Piping	9,819	9,819	
Test - Ozone Equipment	4,627	4,627	
Plumbing			
Plumbing - Floor Drain System	50,353	50,353	
Plumbing - NPW/CW System	52,087	52,087	
HVAC			
HVAC - Equipment, Ductwork, Controls	59,902	59,902	
Electrical			
Electrical - Rough Branch Power	109,800	-	[1]
Electrical - Rough Devices	68,600	-	[1]
Electrical - Rough Fixtures	34,300	-	[1]
Electrical - Rough Equipment	61,800	-	[1]
Electrical - Wire Branch Power	82,500	-	[1]
Electrical - Wire Lighting	13,700	-	[1]
Electrical - Wire Equipment	68,699	-	[1]
Electrical - Wire Instrumentation	151,000	-	[1]
Electrical - Install Gear & Terminate	27,500	-	[1]
Electrical - Data & Security	47,429	-	[1]
Electrical - Light Fixtures	28,500	-	[1]
Electrical - Grounding	31,251	-	[1]

LOX Equipment			
Structural			
Earthwork - Excavation	3,423	3,423	
Earthwork - Aggregate Base Below Pads	2,030	2,030	
Earthwork - 3/4" Washed Rock	11,127	11,127	
Earthwork - Backfill	2,476	2,476	
Concrete - Perimeter Curb	12,234	12,234	
Concrete - Equipment & Misc. Pads	103,588	103,588	
Metals - Guard Post	1,539	1,539	
Mechanical			
Paint Piping	19,171	19,171	
Specialties - Signage	3,290	3,290	
Equipment - LOX Tank LST-Z-01	10,519	10,519	
Equipment - Vaporizers VAP-Z-01, 02, 03	12,097	12,097	
Piping - LOX System Piping	54,616	54,616	
Insulation - Lox Piping	24,353	24,353	
Test - Piping	4,685	4,685	
Test - Ozone Equipment	7,545	7,545	
Electrical			
Electrical - Rough Branch Power	56,000	56,000	
Electrical - Rough Devices	40,000	40,000	
Electrical - Rough Fixtures	25,765	25,765	
Electrical - Light Fixtures	22,000	22,000	
Electrical - Wire Branch Power	25,500	25,500	
Electrical - Wire Lighting	12,000	12,000	
Electrical - Wire Equipment	28,000	28,000	
Electrical - Wire Instrumentation	40,840	40,840	
Electrical - Grounding	22,728	22,728	
Ozone Generation			
Structural			
Concrete - Fill	14,525	14,525	
Masonry	24,967	24,967	
Doors - Steel Doors and Hardware	2,087	2,087	
Finishes - Acoustical Treatment	28,249	28,249	
Concrete - Equipment Pads	18,227	18,227	
Mechanical			
Protective Coatings	61,717	61,717	
Equipment - Ozone Generators	354,521	354,521	
Equipment - Blowers	26,128	26,128	
Equipment - Supplemental Air Equipment	3,952	3,952	
Piping - 6" COWL	28,186	28,186	
Piping - 4" COWL	22,582	22,582	
Piping - 3" GOX	86,224	86,224	
Piping - 2" GOX	18,811	18,811	
Piping - 3" OZN	86,225	86,225	
Piping - 2" OZN	16,436	16,436	
Piping - 3" Air In Blower Room	53,863	53,863	
Piping - 1" SA	17,934	17,934	
Piping - 3/4" Sample	5,968	5,968	
Piping - Oxygen Cleaning	228,928	228,928	
Test - Piping	32,143	32,143	
Test - Equipment	16,320	16,320	
Test - Ozone Equipment	170,000	170,000	
Deliver Ozone Equipment	3,530,000	3,530,000	
HVAC			
HVAC - Equipment, Ductwork, Controls	17,349	17,349	
HVAC - Gas Unit Heater @ File Storage Room	8,195	8,195	
Electrical			
Electrical - Rough Branch Power	74,000	-	[1]
Electrical - Rough Devices	33,000	-	[1]
Electrical - Rough Fixtures	15,000	-	[1]
Electrical - Rough Equipment	22,000	-	[1]
Electrical - Install Fixtures	11,000	-	[1]
Electrical - Wire Branch Power	63,000	-	[1]

Electrical - Wire Lighting	4,116	-	[1]
Electrical - Wire Equipment	26,000	-	[1]
Electrical - Wire Instrumentation	74,000	-	[1]
Electrical - Install Gear & Terminate	48,000	-	[1]
Electrical - Ground	21,104	-	[1]
Electrical - Demolition	53,752	-	[1]
Totals	9,972,906	8,802,855	
Cost per System	9,972,906	8,802,855	

NOTES
1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	8185	(Jun 2008)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.286		11,325,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		12,599,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	4,300,000
10	6,517,000
15	8,312,000
20	9,878,000
25	11,293,000
30	12,599,000
34	13,582,000
40	14,973,000
45	16,069,000

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: Flash Mix Cost Derivation		

COST ANALYSIS

Develop base cost for flash mix from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Flash Mix Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Excavate and Prep for Flash Mix Facility Slab	21,567	21,567	
Final Backfill around Perimeter of Facility	7,189	7,189	
Form / Rebar / Pour - Flash Mix Facility Slab	43,134	43,134	
Form / Rebar / Pour - Equipment Pedestals	7,189	7,189	
Install Underslab Pipe - Flash Mix Facility	21,567	21,567	
Install Above Ground Piping - Rough-in - Flash Mix Facility	275,000	275,000	
Install Jet Mix Pumps	20,756	20,756	
Piping Hook-up - Jet Mix Pumps	58,231	58,231	
Install Sample Piping and Hookup	8,000	8,000	
Test/Flush Piping	29,115	29,115	
Install Underslab Electrical	3,000	-	[1]
Rough-in Aboveground Electrical and I&C	5,000	-	[1]
Install Stands & Fitup Electrical Equipment and I&C	3,000	-	[1]
Pull / Terminate / Test Electrical and I&C	2,500	-	[1]
Pating / Coatings - Pipe and Equipment	20,000	20,000	
Totals	525,000	512,000	
Cost per System	525,000	512,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		541,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		602,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	205,000
10	311,000
15	397,000
20	472,000
25	540,000
30	602,000
35	660,000
40	715,000
45	768,000

COST ANALYSIS

Develop base cost for Actiflo ballasted flocculation and sedimentation facilities from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Actiflo Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
SAND BALLASTED CLARIFICATION EQUIPMENT	2,800,508	2,800,508	
17 - Over-Excavate/Fill for U/S Pipe and Foundation Slab - SBC - South E	45,400	45,400	
17 - Backfill / Prep to bottom of Foundation Slab - SBC Middle North End a	26,490	26,490	
17 - Final Backfill around facility	14,378	14,378	
17 - Form/Rebar/Pour - Foundation Slab - SBC South End	170,347	170,347	
17 - Form/Rebar/Pour - Foundation Slab - SBC Middle North End	130,000	130,000	
17 - Form/Rebar/Pour - Foundation Slab - SBC Very North End	72,918	72,918	
17 - Form/RebarPour - Wall Pour #1 - SBC	151,867	151,867	
17 - Form/Rebar/Pour - Wall Pour #2 - SBC	99,499	99,499	
17 - Form/Rebar/Pour - Wall Pour #3 - SBC	68,078	68,078	
17 - Form/Rebar/Pour - Wall Pour #4 - SBC	94,262	94,262	
17 - Form/Rebar/Pour - Wall Pour #5 - SBC	109,974	109,974	
17 - Form Rebar Pour Equipment Pedestals for Sand Recirculation Pumps	4,189	4,189	
17 - Shoring for Basin Decking - SBC Basins	75,000	75,000	
17 - Shoring for Effl Channel - SBC Channel	25,000	25,000	
17 - Form/Rebar/Pour Basin Decking and Effl Channel - SBC Basins	201,604	201,604	
17 - Remove Shoring for Basin Decking - SBC Basins	22,500	22,500	
17 - Remove Shoring for Basin Decking - SBC Basins	3,000	3,000	
17 - Form/Rebar/Pour - Walls for Effl Channel	108,917	108,917	
17 - Remove Shoring for Effluent Channel	20,000	20,000	
17 - Water Leak Test - Basins	2,156	2,156	
17 - Form/Rebar/Pour - In-fill for Settling Tank Floors	116,591	116,591	
17 - Install Handrail on Perimeter of Decking - SBC	273,182	273,182	
17 - Install Stairway and Grating- SBC	71,891	71,891	
17 - Install Underslab Pipe - SBC South End	4,378	4,378	
17 - Install Underslab Pipe - SBC North End	250,000	250,000	
17 - Install In-slab pipe - SRC - Settling Tank In-Fill	10,000	10,000	
17 - Install SBC Sand Recirculation Pumps at Pump Gallery	19,657	19,657	
17 - Install Sand/Solids Scrappers at Settling Tanks	66,860	66,860	
17 - Install Draft Tubes & Baffles - Maturation Tanks w/Support Steel	35,379	35,379	
17 - Install Vertical Mixers for Maturation & Coagulation Tanks	23,589	23,589	
17 - Install Hydro-Cyclones - on Deck of SBC Basins	23,589	23,589	
17 - Install Settling Tubes - in Settling Tanks	35,379	35,379	
17 - Install Collection Troughs - in Settling Tanks	35,379	35,379	
17 - Install Sample Piping	11,789	11,789	
17 - Install A/G Piping - 6"-USL Sys and SB PO, SAM, W2 Sys's	378,037	378,037	
17 - Test/Flush Piping Systems - SBC	75,485	75,485	
17-Install Underslab Electrical - SBC North End	36,522	-	[1]
17 - Install In-Slab Electrical on Deck - SBC Basin	52,173	-	[1]
17 - Install / Fit-up Equipment Electrical Stands - SBC	138,319	-	[1]
17 - Install / Fit-up Instrument Stands - SBC	138,319	-	[1]
17 - Pull/Term/Test - Equipment & Instrument Circuits (Including Interconn	80,217	-	[1]
17 - Paint A/G Pipe and Equipment - SBC	51,323	51,323	
		-	
Totals	6,174,000	5,729,000	
Cost per System	6,174,000	5,729,000	

NOTES
1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Flocculation/Sedimentation Facilities Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		6,050,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		6,731,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (MGD)

Capacity Increments	Unit Component Cost, $
5	2,297,000
10	3,482,000
15	4,441,000
20	5,277,000
25	6,034,000
30	6,731,000
35	7,383,000
40	7,999,000
45	8,585,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 Date: 3/28/2017
Calc. By:	W. Sandelin Chkd. By: A. Smith
Subject:	Flocculation/Sedimentation Facilities Cost Derivation

COST ANALYSIS

Develop base cost for flocculation/sedimentation from actual costs obtained for similar work at the SCWA Vineyard WTP.

Project Cost Breakdown for Flocculation/Sedimentation Facility at the SCWA Vineyard WTP

Work Element	SOV	Use	Notes
Structural			
Excavation	100,000	100,000	
Subgrade Preparation	202,000	202,000	
Form Slabs On Grade	868,000	868,000	
Rebar Slabs On Grade	1,550,000	1,550,000	
Place Slabs On Grade	550,000	550,000	
Form Walls/Columns	2,800,000	2,800,000	
Rebar Walls/Columns	800,000	800,000	
Place Walls/Columns	1,090,000	1,090,000	
Form Suspended Slabs	1,200,000	1,200,000	
Rebar Suspended Slabs	250,000	250,000	
Place Suspended Slabs	199,500	199,500	
Stairs	96,000	96,000	
Hydrostatic Structure Testing	30,000	30,000	
Backfill	150,000	150,000	
Metals	319,500	319,500	
Carpentry	263,000	263,000	
Moisture Protection	112,000	112,000	
Insulation	10,000	10,000	
Doors	10,000	10,000	
Louvers	2,000	2,000	
Specialties	1,000	1,000	
Mechanical - Furnish			
Vertical Shaft Flocculators	500,000	500,000	
Chain and Flight Collectors	900,000	900,000	
FURNISH SMALL ABOVE GROUND PIPING	15,000	15,000	
FURNISH LARGE ABOVE GROUND PIPE, DIV 02	4,500	4,500	
MECH PIPING 2 TO 10 IN	12,800	12,800	
Mechanical - Install			
VERTICAL SHAFT FLOCCULATORS	145,000	145,000	
CHAIN AND FLIGHT COLLECTORS	160,000	160,000	
SET PIPE SPOOLS AND SLEEVES	8,000	8,000	
PIPE SUPPORTS	15,000	15,000	
LAY SMALL ABOVE GROUND PIPING	10,000	10,000	
LAY LARGE ABOVE GROUND PIPE, DIV 02	3,375	3,375	
MECH PIPING 2 TO 10 IN	6,400	6,400	
Plumbing	90,000	90,000	
HVAC			
Layout Drawings	3,830	3,830	
Deliver HVAC Equipment (EF, EH, AC)	20,000	20,000	
Deliver Duct	16,080	16,080	
Install Rooftop Unit, Unit Heater, Louver	13,040	13,040	
Rough-In SS Duct	10,060	10,060	
Rough-In Duct	2,650	2,650	
Test Duct	620	620	
Install Air Outlet	1,230	1,230	
Install Controls	2,195	2,195	
Start Up HVAC	1,000	1,000	
Test and Balance HVAC	1,000	1,000	
O&M Manuals			
Vertical-Shaft Flocculator Units (11210-1.2-C)	50,000	50,000	
Chain and Flight Sludge Collectors (11234)	50,000	50,000	
Totals	12,645,000	12,645,000	
No. Units (Trains)	1		
Cost per Unit (Train)	12,645,000	12,645,000	

NOTES

1. Not used
2. Costs for electrical, instrumentation and chemical feed systems not included in component base costs. Use overall multiplier for electrical costs, and treat chemical feed as separate system.

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 — Date: 3/28/2017
Calc. By:	W. Sandelin — Chkd. By: A. Smith
Subject:	Flocculation/Sedimentation Facilities Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	8564	(Aug 2009)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.230		15,548,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		17,297,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 50 (mgd)

Capacity Increments (Per Train)	Unit Component Cost, $
1	1,654,000
2	2,507,000
3	3,198,000
4	3,800,000
5	4,345,000
7.5	5,541,000
10	6,586,000
15	8,399,000
20	9,982,000
25	11,412,000
30	12,731,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Flocculation/Sedimentation Facilities Cost Derivation

COST ANALYSIS

Develop base cost for flocculation/sedimentation from actual costs obtained for similar work at the SCWA Vineyard WTP.

Project Cost Breakdown for Flocculation/Sedimentation Facility at the SCWA Vineyard WTP

Work Element	SOV	Use	Notes
Structural			
Excavation	100,000	41,000	[3]
Subgrade Preparation	202,000	82,820	[3]
Form Slabs On Grade	868,000	355,880	[3]
Rebar Slabs On Grade	1,550,000	635,500	[3]
Place Slabs On Grade	550,000	225,500	[3]
Form Walls/Columns	2,800,000	1,148,000	[3]
Rebar Walls/Columns	800,000	328,000	[3]
Place Walls/Columns	1,090,000	446,900	[3]
Form Suspended Slabs	1,200,000	492,000	[3]
Rebar Suspended Slabs	250,000	102,500	[3]
Place Suspended Slabs	199,500	81,795	[3]
Stairs	96,000	39,360	[3]
Hydrostatic Structure Testing	30,000	12,300	[3]
Backfill	150,000	61,500	[3]
Metals	319,500	130,995	[3]
Carpentry	263,000	107,830	[3]
Moisture Protection	112,000	45,920	[3]
Insulation	10,000	4,100	[3]
Doors	10,000	10,000	
Louvers	2,000	2,000	
Specialties	1,000	410	[3]
Mechanical - Furnish			
Vertical Shaft Flocculators	500,000	500,000	
Chain and Flight Collectors	900,000	-	[1]
FURNISH SMALL ABOVE GROUND PIPING	15,000	15,000	
FURNISH LARGE ABOVE GROUND PIPE, DIV 02	145,000	145,000	
MECH PIPING 2 TO 10 IN	12,800	5,248	[3]
Mechanical - Install			
VERTICAL SHAFT FLOCCULATORS	145,000	145,000	
CHAIN AND FLIGHT COLLECTORS	160,000	-	[1]
SET PIPE SPOOLS AND SLEEVES	3,830	3,830	
PIPE SUPPORTS	15,000	6,150	[3]
LAY SMALL ABOVE GROUND PIPING	10,000	4,100	[3]
LAY LARGE ABOVE GROUND PIPE, DIV 02	3,830	3,830	
MECH PIPING 2 TO 10 IN	6,400	2,624	[3]
Plumbing	90,000	36,900	[3]
HVAC			
Layout Drawings	3,830	3,830	
Deliver HVAC Equipment (EF, EH, AC)	20,000	20,000	
Deliver Duct	16,080	16,080	
Install Rooftop Unit, Unit Heater, Louver	13,040	13,040	
Rough-In SS Duct	10,060	10,060	
Rough-In Duct	2,650	2,650	
Test Duct	620	620	
Install Air Outlet	1,230	1,230	
Install Controls	2,195	2,195	
Start Up HVAC	1,000	1,000	
Test and Balance HVAC	1,000	1,000	
O&M Manuals			
Vertical-Shaft Flocculator Units (11210-1.2-C)	50,000	50,000	
Chain and Flight Sludge Collectors (11234)	50,000	-	[1]
Totals	12,782,000	5,344,000	
No. Units (Trains)	1		
Cost per Unit (Train)	12,782,000	5,344,000	

NOTES

1. Removed to reflect coagulation and flocculation only.
2. Costs for electrical, instrumentation and chemical feed systems not included in component base costs. Use overall multiplier for electrical costs, and treat chemical feed as separate system.
3. Factored by 0.41 to reflect relative quantities of concrete for [coagulation/flocculation/settled water collection] and total facility

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 — Date: 3/28/2017
Calc. By:	W. Sandelin — Chkd. By: A. Smith
Subject:	Flocculation/Sedimentation Facilities Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	8564	(Aug 2009)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.230		6,571,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		7,310,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 50 (mgd)

Capacity Increments (Per Train)	Unit Component Cost, $
1	699,000
2	1,060,000
3	1,351,000
4	1,606,000
5	1,836,000
7.5	2,342,000
10	2,783,000
15	3,550,000
20	4,218,000
25	4,823,000
30	5,380,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 · Date: 3/28/2017
Calc. By:	W. Sandelin · Chkd. By: A. Smith
Subject:	Granular Media Filters Cost Derivation

COST ANALYSIS

Develop base cost for granular media filtration from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Granular Media Filtration Facility at the WDCWA Regional Water Treatment Facili

Work Element	SOV	Use	Notes
Excavate for Underslab Piping	70,093	70,093	
Excavate and Prep for Floor Slabs	70,093	70,093	
Final Backfill	46,728	46,728	
Form/Rebar/Pour - Slab Pour 1 (Includes Form/Rebar on Slab Pour 2)	192,092	192,092	
Complete Form/Rebar/Pour - Slab Pour 2	192,092	192,092	
Form/Rebar Pour - Short Wall Pour 1 (Includes Form/Rebar on Short Wall	48,023	48,023	
Complete Form/Rebar/Pour - Short Wall 2	48,023	48,023	
Form/Rebar/Pour - Slab Pour 3 (Includes Form/Rebar on Slab Pour 4A)	348,167	348,167	
Complete Form/Rebar/Pour - Slab Pour 4A	186,090	186,090	
Form/Rebar/Pour - Slab Pour 4B	186,090	186,090	
Form/Rebar/Pour - Wall Pour 1A	139,367	139,367	
Form/Rebar/Pour - Wall Pour 2	114,028	114,028	
Form/Rebar/Pour - Wall Pour 3	63,349	63,349	
Form/Rebar/Pour - Wall Pour 4	126,698	126,698	
Form/Rebar/Pour - Wall Pour 5	152,037	152,037	
Form/Rebar/Pour - Wall Pour 6	126,698	126,698	
Form/Rebar/Pour - Wall Pour 7	152,037	152,037	
Form/Rebar/Pour - Wall Pour 8	152,037	152,037	
Form/Rebar/Pour - Wall Pour 9	63,349	63,349	
Form/Rebar/Pour - Wall Pour 10	88,688	88,688	
Form/Rebar/Pour - Wall Pour 11	88,688	88,688	
Shore/Rebar/Pour - Elev Floor Dividing Influent and Effuent Channels	136,457	136,457	
Shore/Rebar/Pour - Perimeter Deck	326,292	326,292	
Remove Shoring Perimeter Deck	10,000	10,000	
Water Leak Test	21,567	21,567	
Install Misc Steel - Filter Facility	893,625	893,625	
Install Rigid Frame and Purlins - at Blower Canopy	50,890	50,890	
Install Metal Roof, Flashing, Gutters, Downspouts - at Blower Canopy	21,000	21,000	
Install U/S Pipe - under Filter Facility Pipe Gallery	1,288,550	1,288,550	
Install Air Scour Blowers - Filter Blower Area	50,000	50,000	
Install Under Drain Equipment- Filter Basins	441,935	441,935	
Install Backwash Waste Troughs - Filter Basins	80,000	80,000	
Receive and Install Large Bore A/G Pipe Headers - Filter Pipe Gallery	2,249,915	2,249,915	
Sample Pump and Sumps - Install and Hookup - Filter Influent	4,800	4,800	
Receive and Install Large Bore A/G Pipe Branch Piping - Filter Facility Ove	1,453,714	1,453,714	
Test/Flush Piping Systems - Filter Facility Piping Systems	100,000	100,000	
Install Under-Slab Electrical - Filter Facility	63,630	63,630	
Rough-in Electrical - In-Slab - Filter Facility	190,498	190,498	
Rough-in Electrical - In Wall - Filter Facility	54,000	54,000	
Install/Fit-up Equipment Electrical Stands - Filter Facilty	199,218	199,218	
Install/Fit-up Instrument Stands - Filter Facility	129,043	129,043	
Pull/Terminate/Test - Electrical and Instrument Circuits - Filter Facility (incl	99,130	99,130	
Paint A/G Pipe and Equipment - Filter Facility	105,000	105,000	
Granular Activated Carbon Media	903,407	903,407	
Granular Activated Carbon Underdrain System and Media	882,896	882,896	
SUBMITTAL Backwash Troughs	9,810	9,810	
REC ON SITE BACKWASH TROUGHS	88,290	88,290	
Submittal - Air Scour Blowers	19,974	19,974	
Rec. On Site - Air Scour Blowers	179,769	179,769	
Totals	12,708,000	12,708,000	
No. Units (Trains)	5		
Cost per System	2,542,000	2,542,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		13,419,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		14,929,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (MGD)

Capacity Increments	Unit Component Cost, $
5	5,095,000
10	7,723,000
15	9,849,000
20	11,705,000
25	13,382,000
30	14,929,000
35	16,376,000
40	17,742,000
45	19,041,000

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: Membrane Filtration Cost Derivation		

COST ANALYSIS

Develop base cost for membrane filtration from actual costs obtained for similar work at the Lodi Surface Water Treatment Plant.

Project Cost Breakdown for Membrane Filtration Facility at the Lodi Surface Water Treatment Plant

Work Element	SOV	Use	Notes
REBAR OPS BLDG	155,000	80,600	[1]
STR STEEL OPS BLDG SHOP DWGS	10,000	5,200	[1]
STR STEEL OPS BLDG FOB ITEMS	56,575	29,419	[1]
STR STEEL OPS BLDG ROOF STRUCTURE	91,900	47,788	[1]
STR STEEL OPS BLDG JOIST	126,150	65,598	[1]
STR STEEL OPS BLDG MASONRY EMBEDS	46,525	24,193	[1]
STR STEEL OPS BLDG DECKING	76,625	39,845	[1]
MISC STEEL OPS BLDG	55,000	55,000	
SHEETMETAL ROOFING OPS BLDG	118,500	61,620	[1]
COATINGS OPS BLDG	159,500	159,500	
PLUMBING OPS BLDG UNDER SLAB	33,660	17,503	[1]
PLUMBING OPS BLDG A/G	34,328	17,851	[1]
PLUMBING OPS BLDG FINISH	15,330	7,972	[1]
HVAC OPS BLDG	192,000	99,840	[1]
REV FILT WASTE TANK	35,000	35,000	
RECIRCULATION PS	20,000	20,000	
FTW PS COMPLETE	15,000	15,000	
PIT SOG	45,000	45,000	
PIT WALLS	90,000	90,000	
FOOTINGS	60,000	31,200	[1]
SOG	226,320	117,686	[1]
PERIMTER WALLS 1	15,000	7,800	[1]
PERIMTER WALLS 2	15,000	7,800	[1]
WOOD BLOCKING AT ROOF	48,000	24,960	[1]
PLYWOOD SOFFITS	25,000	13,000	[1]
Membranes	60,000	60,000	
Aut Str/Membrane Feed	65,000	65,000	
Membrane Filter Underslab	30,000	30,000	
Membrane FIL	45,000	45,000	
Membrane RFS	30,000	30,000	
Membrane RFS/PW Copper	25,000	25,000	
Membrane RFW Underslab	18,000	18,000	
Membrane RFW	15,000	15,000	
Membrane MF Underslab	12,000	12,000	
Membrane MF	28,000	28,000	
Membrane CIPR	38,000	38,000	
Membrane CIPS	15,000	15,000	
Membrane CIP/REC/EFM	35,000	35,000	
Membrane SB Chemical Piping	28,000	28,000	
Membrane Air	15,000	15,000	
Pall Corp Coordination	47,766	47,766	
Pall System Modifications	8,962	8,962	
Pall Membrane System	3,926,081	3,926,081	
RFR TANK	14,000	14,000	
FW TANK / DRAINAGE PS	18,000	18,000	
CHEMICAL SYSTEMS	85,000	85,000	
CO 9 CREDIT CATHODIC PROTECTION AT RFWT	(4,675)	(4,675)	
CO 11 RFI 150 155 OPS/CHEM TOP OF WALL EMBED COATING	15,515	5,275	[2]
CO 11 RFI 171 OPS AND CHEM RAFTER TAIL	33,639	11,437	[2]
CO 12 AIR DRYER AND FILTER	9,319	9,319	
CO 12 OPS PIT SUMP PUMP	2,899	2,899	
CO 13 RFI 98 8" RFS OVERFLOW AT RFT TNK	4,163	4,163	
CO 13 RIF 279 CIP TANK HEATERS/NEUT TANK BKR	2,420	2,420	
CO 13 COAT CHEM METERING PUMP SUPPORTS	4,833	4,833	
CO 13 RFI 2043 ADDED CIP DRAIN AT PALL SYSTEM	1,779	1,779	
CO 13 RFI 3001B PALL COORD EYEWASH, DRAIN, TOTES	30,057	30,057	
CO 13 BOOSTER PUMP FOR CHEM SYSTEM	17,992	17,992	
Totals	6,442,000	5,764,000	
Cost per System	6,442,000	5,764,000	

NOTES

1. Factored by 0.52 to reflect relative footprint for [membranes/mechanical room/CIP chemicals] and total Ops bldg

2. Factored by 0.34 to reflect relative footprint for [membranes/mechanical room/CIP chemicals] and total of Ops and Chem bldgs

WEST YOST ASSOCIATES Consulting Engineers

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Membrane Filtration Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9290	(May 2012)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.133		6,533,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		7,268,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 8 (mgd)

Capacity Increments	Unit Component Cost, $
5	5,482,000
10	8,309,000
15	10,598,000
20	12,594,000
25	14,399,000
30	16,063,000
34	17,316,000
40	19,090,000
45	20,487,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 Date: 3/28/2017
Calc. By:	W. Sandelin Chkd. By: A. Smith
Subject:	Membrane Filtration Cost Derivation

COST ANALYSIS

Develop base cost for membrane filtration from actual costs obtained for similar work at the MID Regional Water Treatment Plant.

Project Cost Breakdown for Membrane Filtration Facility at the MID Regional Water Treatment Plant

Work Element	SOV	Use	Notes
Structural		-	
Earthwork - Shoring at Membrane Building	140,707	140,707	
Earthwork - Aggregate Base	42,697	42,697	
Earthwork - Backfill	261,788	261,788	
Earthwork - Excavation	500,092	500,092	
Concrete - Encase 20" BWW Piping	18,070	18,070	
Concrete - Encase 60" FLT Piping	207,820	207,820	
Concrete - Footings at Exterior CMU Columns	33,122	33,122	
Concrete - Slabs at Elev. 174.50'	843,517	843,517	
Concrete - Slabs at Elev. 192.50'	315,889	315,889	
Concrete - Walls	1,128,663	1,128,663	
Concrete - Beams	21,740	21,740	
Concrete - Columns	12,496	12,496	
Concrete - Decks	163,398	163,398	
Concrete - Equipment Pads & Curbs	28,542	28,542	
Masonry	630,891	630,891	
Metals - Roof Joist & Deck at EL. 206.50	290,400	290,400	
Metals - Roof Joist & Decking at El 214.50	824,400	824,400	
Metals - Steel Cormer Roof Support	49,179	49,179	
Metals - Metal Deck (1") at Mansard	42,468	42,468	
Metals - Mansard Framing	264,217	264,217	
Metals - Light Gauge Framing Room 103 & 104	46,984	46,984	
Metals - Handrail	44,492	44,492	
Metals - Grating & Supports at El. 197.83	30,765	30,765	
Metals - Stairs	32,370	32,370	
Rough Carpentry - Roof & Accent Blocking Detail AM301	171,944	171,944	
Dampproofing - Walls Below Grade	79,980	79,980	
Roofing - Standing Seam Metal Panel System	190,413	190,413	
Roofing - Membrane	119,805	119,805	
Roofing Specialties - Skylights	115,699	115,699	
Roofing Specialties - Mansard & Skylight Curbs & Blocking	128,317	128,317	
Doors - Steel Doors and Hardware	37,537	37,537	
Doors - Rolling Steel Doors	17,137	17,137	
Finishes - Stucco	166,777	166,777	
Finishes - Gypsum Board @ Rooms 103 &104	32,379	32,379	
Finishes - Acoustical Treatment at Blower Room	50,752	50,752	
Specialties - Louvers	13,750	13,750	
		-	
Mechanical - Furnish		-	
Protective Coatings	342,444	342,444	
Equipment - TR Pumps	49,171	49,171	
Equipment - CIP Pumps	10,591	10,591	
Equipment - Backwash Pumps	12,993	12,993	
Equipment - Blowers	17,352	17,352	
Equipment - Filtrate Pumps	52,058	52,058	
Equipment - Membrane Cell Internals	201,502	201,502	
Equipment - Membrane Modules	119,395	119,395	
Equipment - Membrane Crane	15,684	15,684	
Equipment - Memsap Rails	26,689	26,689	
Equipment - Jib Crane	63,856	63,856	
Equipment - Sump Pumps	23,664	23,664	
Equipment - Pilot Plant Equipment	293,635	293,635	
Equipment - Chemical Pumps & Equipment @ CIP Area	16,675	16,675	
Equipment - Adjustable Frequency Drives in Room 103	1,495	1,495	

Project: SRWA Surface Water Supply Project			
Job No.: 693-20-16-01		Date: 3/28/2017	
Calc. By: W. Sandelin		Chkd. By: A. Smith	
Subject: Membrane Filtration Cost Derivation			
Piping - Fire Sprinkler System	96,678	96,678	
Piping - 60" FLT (Below Slab)	2,507,725	2,507,725	
Piping - 20" BWW (Below Slab)	84,000	84,000	
Piping - 60" MI Piping	205,338	205,338	
Piping - 24" MI	679,000	679,000	
Piping - 24" & 20" FLT	802,000	802,000	
Piping - 18" BWS	132,000	132,000	
Piping - 14" ARW	300,000	300,000	
Piping - 20" & 12" BWW (Exposed)	68,213	68,213	
Piping - 10" CIP	94,914	94,914	
Piping - 8" TR	21,726	21,726	
Piping - 6" HW	22,477	22,477	
Piping - Instrument Air at Blower Room	129,413	129,413	
Piping - Instrument Air at Membrane Area (Header to Valves)	165,496	165,496	
Piping - Instrument Air (2" Header & Underslab)	189,270	189,270	
Piping - Pilot Plant System	319,473	319,473	
Piping - Small Diameter CIP System in Membrane Area	31,316	31,316	
Piping - CIP System in CIP Room	108,326	108,326	
Piping - Sample Within 60" FLT	21,790	21,790	
Piping - Sample at Membrane Area	74,485	74,485	
Insulation - Air Piping	94,372	94,372	
Test - Leak Test Filters & Tanks	5,897	5,897	
Test - Piping	72,036	72,036	
Test - TR Pumps	695	695	
Test & Start Membrane Filtration Equipment	165,357	165,357	
Deliver Membrane Filtration Equipment	5,118,079	5,118,079	
		-	
Plumbing		-	
Insulation - Plumbing Piping	57,601	57,601	
Plumbing - Roof Drain System	393,325	393,325	
Plumbing - Floor Drain System (Lower Level)	248,646	248,646	
Plumbing - Floor Drain System (Upper Level)	106,563	106,563	
Plumbing - CW Plumbing System	64,292	64,292	
Plumbing - TW Plumbing System	33,320	33,320	
Plumbing - HW Plumbing System	33,320	33,320	
Plumbing - Propane Gas	59,513	59,513	
		-	
HVAC		-	
HVAC - Equipment & Ductwork	301,823	301,823	
HVAC - Controls	112,505	112,505	
		-	
Electrical		-	
Electrical - Rough Branch Power	127,000	-	[1]
Electrical - Rough Devices	44,000	-	[1]
Electrical - Rough Fixtures	34,000	-	[1]
Electrical - Rough Equipment	44,000	-	[1]
Electrical - Wire Branch Power	73,000	-	[1]
Electrical - Wire Lighting	20,000	-	[1]
Electrical - Wire Equipment	48,000	-	[1]
Electrical - Wire Instrumentation	44,000	-	[1]
Electrical - Install Gear & Terminate	20,000	-	[1]
Electrical - Data & Security	32,880	-	[1]
Electrical - Light Fixtures	110,500	-	[1]
Electrical - PLC4	197,400	-	[1]
Electrical - Light Fixtures	110,500	-	[1]
Electrical - Lighning Protection System	31,251	-	[1]
Electrical - Grounding	30,001	-	[1]
Electrical - MCC 2A	156,000	-	[1]
Totals	22,389,917	21,267,385	
Cost per System	22,389,917	21,267,385	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project
	Job No.: 693-20-16-01 Date: 3/28/2017
	Calc. By: W. Sandelin Chkd. By: A. Smith
	Subject: Membrane Filtration Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	8185	(Jun 2008)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.286		27,360,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		30,438,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	10,388,000
10	15,745,000
15	20,082,000
20	23,865,000
25	27,284,000
30	30,438,000
34	32,812,000
40	36,173,000
45	38,821,000

WEST YOST ASSOCIATES Consulting Engineers

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 — Date: 3/28/2017
Calc. By:	A. Smith — W. Sandeli — Chkd. By:
Subject:	UV Disinfection Facility Cost Derivation

COST ANALYSIS

Develop base cost for a UV disinfection facility from preliminary design criteria for the SRWA WTP

Project Cost Breakdown for UV Disinfection Facility at the SRWA WTP

Item Description	Quantity	Units	Unit Price	Total
Division 2-Site Work	$ 15,000			
Underslab Pipe Encasement	1	LS	$10,000	$10,000
Install Underslab AB	22	CY	$200	$4,467
Division 3-Concrete	$ 16,000			
Slabs/Foundations	22	CY	$600	$13,400
Misc Concrete	5	CY	$600	$3,000
Division 5-Metals	$ 10,000			
Miscellaneous Metals (Supports)	1	LS	$10,000	$10,000
Division 9-Coating Systems	$ 11,000			
Piping Systems	2%	%		$11,000
Division 11-Equipment	$ 462,000			
UV Equipment	1	LS	$440,000	$440,000
Installation	5%	%	$22,000	$22,000
Division 13-Special Construction	$ 10,000			
Canopy Structure	1	LS	$10,000	$10,000
Division 15-Mechanical	$ 110,000			
24 inch inlet piping (exposed)	30	LF	$240	$7,200
24 inch outlet piping (exposed)	30	LF	$240	$7,200
2 inch cooling water/drain piping (exposed)	20	LF	$20	$400
24" BFV Valves	4	EA	$20,000	$80,000
Misc Valves	1	LS	$15,000	$15,000
				$0
Estimated Component Cost				$634,000

Current Date		(Mar 2017)	
Inflation to Future Dollars			
Months to SRWA Construction Midpoint	39	(Jun 2020)	
Years to SRWA Construction Midpoint	3.2		
Most Recent Year/Year Inflation	3%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.10		**$ 700,000**

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: In-Plant Pump Station Cost Derivation		

COST ANALYSIS

Develop base cost for an in-plant pump station from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for In Plant Pump Station at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-excavation / Backfill to Bottom of Foundation Slab	73,235	73,235	
Backfill PS Wet Well	24,412	24,412	
Backfill Facility to Subgrade	3,000	3,000	
Form / Rebar - Foundation Slab	46,890	46,890	
Pour - Foundation Slab	25,000	25,000	
Form / Rebar / Pour - North Walls	136,591	136,591	
Form / Rebar / Pour - South Walls	91,591	91,591	
Shore - Upper Deck	44,701	44,701	
Form / Rebar / Pour - Upper Deck	39,000	39,000	
Remove Shoaring from Deck	15,000	15,000	
Water Leak Test	7,189	7,189	
Form / Rebar / Pour - PS Electrical Bldg and FW Pipe Support Slab	35,756	17,878	[2]
Form / Rebar / Pour - Pipe Pedestals	11,189	11,189	
Install Access Hatch and Ladder	86,268	86,268	
Erect Bldg Structural Steel, Girts and Purlins - PS Electrical Bldg	54,000	-	[1]
Erect Insulated Metal Panels, Roof/Siding - PS Electrical Bldg	50,835	-	[1]
Install GW Piping - Under Foundation Slab	21,567	21,567	
Install Vertical In-Plant Pumps	107,835	107,835	
Install Aboveground FW Piping	440,908	440,908	
Test/Flush Piping	25,000	25,000	
Install HVAC System - PS Electrical Bldg	28,756	-	[1]
In-Slab Electrical - Deck for PS	10,000	-	[1]
Under-Slab Electrical - PS Elect Bldg	157,978	-	[1]
Backfill & Underslab Electrical	13,915	-	[1]
Install / Fit-up Equipment Electrical Stands	25,000	-	[1]
Install / Fit-up Instrument Stands	20,000	-	[1]
Install Electrical and I&C Equipment	350,000	-	[1]
Pull / Terminate / Test - Equipment and Instrument Circuits	84,039	-	[1]
Pull / Terminate from Elect Bldg to XFMR	20,000	-	[1]
Energize and Test	16,174	-	[1]
Paint Aboveground Pipe and Equipment	51,700	51,700	
Install Doors - PS Electrical Bldg	3,000	-	[1]
SUBMITTAL VERTICAL TURBINE PUMPS	152,804	44,313	[3]
REC ON SITE VERTICAL TURBINE PUMPS	1,150,234	333,568	[3]
Totals	3,424,000	1,647,000	
Cost per System	3,424,000	1,647,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Assume half of this cost is associated with finished water (FW) piping slab.
3. Factored by (4/14 = .29) to reflect four (4) VT pumps for IPPS out of 14 total VT pumps for WTP

WEST YOST ASSOCIATES Consulting Engineers

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	In-Plant Pump Station Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		1,739,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		1,935,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	660,000
10	1,001,000
15	1,277,000
20	1,517,000
25	1,734,000
30	1,935,000
35	2,123,000
40	2,300,000
45	2,468,000

Project:	SRWA Surface Water Supply Project		
Job No.:	693-20-16-01	Date:	3/28/2017
Calc. By:	W. Sandelin	Chkd. By:	A. Smith
Subject:	Chlorine Contact Tank Cost Derivation		

COST ANALYSIS

Develop base cost for chlorine contact tank from detailed cost estimate prepared for the DWWSP Benchmark WTP.

Project Cost Breakdown for Chlorine Contact Tank at the DWWSP Benchmark WTP

Work Element	SOV	Use	Notes
Sitework			
Survey and layout	305	305	
Structure excavation	19,613	19,613	
Structure backfill	16,284	16,284	
Install underslab gravel - AB	5,234	5,234	
Transport to Stockpile	4,370	4,370	
Transport to Backfill	3,651	3,651	
Assist pile driver	2,502	-	[1]
Furnish and install concrete piles	87,328	-	[1]
Clean up after piles	1,544	-	[1]
Prepare dowels in top of concrete piles	4,296	-	[1]
Concrete		-	
Fine Grade	582	582	
Form Footing	3,513	3,513	
Form Construction Joint	6,561	6,561	
Form Wall	94,221	94,221	
Pour Concrete	71,488	71,488	
Sandblast Joints	473	473	
Install Waterstop	3,194	3,194	
Strip & Patch	57,951	57,951	
Exposed Finish - Sacking	1,238	1,238	
JFM/CFM	46,640	46,640	
Rebar	58,609	58,609	
Rebar Couplers - Form Savers	11,671	11,671	
Install Caulking	1,100	1,100	
Install Sleeves - Baffle Walls	1,455	1,455	
Watertest Structure	5,842	5,842	
Grout Basin Floor - (furnish conc. Included above)	9,857	9,857	
Metals			
Receive/Inventory/Store Metals	157	157	
F&I Beam Support Brackets	2,864	2,864	
F&I Aluminum Beam Supports for FRP Grating	6,653	6,653	
Specialties			
F&I Gasketed FRP Covers	85,252	85,252	
Mechanical			
Receive/Inventory Pipe	88	88	
Cores and Spools	-	-	
Install Very Large Wall Spools- >48"	2,893	2,893	
Furnish Prefabricated Steel Pipe	8,000	8,000	
Totals	625,000	530,000	
Cost per Unit (Train)	625,000	530,000	

NOTES

1. No piles assumed for this project.
2. Costs for electrical, instrumentation and chemical feed systems not included in component base costs. Use overall multiplier for electrical costs, and treat chemical feed as separate system.

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Chlorine Contact Tank Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9080	(Jul 2011)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.160		615,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		684,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 212,000 gal

Capacity Increments (Per Train)	Unit Component Cost, $
600,000	1,277,000
605,000	1,283,000
610,000	1,290,000
615,000	1,296,000
620,000	1,302,000
625,000	1,309,000
630,000	1,315,000
635,000	1,321,000
640,000	1,327,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 Date: 3/28/2017
Calc. By:	W. Sandelin Chkd. By: A. Smith
Subject:	Clearwell Cost Derivation

COST ANALYSIS

Develop base cost for clearwell from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Clearwell Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Excavate for Tank Floor Slab - CW Tank - Both Tanks	158,518	158,518	
Backfill with Aggregate, In Conjunction with Drain Pipe - CW Tank - Both Ta	237,776	237,776	
Backfill Tanks to Sub-Grade - CW Tank - Both Tanks	132,098	132,098	
Form/Rebar/Pour Floor and Wall Footing & Wall Bearing Pads - CW Tank (	419,111	419,111	
Place Wall Bearing Pads - CW Tank (west)	2,500	2,500	
Assemble Wall Forms - CW Tanks	132,222	132,222	
Form/Rebar/Pour Core Walls 1 thru 8 - CW Tank (west)	432,171	432,171	
Shoring for Dome Roof - CW Tank (west)	50,707	50,707	
Form/Rebar/Pour Core Wall 9 - CW Tank (west)	69,148	69,148	
Concrete Dome Roof - CW Tank (west)	390,094	390,094	
Stress Vertical Tendons and Epoxy - CW Tank (west)	42,500	42,500	
Set-up Pre-Stressing Equipment - CW Tank (west)	12,500	12,500	
Abrasive Blast, Wrapping and Shotcrete (includes Cure Time - CW Tank (w	787,500	787,500	
Dismantle Dome Shoring & Tear Down Pre-Stress Equipment- CW Tank (\	63,207	63,207	
Install Ladders, Pipe Supports, Paint Interior Pipe and Seal Tank - CW Tan	40,500	40,500	
Water Leak Test - CW Tank - CW Tank (west)	12,000	12,000	
Form/Rebar/Pour Floor and Wall Footing & Wall Bearing Pads - CW Tank (	418,111	418,111	
Place Wall Bearing Pads - CW Tank (east)	2,500	2,500	
Form/Rebar/Pour Core Walls 1 thru 8 - CW Tank (east)	432,171	432,171	
Shoring for Dome Roof - CW Tank (east)	50,707	50,707	
Form/Rebar/Pour Core Wall 9 - CW Tank (east)	69,148	69,148	
Concrete Dome Roof - CW Tank (east)	390,094	390,094	
Stress Vertical Tendons and Epoxy - CW Tank (east)	42,500	42,500	
Set-up Pre-Stressing Equipment - CW Tank (east)	12,500	12,500	
Abrasive Blast, Wrapping and Shotcrete (includes Cure Time - CW Tank (e	787,500	787,500	
Dismantle Dome Shoring & Tear Down Pre-Stress Equipment- CW Tank (e	63,207	63,207	
Install Ladders, Pipe Supports, Paint Interior Pipe & Seal Tank - CW Tank (	40,500	40,500	
Water Leak Test - CW Tank - CW Tank (east)	12,000	12,000	
Install Underslab Piping - FW & OF Piping - CW Tanks (both)	503,230	503,230	
Install Underslab Piping - GW Piping - CW Tanks (both)	503,230	503,230	
Install A/G Pipe - FW and OF Piping - Both Tanks	3,500	3,500	
Install Sample Pump - CW Tank	3,500	3,500	
Rough-in for Electrical & I&C	19,565	-	[1]
Set/Fitup - Sample Pump & Level Instrument Stands - CW Tank	5,000	-	[1]
Pull/Terminate/Test - Electrical and I&C Circuits - CW Tank (including inter	9,261	-	[1]
Paint A/G Pipe - CW Tank	1,000	1,000	
Install Exterior Ladder and Handrail on Tanks	10,000	10,000	
Paint Exterior of Tanks	45,000	45,000	
Totals	6,407,000	6,373,000	
Cost per System	6,407,000	6,373,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Project:	SRWA Surface Water Supply Project		
Job No.:	693-20-16-01	Date:	3/28/2017
Calc. By:	W. Sandelin	Chkd. By:	A. Smith
Subject:	Clearwell Cost Derivation		

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		6,730,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		7,487,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 5.75 (MG)

Capacity Increments	Unit Component Cost, $
2.1	4,091,000
2.2	4,207,000
2.3	4,321,000
2.4	4,432,000
2.5	4,542,000
2.6	4,650,000
2.7	4,757,000
2.8	4,862,000
2.9	4,965,000

	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: Backwash Supply & FWPS Cost Derivation		

COST ANALYSIS

Develop base cost for backwash supply and finished water pump station from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Backwash Supply and Finished Water Pump Station Facility at the WDCWA Regi

Work Element	SOV	Use	Notes
Mass Excavate/Waste Slab for Pump Cans - FW PS	75,000	75,000	
Backfill up to FW Inlet at Pump Cans - FW PS	10,000	10,000	
Backfill up to Bottom of Foundation Slab - FW PS	10,000	10,000	
Excavate for Surge Tank Foundations - FW PS Exterior	7,500	7,500	
Final Backfill at Facility	16,119	16,119	
Form/Rebar/Pour - Lower Encasement of Pump Cans - FW PS	41,120	41,120	
Form/Rebar/Pour - Encasement of FW Inlet Pipe - FW PS	42,200	42,200	
Form/Rebar/Pour - Upper Encasement of Pump Cans	50,000	50,000	
Form/Rebar/Pour - Foundation Slab - FW PS	312,088	312,088	
Form/Rebar/Pour - Surge Tank Foundations - FW PS Exterior	25,945	25,945	
Form/Rebar/Pour - Pump Pedestals - FW PS	15,378	15,378	
Form/Rebar/Pour - Pipe Supports FW PS	15,378	15,378	
Form/Rebar/Pour - HVAC Unit(s) Foundation - FW PS	13,000	13,000	
Erect Rigid Frame, Girts, Purlins, Hatch Framing - FW PS	180,846	180,846	
Install Insulated Metal Panels - Roof/Siding - FW PS	150,316	150,316	
Install Interior Divider Wall, Doors, Rollup Doors, Windows & Skylights - F	130,186	130,186	
Set Pump Cans - FW PS	208,617	208,617	
Install Remaining Underslab Pipe - FW PS	195,510	195,510	
Set Surge Tanks - FW PS Exterior	40,000	40,000	
Install FW and Backwash Pumps - FW PS	304,633	304,633	
Install A/G Piping - FW PS	1,778,180	1,778,180	
Test/Flush Piping Systems in Facility - FW PS	50,000	50,000	
Set HVAC Units - Outside	140,000	140,000	
Rough-in Interior HVAC Ductwork - FW PS	152,772	152,772	
Finsh HVAC and HVAC Controls - FW PS	17,560	17,560	
Install Underslab Electrical - FW PS	254,226	-	[1]
Install In-Slab Electrical Rough-in - FW PS	152,121	-	[1]
Install U/S Electr/I&C Under Surge Tank Slabs - FW PS Exterior	7,000	-	[1]
Rough-In Overhead Lighting and Security - FW PS	91,304	-	[1]
Install Electrical & I&C Equipment - FW PS	300,000	-	[1]
Pull/Term from Electrical Room to XFRR - FW PS	20,000	-	[1]
Install Equip Elec Stands and Fit-up Equpment - FW PS	183,738	-	[1]
Install Instr Stands and Fit-up - Field Instruments - FW PS	100,000	-	[1]
Pull/Term/Test Electrical and I&C Circuits - FW PS (Including Interconnec	150,606	-	[1]
Energize Electrical Room - FW PS	16,174	-	[1]
Paint Interior Divider Wall - FW PS	10,000	10,000	
Paint Pipe, Equipment, Doors and Door Frames - FW PS	191,821	191,821	
SUBMITTAL VERTICAL TURBINE PUMPS	152,804	108,491	[3]
SUBMITTAL PUMP CANS	22,500	15,975	[3]
REC ON SITE VERTICAL TURBINE PUMPS	1,150,234	816,666	[3]
REC ON SITE PUMP CANS	202,500	143,775	[3]
SURGE TANKS	421,075	298,963	
Totals	7,408,000	5,568,000	
Cost per System	7,408,000	5,568,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.
3. Factored by (10/14 = .71) to reflect ten (10) VT pumps for BWS/FWPS out of 14 total VT pumps for WTP

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 · Date: 3/28/2017
Calc. By:	W. Sandelin · Chkd. By: A. Smith
Subject:	Backwash Supply & FWPS Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		5,880,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		6,541,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	2,232,000
10	3,384,000
15	4,315,000
20	5,128,000
25	5,863,000
30	6,541,000
35	7,175,000
40	7,773,000
45	8,343,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Backwash EQ Basin Cost Derivation

COST ANALYSIS

Develop base cost for backwas EQ basin from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Backwash EQ Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Ex/Backfill to Bottom of Foundation Slab	172,536	172,536	
Partial Backfill BWR EQ Basin	47,512	47,512	
Complete Backfill BWR EQ Basin at BWW/OF Wet Well	10,000	10,000	
Form/Rebar/Pour - Foundation Slab - Lower Slab - Slab Pour 1	224,357	224,357	
Form/Rebar/Pour - 1st Foundation/Slab and Stem Wall Upper - Slab Pour	246,491	246,491	
Form/Rebar/Pour - 2nd Foundatiion/Slab and Stem Wall Upper - Slab Pou	246,491	246,491	
Form/Rebar/Pour - Walls - Pour #1	129,870	129,870	
Form/Rebar/Pour - Walls - Pour #2	103,328	103,328	
Form/Rebar/Pour - Walls - Pour #3	98,588	98,588	
Form/Rebar/Pour - Walls - Pour #4	60,669	60,669	
Form/Rebar/Pour - Walls - Pour #5	66,357	66,357	
Form/Rebar/Pour - Walls - Pour #6	66,357	66,357	
Shore/ Form/Rebar - Deck at East End - Lower Level	5,000	5,000	
Pour - Deck at East End - Lower Level	10,945	10,945	
Remove Shoring - Deck at East End - Lower Level	2,000	2,000	
Water Leak Test - BW EQ Basin	3,595	3,595	
Form/Rebar/Pour - Valve Station Slab - SOG East end Facility	10,567	10,567	
Form/Rebar/Pour - Fdn Slab - BWW/OF Wet Well	22,378	22,378	
Form/Rebar/Pour - Walls - BWW/OF Wet Well	14,000	14,000	
Water Leak Test BWW/OF Wet Well	1,000	1,000	
Erect Stairs and Handrail - BW EQ Basin	158,158	158,158	
Install GW Piping - Under Foundation Slab - BWEQ	143,782	143,782	
Set - Sub. Backwash Return Pumps (including rails)	35,000	35,000	
Set - Sub. Unthickened Slidge Pumps (including rails)	35,000	35,000	
Set - Hoseless Sludge Collection System	150,000	150,000	
Set - Water Control Gates (assuming surface mounted)	47,560	47,560	
Erect A/G Pipe and Instruments - BW EQ Basin	176,292	176,292	
Test/Flush Piping - BW EQ Basin	10,000	10,000	
In-Slab Electrical - Deck at East End	23,478	-	[1]
Rough-in A/G Electrical - BW EQ Basin	24,783	-	[1]
Set Stands and Fitup Equipment - BW EQ Basin	21,000	-	[1]
Set Stands and Fitup Instrumentation - BW EQ Basin	13,043	-	[1]
Pull / Term / Test Electrical & I&C Circuits - BW EQ Basin (including Interc	10,735	-	[1]
Paint Pipe and Equipment - BW EQ Basin	15,000	15,000	
SUBMITTAL SLUDGE COLLECTORS	10,937		
REC ON SITE SLUDGE COLLECTORS	98,430		
SUBMERSIBLE PUMPS	190,899	102,792	[2]
WATER CONTROL GATES	63,560		
Totals	2,769,698	2,415,625	
Cost per System	2,769,698	2,415,625	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Factored by 0.54 to reflect that 7 of 13 submersible pumps for the project are associated with this facility.

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project
	Job No.: 693-20-16-01 Date: 3/28/2017
	Calc. By: W. Sandelin Chkd. By: A. Smith
	Subject: Backwash EQ Basin Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		2,551,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		2,838,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	969,000
10	1,468,000
15	1,872,000
20	2,225,000
25	2,544,000
30	2,838,000
35	3,113,000
40	3,373,000
45	3,620,000

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: Gravity Thickeners Cost Derivation		

COST ANALYSIS

Develop base cost for gravity thickeners from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Gravity Thickener Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Ex/Backfill to Bottom of Foundation Slabs	99,209	99,209	
Backfill to Sub-Grade - Gravity Thickeners	33,069	33,069	
Form/Rebar/Pour - Pedestal Sprt Base - Gravity Thickeners #1	28,756	28,756	
Form/Rebar/Pour - Pedestal Sprt Base - Gravity Thickeners #2	28,756	28,756	
Form/Rebar/Pour - Foundation Slab - Gravity Thickener #1	194,835	194,835	
Form/Rebar/Pour - Foundation Slab - Gravity Thickener #2	194,835	194,835	
Form/Rebar/Pour - Tank Walls - Gravity Thickener #1	200,560	200,560	
Shore for Launder Construction - Gravity Thickener #1	25,100	25,100	
Form/Rebar/Pour - Launder Floor - Gravity Thickener #1	35,000	35,000	
Form/Rebar/Pour - Launder Walls - Gravity Thickener #1	26,268	26,268	
Water Leak Test - Gravity Thickeners - Gravity Thickener #1	3,494	3,494	
Form/Rear/Pour - Tank Walls - Gravity Thickener #2	200,560	200,560	
Shore for Launder Construction - Gravity Thickener #2	25,100	25,100	
Form/Rebar/Pour - Launder Floor - Gravity Thickener #2	35,000	35,000	
Form/Rebar/Pour - Launder Walls - Gravity Thickener #2	26,268	26,268	
Water Leak Test - Gravity Thickeners - Gravity Thickener #2	3,495	3,495	
Form/Rebar/Pour - TS Pump & Misc Slabs and Equip Pedestals - Gravity	21,567	21,567	
Erect Center Walkways/Handrails- Gravity Thickeners	90,323	90,323	
Erect Stairs/Platforms/Handrails - Gravtity Thickeners	35,945	35,945	
Install Underslab Piping - Gravity Thickeners	43,134	43,134	
Install Gravity Thickener Mechanisms	90,000	90,000	
Install A/G Piping & Instr on Tanks - Gravity Thickeners	25,000	25,000	
Install Mechanism Drives - Gravity Thickeners	20,000	20,000	
Install TS Pumps - Gravity Thickeners	34,103	34,103	
Install A/G Pipe, Pipe Supports & Instr at TS Pumps - Gravity Thickeners	109,725	109,725	
Test/Flush Piping Systems - Gravity Thickener Facility	15,000	15,000	
Install Underslab Elec - TS Pump Slab - Gravity Thickeners	14,348	-	[1]
Rough-in A/G Elec - Entire Facility - Gravity Thickeners	18,261	-	[1]
Fitup Stands - Entire facility - Gravity Thickeners	11,087	-	[1]
Pull/Term/Test - Electrical & I&C - Gravity Thickeners (including interconn	17,857	-	[1]
Vendor Inspection and Certification - Gravity Thickeners	10,000	10,000	
Paint Pipe and Equipment - Gravity Thickeners	30,000	30,000	
SUBMITTAL TS SCRAPER MECHANISMS	42,622	42,622	
REC ON SITE TS SCRAPER MECHANISMS	383,596	383,596	
ROTARY LOBE PUMPS	45,091	45,091	
Totals	2,217,964	2,156,411	
Cost per System	2,217,964	2,156,411	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

WEST YOST ASSOCIATES Consulting Engineers

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Gravity Thickeners Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		2,277,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		2,533,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	864,000
10	1,310,000
15	1,671,000
20	1,986,000
25	2,271,000
30	2,533,000
35	2,778,000
40	3,010,000
45	3,231,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01 — Date: 3/28/2017
Calc. By:	W. Sandelin — Chkd. By: A. Smith
Subject:	Drying Beds Cost Derivation

COST ANALYSIS

Develop base cost for drying beds from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Drying Beds Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Excavate one-third of Drying Bed 2	180,000	180,000	
Excavate Remaining two-thirds of Bed 2	370,000	370,000	
Excavate/Build up Berm at Drying Bed 1 and Build up Berm at Dry	660,661	660,661	
Excavate for Decant Structures in Beds 1 & 2	28,756	28,756	
Excavate/Build up Berms at Existing Drying Beds - 3 & 4	403,552	403,552	
Excavate for - Decant Structures in Beds 3,4	28,756	28,756	
Finish Berms / Final Backfill to Subgrade at Facility	64,701	64,701	
Form/Rebar/Pour Fdn Slabs for Decant Struct's & Pump Stations -	12,878	12,878	
Form/Rebar/Pour Fdn Slabs for Decant Struct's & Pump Stations -	12,878	12,878	
Form/Rebar/Pour Walls for Decant Struct's & Pump Stations - Beds	61,741	61,741	
Form/Rebar/Pour Walls for Decant Struct's & Pump Stations - Beds	61,740	61,740	
Form/Rebar/Pour Fdn Slab for entry - Decant Struct's and Pump St	11,000	11,000	
Form/Rebar/Pour Fdn Slab for Entry - Decant Struct's and Pump S	11,000	11,000	
Form/Rebar/Pour Wing Walls for Decant Struct's and Pump Stations	33,000	33,000	
Form/Rebar/Pour Wing Walls for Decant Struct's and Pump Stations	33,000	33,000	
Water Leak Test - Decant Struct's - Beds 1,2	1,798	1,798	
Water Leak Test - Decant Struct's - Beds 3,4	1,797	1,797	
Erect Grating & Handrail - Decant Struct's - Beds 1,2 3,4	71,890	71,890	
Install Slide Gates at Structures - Beds 1,2	12,500	12,500	
Install Slide Gates at Structures - Beds 3,4	12,500	12,500	
Install Sub. Pumps in Beds 1 Pump Structure	12,662	12,662	
Install Sub. Pumps in Beds 3 Pump Structure	12,661	12,661	
Install DSL and TSL Piping at Structures - Beds 1,2	45,323	45,323	
Install DSL and TSL Piping at Structures - Beds 3,4	45,323	45,323	
Test/Flush DSL and TSL Piping - Beds 1,2	5,000	5,000	
Test/Flush DSL and TSL Piping - Beds 3,4	5,000	5,000	
Install / Fitup Equp & I&C Stands - Structures - Beds 1,2	12,391	-	[1]
Install / Fitup Equip & I&C Stands - Structures - Beds ,3,4	12,391	-	[1]
Install Direct Bury from Structures back to Plant -Tie-in and PG	165,652	-	[1]
Pull / Term Elect & I&C circuits - Beds 1,2,3,4	104,243	-	[1]
SUBMERSIBLE PUMPS	190,899	58,738	[2]
WATER CONTROL GATES	63,560	31,780	[3]
Totals	2,749,253	2,290,635	
Cost per System	2,749,253	2,290,635	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Factored by 0.31 to reflect that 4 of 13 submersible pumps for the project are associated with this facility.
3. Factored by 0.5 to reflect that 4 of 8 control gates for the project are associated with this facility.

Project:	SRWA Surface Water Supply Project	
Job No.:	693-20-16-01	Date: 3/28/2017
Calc. By:	W. Sandelin	Chkd. By: A. Smith
Subject:	Drying Beds Cost Derivation	

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		2,419,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		2,691,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	918,000
10	1,392,000
15	1,775,000
20	2,110,000
25	2,412,000
30	2,691,000
35	2,952,000
40	3,198,000
45	3,432,000

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Chemical Facility Cost Derivation

COST ANALYSIS

Develop base cost for chemical facility from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Chermical Facility at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Ex/Backfill Bottom of Slab (lower and Upper slabs)	70,204	70,204	
Re-Grade and Prep for SOG Level - Chem Facility	45,000	45,000	
Backfill and Grading at Perimeter to sub- grade - Chem Facility	14,378	14,378	
Form / Rebar / Pour - Lower Slabs, w/ Fdns for Pre-Engr'd Metal Bldg - Ch	183,435	183,435	
Form / Rebar / Pour - Pedestal for Sodium Bisulfite Tank.	15,512	15,512	
Form / Rebar / Pour - Containment wallls - Chem Facility	82,560	82,560	
Form / Rebar / Pour - SOG Slab w/Fdns for Pre-Engr'd Metal Bldg- Chem	183,434	183,434	
Form / Rebar / Pour - Remaining Tank Pedestals Inside Bldg- Chem Facil	50,000	50,000	
Form / Rebar / Pour - Tank Pedestals Outside Bldg - Chem Facility	50,000	50,000	
Form / Rebar / Pour - HVAC Unit Foundations	10,000	10,000	
Install Stairways and Handrails (FRP & Aluminum))	179,725	179,725	
Erect Rigid-Frame Steel, Girts and Purlins - Chem Facility	234,426	234,426	
Erect Insulated Metal Panels - Roof/Siding - Chem Facility	190,000	190,000	
Erect Purlins and Insulated Roof Panels above SB Tank - Chem Facility	20,000	20,000	
nstall Masonry Walls - Chem Facility	64,701	64,701	
Install All Doors - Chem Facillity	64,701	64,701	
Install Underslab Pipe - Lower Slabs - Chem Facility	50,000	50,000	
Install In-slab Pipe - Lower Slabs - Chem Facility	5,000	5,000	
Install Underslab Pipe - SOG Level - Chem Facility	33,457	33,457	
Install In-slab Pipe - SOG Level - Chem Facility	5,000	5,000	
Install Chem Storage Tanks (Inside Bldg (SHC,SH,NIP) - Chem Facility	85,000	85,000	
Install Chem Storage Tank (Inside Bldg (SB) - Chem Facility	15,000	15,000	
Install Chem Storage Tanks (Outside Bldg (FE, Phos Acid) - Chem Facility	100,000	100,000	
Install High Elev - Process/Chem Pipe - Chem Facility	500,290	500,290	
Install Chemical Pump Skids - Chem Facility	181,340	181,340	
Install PBU Units - Chem Facilty	50,000	50,000	
Install Hookup Piping - Chem Facililty	65,000	65,000	
Test/Flush Piping - Chem Facility	75,500	75,500	
Install High Elev - Fire Protection Pipe - Chem Facility	150,000	150,000	
Install Fire Protection Riser and Hookup - Chem Facility	115,000	115,000	
Hydro-Test Fire Protection Piping - Chem Facility	13,230	13,230	
Install High Elev - HVAC Ductwork - Chem Facility	60,000	60,000	
Install HVAC Equipment - Chem Facility	140,000	140,000	
Install HVAC Ductwork - Equp to Duct - Chem Facility	60,000	60,000	
Install HVAC Controls	20,371	20,371	
Install Underslab Electrical - Lower Slabs - Chem Facililty	21,739	-	[1]
Install In-Slab Electrical - Lower Slabs - Chem Facility	24,247	-	[1]
Install Underslab Electrical - SOG Level - Chem Facility	81,000	-	[1]
Install In-Slab and Above Ground Electtrical - SOG Level - Chem Facility	94,000	-	[1]
Install High Elev - Electrical & I&C Rough-in - Chem Facility	60,868	-	[1]
Install Electrical & I&C Equipment - Electrical Room - Chem Facility	254,564	-	[1]
Pull / Term from Electrical Room to XFMR - Chem Facility	20,000	-	[1]
Install and Fitup Electrical & I&C Stands - Chem Facility	200,000	-	[1]
Pull / Term / Test - Electrical & I&C Circuits - Chem Facility (including inte	121,652	-	[1]
Energize Electric and Test - Chem Facility	16,174	-	[1]
Paint Masonry Walls - Chem Facility	25,000	25,000	
Paint Pipe and Equipment	50,000	50,000	
Install Special Coatings - Sodium Bisulfite Tank Room - Inside Chem Bldg	25,000	25,000	
Install Special Coatings - Containment Areas - Outside Chem Bldg	75,000	75,000	
FRP CHEMICAL STORAGE TANKS	643,717	643,717	
CHEMICAL METERING PUMPS	587,761	587,761	
PBUs	132,727	132,727	
Totals	5,616,000	4,721,000	
Cost per System	5,616,000	4,721,000	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

Project:	SRWA Surface Water Supply Project
Job No.:	693-20-16-01
Date:	3/28/2017
Calc. By:	W. Sandelin
Chkd. By:	A. Smith
Subject:	Chemical Facility Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		4,985,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		5,546,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	1,893,000
10	2,869,000
15	3,659,000
20	4,348,000
25	4,971,000
30	5,546,000
35	6,083,000
40	6,591,000
45	7,074,000

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project
	Job No.: 693-20-16-01 Date: 3/28/2017
	Calc. By: W. Sandelin Chkd. By: A. Smith
	Subject: Operations Bldg Cost Derivation

COST ANALYSIS

Develop base cost for operations building from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Operations Building at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Ex/Backfill to Sub Grade and for Cut Wall	35,947	35,947	
Encase Plumbing and Backfill	10,000	10,000	
Backfill over Elec/Plmg In-Slab & Perimeter of Bldg	76,268	76,268	
Final Backfill to Subgrade around Building	14,378	14,378	
Install Cut-off Wall	10,000	10,000	
FRP 3 Column Foundations	31,550	31,550	
FRP Beams and Remaining Footings	100,000	100,000	
FRP Building Slab	193,457	193,457	
FRP HVAC Equipment Foundations	7,189	7,189	
Install Masonry Walls	295,000	295,000	
Install Structural Roof Steel and Decking	85,000	85,000	
Install Roof Insulation and Standing Seam Roof	140,000	140,000	
Install Exterior Windows and Doors	116,268	116,268	
Install Metal Canopies, Trellis, Flashing and other Misc Metals	97,010	97,010	
Install Under Foundation Plumbing - Operations Bldg	5,000	5,000	
Install Underslab Plumbing	90,000	90,000	
Install In-Slab Plumbing	10,000	10,000	
Install Plumbing Roof Penetrations	5,000	5,000	
Install Above Ceiling Plumbing and Fire Protection - Rough-in	200,000	200,000	
Install In-Wall Plumbing - Rough-in	303,900	303,900	
Install Plumbing Fixtrues	100,000	100,000	
Install Utility Room Equipment and Hook-up	25,000	25,000	
Install Fire Protection Riser and Hookup	24,701	24,701	
Install Fire Sprinklers into Ceiling Grid System	20,000	20,000	
Install Above Ceiling HVAC Ductwork - Rough-in	170,000	170,000	
Hook-up Above Ceiling HVAC Equip - Elec and Plumbing	5,000	5,000	
Install HVAC Unit - Outside	287,560	287,560	
Install HVAC Ductwork for AHU Hookup	30,000	30,000	
Install HVAC Diffusers into Grid system	25,000	25,000	
Startup and Commission HVAC	14,426	14,426	
Install Under Foundation Electrical	7,512	-	[1]
Install Underslab Electrical and Grounding Ring	30,048	-	[1]
Install In-Slab Electrical	25,048	-	[1]
Install all Electrical Roof Penetrations	9,358	-	[1]
Rough-in Electrical Systems Conduit - Above Ceiling	46,785	-	[1]
ough-in Electrical Systems Conduit - In-Wall	62,396	-	[1]
Install Electrical Panels and Equipment	97,826	-	[1]
Install I & C Panels	13,043	-	[1]
Install Fire Alarm Panel and System	45,652	-	[1]
Install Security Panel and System	117,391	-	[1]
Pull / Term / Test Electrical Systems - within Building	82,956	-	[1]
Install Light Fixtures into Grid System - Hookup	71,739	-	[1]
Energize and Test Electrical Room.	16,174	-	[1]
Install Laboratory Cabinets, Shelves and Counters	101,050	101,050	
Install Laboratory Equipment	18,707	18,707	
Install Interior Wall/Ceiling Framing and Opening Frames	215,670	215,670	
Install Sheetrock and Water Board	143,780	143,780	
Install Quarry Tile - Bathrooms/Locker Rooms	100,646	100,646	
Install Cabinetry (not including LAB)	35,945	35,945	
Paint Interior Walls and Ceilings	57,512	57,512	
Install Restroom/Shower/Locker Room Accessories	35,945	35,945	
Install Ceiling Grid - Rough-in	20,000	20,000	
Install Ceiling Tiles	15,945	15,945	
Install Floor Finishes	43,134	43,134	
Interior Doors and Glazing	57,512	57,512	
Final Finishes and Touch-up	21,567	21,567	
Furnish and Install Office Furniture & Cubicles	23,951	23,951	
FURNITURE	50,000	50,000	
Totals	4,094,946	3,469,018	
Cost per System	4,094,946	3,469,018	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

WEST YOST ASSOCIATES Consulting Engineers

Project:	SRWA Surface Water Supply Project		
Job No.:	693-20-16-01	Date:	3/28/2017
Calc. By:	W. Sandelin	Chkd. By:	A. Smith
Subject:	Operations Bldg Cost Derivation		

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		3,663,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		4,075,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60

Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	1,391,000
10	2,108,000
15	2,688,000
20	3,195,000
25	3,653,000
30	4,075,000
35	4,470,000
40	4,843,000
45	5,197,000

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project		
	Job No.: 693-20-16-01	Date:	3/28/2017
	Calc. By: W. Sandelin	Chkd. By:	A. Smith
	Subject: Maintenance Bldg Cost Derivation		

COST ANALYSIS

Develop base cost for maintenance building from actual costs obtained for similar work at the WDCWA Regional Water Treatment Facility.

Project Cost Breakdown for Maintenance Building at the WDCWA Regional Water Treatment Facility

Work Element	SOV	Use	Notes
Over-Exc/Backfill up to bottom of Slab	30,323	30,323	
Backfill Underslab Electricall and Plumbing	20,000	20,000	
Final Backfill around perimeter of Bldg	2,876	2,876	
FRP Building Slab with Thickened Edge (2 Pours)	115,024	115,024	
FRP Slabs for HVAC Equipment	7,189	7,189	
Erect Rigid Steel Frame, Girts and Purlins	101,670	101,670	
Erect Insulated Metal Panels - Roof/Siding	104,000	104,000	
Install Exterior Doors and Glazing	10,000	10,000	
Install Underslab Plumbing - Maint Bldg	16,567	16,567	
Install In-Slab Plumbing	5,000	5,000	
Rough-in Plumbing Above Ceiling Height	143,780	143,780	
Rough-in Plumbing in Walls	147,560	147,560	
Install Plumbing Fixtures	140,000	140,000	
Install HVAC Equipment	107,835	107,835	
Install Ductwork Above typical Suspended Ceiling H	61,890	61,890	
Install Remaining Ductwork	10,000	10,000	
Install Diffusers and Balance	10,784	10,784	
Install Underslab Electrical and Grounding Ring	26,500	-	[1]
Install In-slab Electrical	10,022	-	[1]
Install Electrical Above typical Suspended Ceiling	48,260	-	[1]
Install Electrical at Interior Walls	48,260	-	[1]
Install Electrical Panels.	16,200	-	[1]
Pull / Term / Test Electrical - within Bldg	56,870	-	[1]
Install Building Lights and Hook-up	19,565	-	[1]
Energize Electrical and Test - Maintenance Bldg	16,174	-	[1]
Frame Interior Divider Walls	79,079	79,079	
Install Sheetrock and Waterboard	50,323	50,323	
Paint Interior Walls	28,756	28,756	
Install Quarry Tile in Bathroom / Shower	43,134	43,134	
Install Floor Sealer	35,945	35,945	
Install Ceiling Grid	21,567	21,567	
Install Restroom / Shower Room Accessories	14,378	14,378	
Interior Doors and Glazing	43,134	43,134	
Totals	1,592,665	1,350,814	
Cost per System	1,592,665	1,350,814	

NOTES

1. Do not include in component base. Use overall multiplier for electrical costs.
2. Not used.

WEST YOST ASSOCIATES Consulting Engineers	Project: SRWA Surface Water Supply Project
	Job No.: 693-20-16-01 Date: 3/28/2017
	Calc. By: W. Sandelin Chkd. By: A. Smith
	Subject: Maintenance Bldg Cost Derivation

Adjustments

a. Inflation to Current Dollars

ENR at Construction Midpoint	9972	(Jan 2015)	
Most Recent Available ENR	10530	(Dec 2016)	
ENR Ratio =	1.056		1,427,000

b. Inflation to Future Dollars

Months to SRWA Construction Midpoint	42	(Jun 2020)	
Years to SRWA Construction Midpoint	3.5		
Most Recent Year/Year Inflation	3.1%	(Dec 2015 to Dec 2016)	
Inflation to SRWA Construction Mid-point	1.11		1,588,000

c. Capacity Adjustment

Costs for different sized systems can be estimated by multiplying the base cost by the ratio of their respective treatment capacities raised to a power factor. Power factor derived from AWWA and ASCE, Water Treatment Plant Design 26.6

Power factor = 0.60
Installed capacity = 30 (mgd)

Capacity Increments	Unit Component Cost, $
5	542,000
10	821,000
15	1,048,000
20	1,245,000
25	1,423,000
30	1,588,000
35	1,742,000
40	1,887,000
45	2,025,000