TECHNICAL MEMORANDUM

Stanislaus Regional Water Authority Water Supply Project
Treatment Process Alternatives

Draft Date: August 12, 2016
Final Date: **September 6, 2016**

To: Stanislaus Regional Water Authority (SRWA)

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Subject: Treatment Process Alternatives, TM 1, Part 1

1 - 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 (Cities). As part of the process of identifying the preferred treatment train for SRWA's new WTP, two workshops were scheduled and two Technical Memoranda (TM) were requested to discuss viable treatment options. The first workshop was held June 30, 2016 and included a robust discussion of treatment technologies and processes. The second workshop will be held after the list of candidate treatment processes has been narrowed to one or two preferred trains and feasibility level cost estimates have been developed.

The original intent of TM 1 was to provide descriptions and comparisons of potential treatment train alternatives—incorporating results from the pilot infiltration gallery testing, disinfection byproduct (DBP) modeling and other (optional) bench scale tests—to help screen treatment alternatives and narrow the field of candidate processes. After initial review of historical water quality data, identification of the SRWA's Technical Advisory Committee (TAC) performance goals for the WTP, and initial discussions with the Division of Drinking Water (DDW), it seemed prudent to prepare this TM 1 in two parts. TM 1, Part 1 (this document) will provide a description of the candidate treatment processes, a summary of the June 30, 2016 workshop, and will identify information gaps that can and/or should be addressed prior to completing the evaluation of candidate treatment processes. TM 1, Part 1 is organized as follows:

- Introduction (this section)
- Driver for Treatment Process Evaluation
- Treatment Process Alternatives
- Summary of Treatment Alternatives
- Information Gaps
- Decision Points Necessary to Refine Field of Available Alternatives
- Recommendations and Next Steps

TM 1, Part 2 will be an update of TM 1, Part 1 and will include results from bench-scale and/or pilot-scale tests and all additional information gathered to fill the gaps and allow refinement of the list of candidate alternatives. Depending on guidance from the TAC, it may be possible to narrow the field of alternatives prior to filling all the information gaps. Some of the additional information needs may be more for the purpose of defining design criteria and estimating operation and maintenance (O&M) costs than for process train selection. The second TM will add feasibility-level estimates of capital and O&M costs for the preferred treatment train(s).

2 - DRIVERS FOR TREATMENT PROCESS EVALUATION

This section provides an overview of the drivers expected to shape the TAC's evaluation of treatment process alternatives. The following subtopics are discussed below:

- Potential Contamination Sources
- Source Water Quality
- Treatment Performance Goals
- DDW Input

2.1 Potential Contamination Sources

Several potential sources of contamination were identified in the Turlock Irrigation District's (TID's) Watershed Sanitary Survey (WSS) of the Lower Tuolumne River and Turlock Lake (Brown and Caldwell, 2008), and online visual searches using Google Earth (US Dept. of State Geographer © 2016 Google) between La Grange Dam and the infiltration gallery. The following are the main potential contamination sources, with locations indicated in Figure 1:

- City of Waterford Wastewater Treatment Plant (WWTP). This is the only municipal WWTP in this reach of the River that could impact water quality at the infiltration gallery site; the remainder of the study area uses septic systems for wastewater disposal. The effluent from the storage ponds is pumped across the Tuolumne River (South side), to four drying beds/percolation basins. As of 2006, the facility met existing requirements of the Central Valley Regional Water Quality Control Board, but upgrades were needed to meet secondary treatment standards and future discharge standards (City of Waterford, 2006).

- Dairy, Poultry and Ranching Operations[1]. There are a number of dairy, poultry, and ranching operations located near the bank of the River. Potential contaminants from these operations include microbial pathogens (e.g., coliforms, *E. coli*, etc.), nitrogen compounds (e.g., ammonia, nitrate) that may potentially promote algae growth in stagnant reaches, and antibiotics and hormones that may be present at the animal operations.

- Geer Road Landfill. The Geer Road Landfill, which is closed now, is located directly across the river from the site of the infiltration gallery. As discussed in the 2008 TID WSS, although there are no active solid waste or hazardous waste disposal facilities within the study area, this closed landfill continues to be regulated by RWQCB waste discharge requirements during its closure (Brown and Caldwell, 2008). Results from the Second Semiannual and Annual 2015 Detection, Evaluation and Corrective Action Monitoring Report do not indicate degradation of the Tuolumne River from the landfill site (Tetra Tech BAS, January 2016).

- Recreational Areas: There are several recreational areas nearby and in the upper reaches of the Lower Tuolumne watershed, including La Grange Off-Highway Vehicle Use, Basso Bridge River Access, Turlock Lake State Recreational Area, and Fox Grove County Park.

- Pesticide and Herbicide Application to Agricultural Areas[1]: Given the large percentage of the watershed dedicated to agriculture, stormwater and irrigation runoff from these areas is a known source of contamination to the River. The Lower Tuolumne River, downstream of Don Pedro Reservoir, is listed as an impaired water body under USEPA Clean Water Act Section 303(d) (California State Water Resources Control Board, 2010). This designation is discussed in more detail in Section 2.2.

[1] According to the United States Department of Agriculture (USDA, 2012), Stanislaus County ranks 7th among California's 58 counties in total value of agricultural products sold, 4th in value of livestock, poultry, and their products, and 3rd in value of sales for both poultry and eggs, as well as milk from cows (4th overall in the United States). In addition to livestock, the top three crops, in terms of land area, grown locally include almonds (3rd in the state and U.S.), forage land (hay and haylage, grass silage, and greenchop; 10th in the state and 84th in the U.S.), and corn for silage (3rd in the state and 4th in the U.S.). In terms of land use, approximately 50% of the county's farmland is pastureland and 44% is cropland.

Figure 1. Potential Sources of Contamination in Project Vicinity

2.2 Source Water Quality

As part of the source water characterization process, historical water quality data collected on the Tuolumne River at locations between Don Pedro Reservoir and the confluence of Dry Creek at Modesto were reviewed. The sampling locations and monitoring agencies for the historical data have been presented elsewhere, in the Source Water Quality Assessment TM (Trussell Technologies, September 2016) and the Draft Source Water Characterization Sampling Plan for the SRWA Surface Water Supply Project (Trussell Technologies, July 2016) (Sampling Plan), and are not repeated here. Key points about water quality parameters that are drivers for process train selection are summarized below.

Turbidity. While limited to the period between May 2006 and April 2008, the historical turbidity data collected at the infiltration gallery site, are low—consistently less than 10 NTU. A plot of these turbidity data from the infiltration gallery location along with data from two upstream locations are shown in Figure 2. There is no apparent seasonal fluctuation and it is difficult to tell if or how much the turbidity increases in response to storm events or releases from Don Pedro Reservoir, but the amount of data is limited. Additionally, filtration through the rock and gravel media above the infiltration gallery is expected to reduce storm related turbidity spikes, should they occur in the river. SRWA may decide to test a pilot filter column containing media representative of the cover over the infiltration gallery to evaluate changes in turbidity under ambient and simulated high turbidity conditions. Refer to Section 5 of this TM for further discussion of optional pilot- and bench-scale tests.

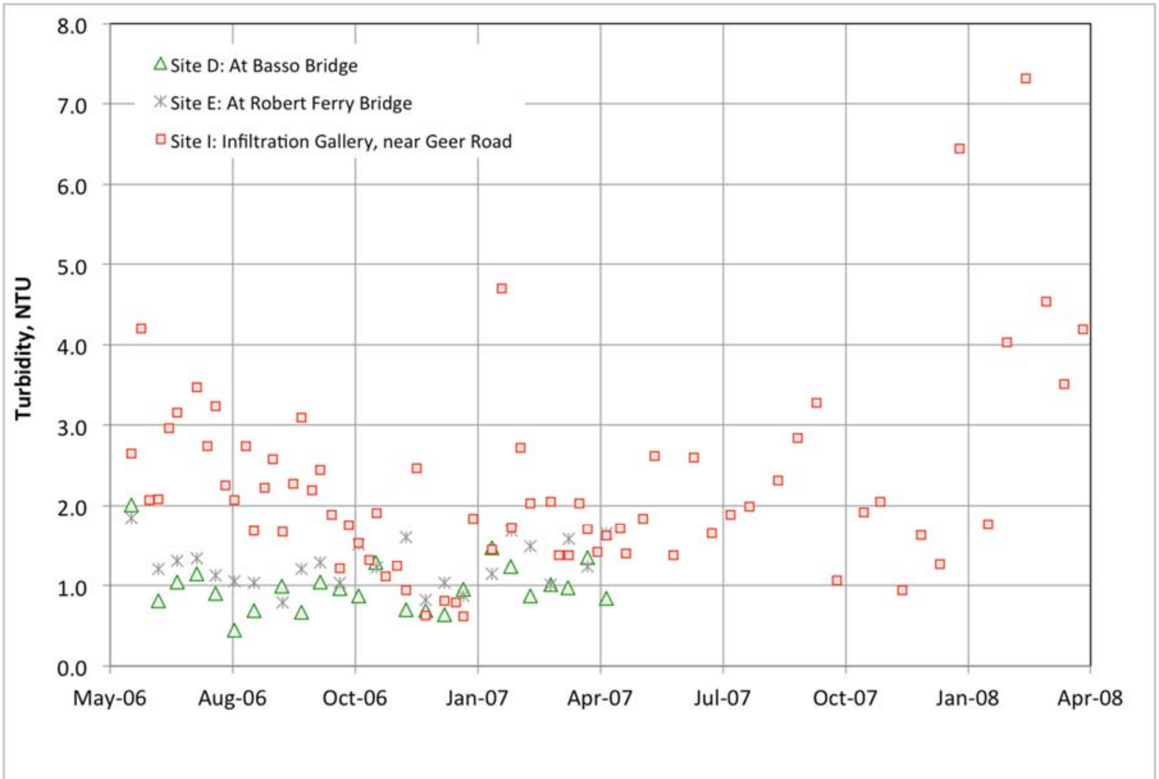

Figure 2. Turbidity of the Tuolumne River Sites D (Basso Bridge), E (Robert Ferry Bridge), and I (Infiltration Gallery) Based on Data from TID's 2008 Watershed Sanitary Survey.

Total Organic Carbon (TOC). Based on historical data, the average TOC concentration at the infiltration gallery is somewhat higher than at upstream and downstream locations. The average concentration at the infiltration gallery was 3.3 mg/L (ranging from 1.4 mg/L – 6.5 mg/L) versus 2.9 mg/L at Robert Ferry Bridge approximately 14 river miles upstream, and 1.7 mg/L at Mitchell Road downstream near Modesto. The concentrations reported at the infiltration gallery location are high enough that DBP formation will be a concern with free chlorine unless TOC reduction is achieved during treatment. According to the 2008 TID pilot report, total trihalomethane (TTHM) formation in samples of raw water (using a 3 mg/L chlorine dose) was close to 100 micrograms per liter (µg/L), and well above the regulatory limit of 80 µg/L.

TOC concentrations reported at the infiltration gallery location seem uncharacteristically high and variable, as shown in Figures 3 and 4. In order to obtain a better understanding of the TOC levels at this location, and potentially to characterize seasonal and storm related influences, TOC will be measured monthly as part of the source water monitoring program, expected to start during the fall of 2016.

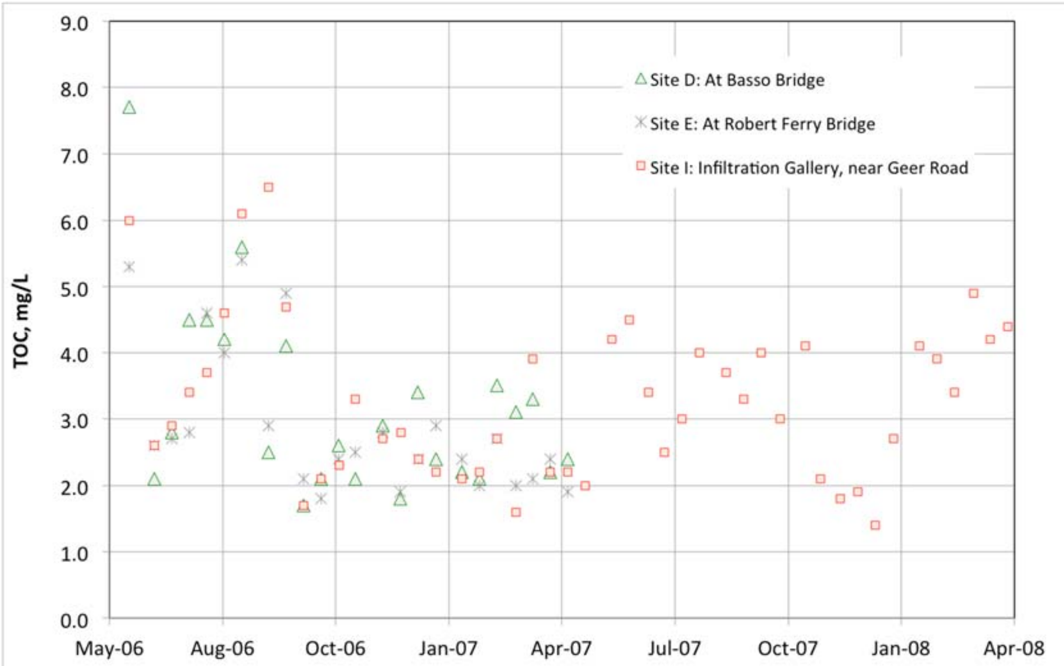

Figure 3. TOC Concentrations of the Tuolumne River at Sites Between La Grange Dam and the Infiltration Gallery Location

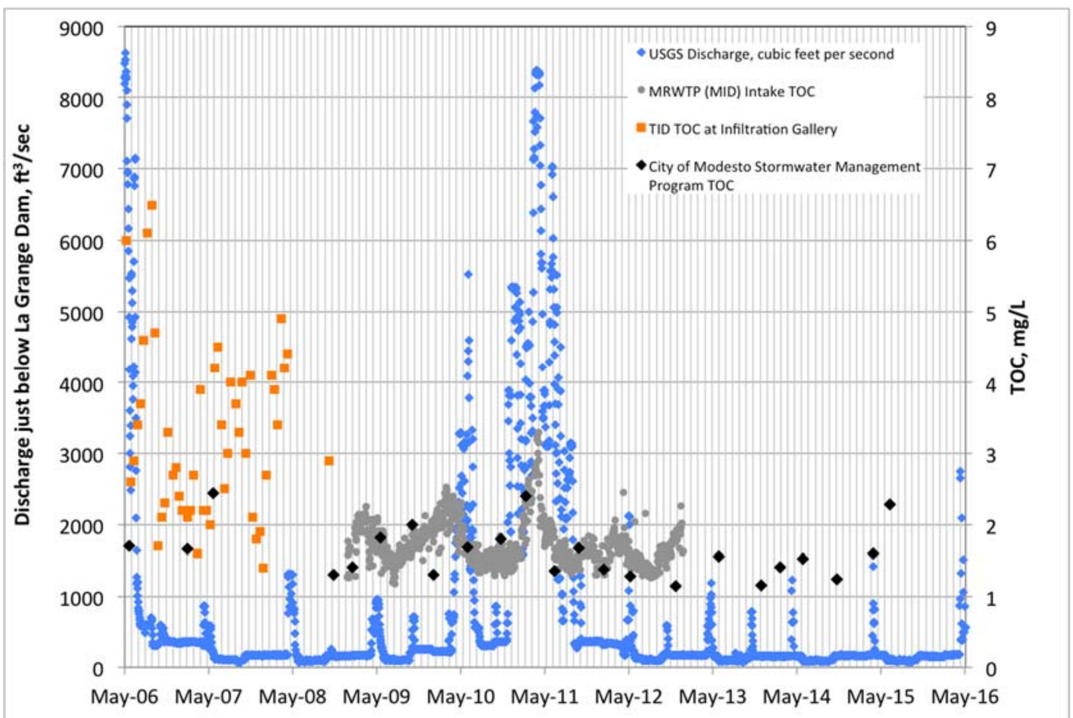

Figure 4. TOC of Modesto Reservoir, the Tuolumne River at the Infiltration Gallery Location, and Downstream of Modesto near Mitchell Road as a Function of River Flows

Ammonia, Nitrite, and Nitrate. The nitrate levels measured in the study area reflect the presence of upstream cattle and poultry facilities, and possibly the City of Waterford's WWTP percolation ponds. Ammonia (NH_3) and nitrite (NO_2) concentrations at the infiltration gallery location were below detection, but nitrate (NO_3) concentrations were measured between 1.3 mg/L and 3.8 mg/L as NO_3 (Figure 9). Nitrate concentrations at the upstream Basso Bridge and Roberts Ferry Bridge sites were below the detection level. These nitrate concentrations measured at the infiltration gallery location are not a regulatory or health concern and nowhere near the primary maximum contaminant level (pMCL) of 45 mg/L as NO_3. They are, however, indicative of the potential for biological and algae growth in stagnant areas of the river, along with the potential for taste and odor occurrences often associated with algal blooms. During a June 29, 2016 meeting with SRWA, DDW noted recent increased impacts to water quality due to algae in locations where algae have not been previously observed. Additionally, MID offered that ozone was included in their WTP treatment train to provide treatment for tastes and odors (T&O).

Pesticides and Other Synthetic Organic Chemicals (SOCs). The Lower Tuolumne River Watershed (downstream of Don Pedro Reservoir) is a large agricultural area with several pesticides applied to crops throughout the year (as spray or fumigants) and is listed as an impaired water body under USEPA Clean Water Act Section 303(d) (California State Water Resources Control Board, 2010). This designation is largely due to the presence of several pesticides, including chlopyrifos, diazinon, Group A pesticides (aldrin, dieldrin, chlordane, endrin, heptachlor, heptachlor epoxide, hexachlorocyclohexane - including lindane, endosulfan, and toxaphene), as well as pollution from mercury, warm water, and an unknown toxicity. As of 2014, total maximum daily loads (TMDLs) were established by the California Regional Water Quality Control Board Central Valley Region to limit diazinon and chlorpyrifos in the San Joaquin River and Sacramento River basins.

There are only limited historical data for pesticides in the Tuolumne River, with the most recent being collected between 2005 and 2008. The pesticides measured in the river between 1995 and 2008 are shown in Table 1. The pesticides with an enforceable regulatory limit are shown in blue font, and those measured above the limit are shown in red font. In addition, the California Department of Pesticide Regulation's (CDPR's) Pesticides Use Reporting (PUR) database indicates there were 19 pesticides applied in the Lower Tuolumne River Watershed at a high application rate—greater than 5,000 lbs/year or greater than 10,000 acres per year. So, it is a distinct possibility that the source water for the SRWA's WTP will contain low levels of pesticides or other organic contaminants.

There are also several cattle feedlots and poultry operations along the river in the Lower Tuolumne River Watershed, where hormones and/or antibiotics may be used and may be potential contaminants [this is an assumption and not based on monitoring data].

Table 1. Historical Dataset of Pesticides Measured in the Tuolumne River

Location	Year	Pesticides Detected	Con-centration (µg/L)	Regulatory List	MCL/NL (µg/L)
Between La Grange Dam and Modesto	1995	Diazinon Napropamide Simazine Chlorpyrifos (Dursban) Chlorthal-dimethyl Trifluralin	0.003 – 0.04 0.024 0.069 – 0.22 0.007 – 0.021 0.003 – 0.013 0.007	- NL - None - Primary MCL - UCMR4 - EPA HA - EPA HA	1.2 -- 4 -- -- --
Waterford LM Spill; Regional Board Irrigation Lands Monitoring site code: 535MIDWFS	2005 - 2008	Diuron Glyphosate Isoxaben Norflurazon Oryzalin Prodiamine	1.2 – 860 8.1 – 20 5.5 – 9.7 0.084 – 1.4 24 – 170 0.47 – 1.3	- EPA HA; CCL3 - Primary MCL - None - None - None - None	-- 700 -- -- -- --
Between La Grange Dam and Modesto	?	Chlorpyrifos (Dursban) Chlorthal-dimethyl Diazinon Malathion Metolachlor Napropamide Simazine	0.04 – 0.032 0.002 – 0.012 0.003 – 2.9 0.031 – 0.16 0.003 – 0.02 0.017 – 0.059 0.038 – 2.2	- UCMR4 - EPA HA - NL - aNL - UCMR2 - None - Primary MCL	-- -- 1.2 160 -- -- 4
Fox Grove County Park	2007-2008	2,4-Dichlorophenylacetic acid 3,4-Dinitrotoluene Bis(2-Ethylhexyl) Phthalate EPN (ENT) N-Nitrosopyrrolidine Tert-Butyl alcohol (TBA)	0.634 – 3.6 12.2 – 24.2 3.7 1.26 – 3.01 0.009 150	- None - None - Primary MCL - None - None - NL	-- -- 4 -- -- 12

Total Coliform and *E. coli*. The median total coliform concentration at the infiltration gallery location (between May 2006 and October 2008) was 130 MPN/100mL, based on 73 data points. Higher total coliform concentrations were reported both upstream and downstream, but with substantially smaller datasets. The median concentration at Waterford Road (5.7 miles upstream) was 1,733 MPN/100mL, and the median concentration at Ceres River Bluff Park (7 miles downstream) was 2,076 MPN/100mL.

The median *E. coli* concentration at the infiltration gallery location was 12.7 MPN/100mL. Higher *E. coli* levels were measured upstream and downstream of the infiltration gallery location, but again with significantly fewer data points.

The required level of disinfection will be determined from source water monitoring for *Cryptosporidium* as required by the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), and source water total coliform and *E. coli* concentrations. DDW will use the total coliform and *E. coli* data to potentially require additional *Giardia* and virus treatment. Considering that multi-barrier treatment is required under the Surface Water Treatment Rule (SWTR), the selected treatment train will include both filtration and disinfection treatment. Regardless of the specific processes selected, the combination of filtration and disinfection is expected to provide sufficient credit for pathogen removal/ inactivation. Thus, pathogen concentrations in the source water likely will not be a driver for process train selection, but will become important when design criteria for the new WTP are discussed. The SWTR regulations are discussed further in a separate TM, which provides an assessment of the project source water quality (Trussell Technologies, September 2016).

Asian Clams. Asian clams (*Corbicula fluminea*) are considered an invasive mollusk and are widespread through parts of central and southern California (Figure 5). The clams are generally found at sediment surfaces or slightly buried in sediment. Unlike other invasive mollusks, notably Quagga and zebra mussels, Asian clams do not adhere to rock or other hard surfaces (e.g., pipe walls).

Modesto Reservoir has been found to contain Asian clams and MID has routinely encountered the clams within their WTP. In the membrane filtration portion of their WTP, MID has noted the potential for damage to the membranes due to broken clam shell fragments. In the conventional treatment portion of their WTP, MID has found that ozone effectively kills the clams; no shells have been found downstream of the ozone contactor.

It is unknown at this time whether Asian clams are present in the Tuolumne River downstream of the Don Pedro Dam, or whether they are only found in Modesto Reservoir. If the clams are in the Tuolumne River, it is unknown whether the infiltration gallery intake for the WTP will be able to remove small enough sized particles to remove Asian clam larvae[2]; this question should be answered if the TAC elects to conduct a pilot filter column test. Refer to Section 5 of this TM for further discussion of optional pilot- and bench-scale tests.

Regardless, given MID's experience, the design for SRWA's WTP should consider provisions to remove clam shells from the infiltration gallery piping, raw water pump station wet well and WTP treatment basins. If membrane filtration is a selected candidate treatment alternative, adequate protection should be provided to keep the clams and shells from the membrane system.

[2] Asian clam larvae range in size from 0.25 mm to about 1.5 mm. (New York Invasive Species Information, http://www.nyis.info/?action=invasive_detail&id=52). The aperture of the existing infiltration gallery screens is 0.060 inches, or 1.524 mm.

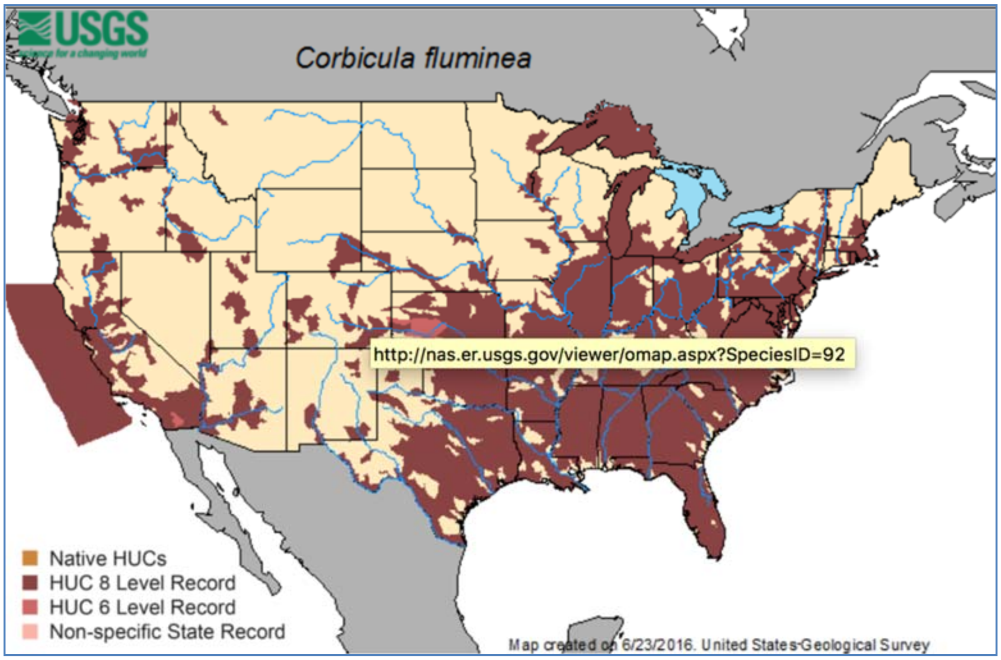

Figure 5. Occurrence of Asian Clams in the United States (USGS, http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=92)

2.3 Treatment Performance Goals

A summary of the treatment performance goals developed by the TAC for the new WTP are shown in Table 2. The discussion for this TM is focused on performance goals related to water quality, specific treatment goals, as well as narrowing the field of alternative treatment processes. The relevant performance goals from Table 2 will be integrated into the discussion of which alternative treatment processes are viable for further consideration and which should be ruled out early in the evaluation process. A more detailed listing of the treatment performance goals identified by the TAC is available in the Treatment Performance Goals TM (Trussell Technology, July 2016) prepared following the May 12, 2016 Workshop.

Table 2. Summary of SRWA Treatment Performance Goals for the New WTP

Treatment Performance Goals	TAC Importance Ranking[A]
Meet drinking water regulations with room for comfort	5
Minimize DBP formation	5
Use proven processes (Demonstration testing required for membranes)	5
Provide a reasonably robust process	5
Design for unmanned night operations	4
Consider processes that reduce aesthetic concerns (e.g., red water, tastes and odors)	5

Treatment Performance Goals	TAC Importance Ranking[A]
Treat pesticides, pharmaceuticals, and other synthetic organic chemicals (SOCs) if they appear in the raw water	3
Design for future unknown regulations	2
[A] Importance Factor: 5 = Most Important, 1 = Least Important	

2.4 DDW Input

On June 29, 2016, representatives of SRWA, West Yost Associates and Trussell Technologies met with DDW to (a) introduce the SRWA Surface Water Supply Project, (b) discuss preliminary information from a review of historical water quality and (c) present the proposed source water monitoring plan. During this meeting, DDW expressed viewpoints about preferred treatment processes. It should be noted that these viewpoints are not regulations, and the SRWA must be able to justify the "preferred" treatment train based on technical merit and cost considerations, among others, and not strictly on DDW input. As the permitting entity, however, DDW's input should be carefully considered. The following is a brief summary of key DDW input from the June 29, 2016 meeting with DDW:

- DDW discourages the use of direct filtration and stated a preference for conventional treatment.
- DDW may require higher levels of disinfection treatment for *Giardia* and viruses, depending on source water sampling results for total coliform and *E. coli*.
- If membrane filtration (MF) is a recommended treatment option, DDW recommends including pretreatment with sedimentation prior to MF.
- Disposal of the clean-in-place chemicals used for cleaning the MF membranes must be considered because DDW will not allow this waste stream to be returned to the influent for blending with the raw water.
- DDW expressed a preference for ozone for primary disinfection, due to its disinfection capabilities, reduced DBP formation (with free chlorine), and treatment for algae by-products and related T&O compounds.
- DDW discouraged the use of chloramines for secondary disinfection, due in part to the added complexity of incorporating chloramines to groundwater wells in the distribution system.
- DDW has noted recent increased negative impacts to water quality due to algae, in locations where algae has not been previously observed.
- Granular media filter re-rating to a higher rate (i.e., above the initial rate of 6 gallons per minute per square foot), based on performance demonstration, is an option for future increases in plant capacity.

3 - TREATMENT PROCESS ALTERNATIVES

This Section presents a logical progression of the various alternatives available for surface water treatment. It is the same progression presented during the June 30, 2016 Treatment Process Alternatives workshop. Each of the following subsections includes process descriptions, applicability information, advantages and disadvantages:

- Typical Treatment Steps in Surface Water Treatment
- Pretreatment
- Clarification and Filtration
- Disinfection

3.1 Typical Treatment Steps in Surface Water Treatment

A typical surface water treatment train includes the following steps:

1. **Pretreatment** for grit, sand and silt removal
2. **Clarification** using a coagulant (e.g., ferric chloride, aluminum sulfate, polyaluminum chloride) for removing particulate matter and organic carbon
3. **Filtration** for additional particulate matter and pathogen removal
4. **Primary disinfection** for pathogen inactivation (e.g., Giardia, viruses)
5. **Secondary disinfection** to maintain a disinfectant residual throughout the distribution system to prevent bacteria regrowth in distribution system piping

Examples of process options for each of the above treatment steps are shown in Figure 6, and discussed in greater detail below.

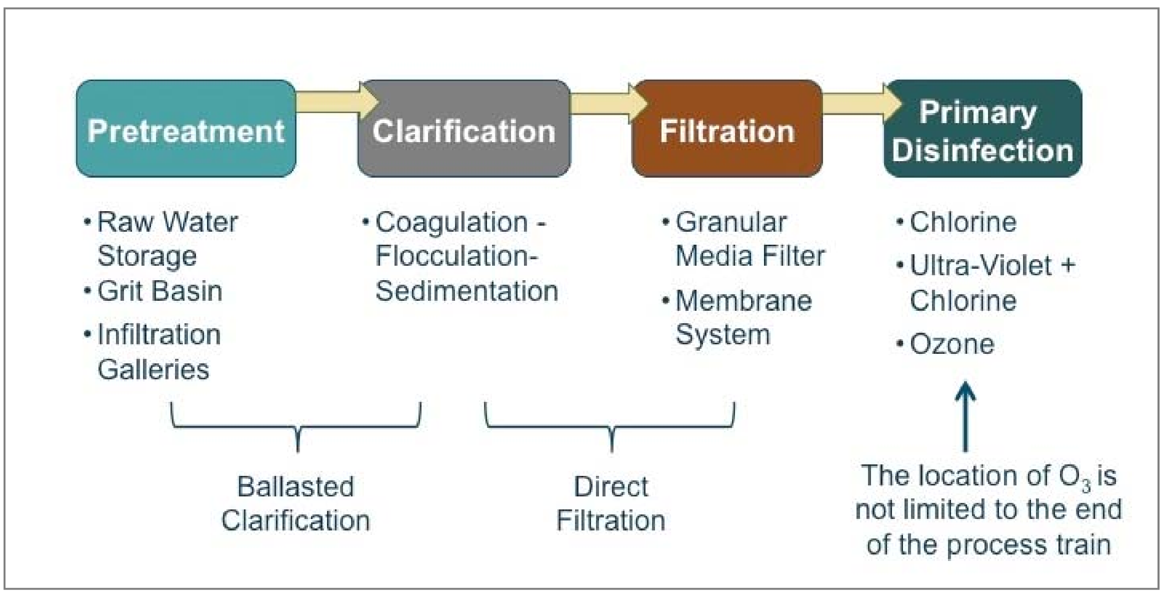

Figure 6. Typical treatment steps in surface water treatment (Note, direct filtration does not include sedimentation)

3.2 Pretreatment

The required degree of pretreatment for a given surface water depends on its average particulate concentration (measured as turbidity), the size of the suspended particles and the variability of particulate concentrations. Some waters, particularly rivers, are “flashy” and exhibit pronounced storm- and runoff-related high turbidity levels that can increase chemical demands and overload the clarification basins, potentially reducing performance of the sedimentation basin, reducing filter run times, and ultimately resulting in ineffective treatment. Even more important, such rivers often carry large particles, sands and silts that settle out in flocculation basins, where their removal is difficult to manage. In general, sediment greater than 0.1 mm in diameter should be removed to prevent abrasion-related damage to equipment, such as pumps and mixers, and accumulation of sediment in basins. Water treatment facilities with large raw water reservoirs or basins often experience sediment removal in conjunction with water storage, via settling of solids. Other available options for sediment removal include conventional grit basins, and grit basins with the addition of enhanced sedimentation devices such as lamella plates.

The intake for the SRWA’s WTP is a partially constructed infiltration gallery, with piping already in-place below the riverbed. This piping is comprised of sixteen (16), 45-foot long sections of 24-inch slotted pipe, covered by four to five feet of pea gravel, washed rock and river cobble. The slotted pipe apertures are 0.060 inches. The wet well and raw water pump station for the infiltration gallery have not yet been constructed.

The infiltration gallery is expected to reduce the particulate load of the raw water pumped to the WTP. Available historical raw water turbidity data is insufficient to assess storm related turbidity spikes on the Tuolumne River. From the available historical data, the turbidity of the river is generally low (i.e., less than 10 NTU). Pilot-scale filter columns containing media representative of the gravel and media covering the infiltration gallery piping may be tested to simulate performance of the infiltration gallery for particulate removal under both ambient low-turbidity and simulated high-turbidity conditions.

Considering that the available historical raw water turbidity is low and that additional particulate removal is expected through the infiltration gallery, it is not expected that a separate sedimentation basin or additional pretreatment would be required for the SRWA WTP. Collection of bi-weekly raw water turbidity data over a two year period has been recommended (SRWA Water Quality Sampling Plan, July 2016) and should provide additional understanding of seasonal changes in particulates. Unless the source water is found to be “flashy”, pretreatment is not needed. This scenario is illustrated in Figure 7.

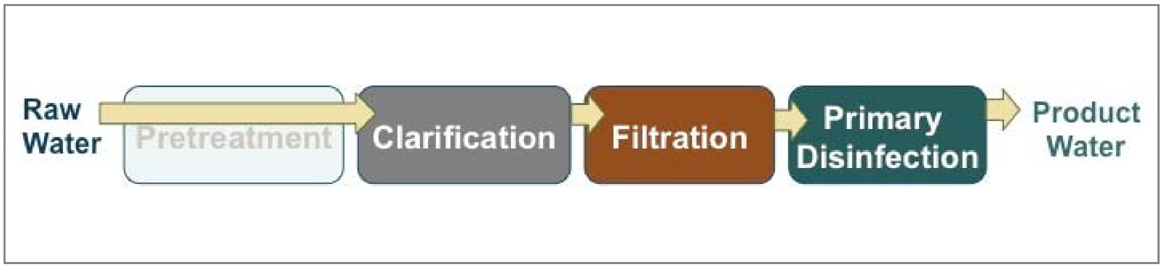

Figure 7. Typical surface water treatment with low source water turbidity

3.3 Clarification and Filtration

After deciding that pretreatment is not required, the next step in the treatment process selection is determining the appropriate clarification and filtration processes. In order to distinguish between the options—direct filtration or conventional clarification with filtration—the relevant questions are, "What degree of clarification is needed for this water?" "Can direction filtration be used?" "Will coagulation be required for TOC removal for controlling disinfection by-product formation?" The various options associated with these two clarification and filtration types are discussed further in this subsection, according to the following subtopics:

- Direct Filtration Options
- Conventional Clarification and Filtration Options

3.3.1 Direct Filtration Options

Direct filtration involves the use of a coagulant, followed by rapid mix and flocculation, ahead of filtration, and effectively skips the sedimentation step. It is sometimes designed with no flocculation as well, in which case it is usually called in-line or contact filtration. A low coagulant dose is used to de-stabilize particles and allow removal through depth filtration. For the purpose of this discussion, direct filtration includes both granular media filtration and membrane filtration. As defined by the SWTR, though, direct filtration includes the use of a granular media filter, while membrane filtration is considered an "alternative filtration technology."

In very general terms, direct filtration is an appropriate technology if the influent turbidity is consistently less than 10 NTU; contact filtration is not often practiced in California. Occasional turbidity spikes up to 20 NTU can be tolerated as long as they are infrequent and do not last long; longer duration spikes may substantially reduce filter runs and turbidity breakthrough may occur. For persistent turbidity spikes above 20 NTU, the WTP would likely have to shut down until the raw water turbidity subsides. Special media can be designed to handle higher turbidities, but, normally, extensive pilot studies are required to optimize media design and assure good performance.

In general, direct filtration precludes the use of enhanced coagulation for the removal of DBP precursor material (i.e., TOC), due the relatively low coagulant doses that direct filtration can accommodate (typically 1-5 mg/L). By contrast, conventional treatment trains can employ higher coagulant doses, often 15-30 mg/L.

If direct filtration is favored and TOC levels are above 1.5 mg/L, DBP formation with free chlorine may be a regulatory concern. If raw water TOC concentrations are routinely above 1.5 mg/L, either (a) chloramines should be used for secondary disinfection to minimize DBP formation in the distribution system, or (b) conventional treatment (i.e., with sedimentation) should be used instead of direct filtration to accommodate a higher coagulant dose and possibly lower pH (i.e., enhanced coagulation) for greater TOC removal.

Direct filtration alone will not address pesticide/SOC removal. The combination of ozone and biologically active carbon (BAC) filtration need to be included with direct filtration to address pesticides and SOCs.

Other considerations for direct filtration are:

- DDW discourages the use of direct filtration
- For direct filtration with GMF, at least 6 months of pilot testing is recommended for proper selection of media size, design of the filter bed, and selection of design filtration rate.
- For direct filtration with membranes, at least 4 to 6 months of demonstration testing, covering multiple seasons is also recommended for proper selection of the design flux and to confirm the acceptable low rate of fouling.

The following subsections discuss the pairing of the direction filtration process with granular media and membrane filtration processes.

3.3.1.1 Direct Filtration with Granular Media Filtration (GMF)

Based on historical data, the turbidity of the Tuolumne River in the reach near the infiltration gallery is less than 10 NTU and low enough for a direct filtration option. As stated, though, there is not enough data to assess storm related turbidity levels or the duration of storm related turbidity spikes, if they occur. Also, water quality improvements afforded by the infiltration gallery is unknown at this time. Pilot filter column tests may be performed to evaluate turbidity removal through the infiltration gallery.

A simplified depiction of a direct filtration treatment train with a granular media filter is shown in Figure 8. In the coagulation step, a low dose of coagulant is added in a high-speed mixing environment for particle de-stabilization. The flocculation step follows, with slow mixing speeds that promote floc formation. The flocculation time for a direct filtration plant is shorter than the flocculation time in a conventional treatment plant—10 to 20 minutes vs. 20 to 30 minutes, respectively (Crittenden, et al., 2012). Sedimentation is not needed with direct filtration treatment.

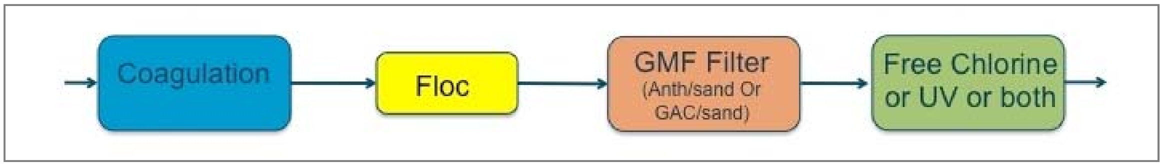

Figure 8. Direct Filtration using a Granular Media Filter

Both anthracite/sand and GAC/sand are appropriate and effective filter media but GAC is marginally more expensive that anthracite. A GAC/sand filter is operated the same as an anthracite/sand filter; the filter is backwashed every 48 to 72 hours, as needed, based on headloss buildup or turbidity breakthrough. The GAC in a GAC/sand filter is not included for purposes of SOC or TOC adsorption, although adsorption can be expected to occur during the first 6 months to a year of operation. Once the GAC's adsorption capacity is exhausted, the media is not regenerated as would occur in a strict GAC adsorption column. GAC/sand is often the filter media of choice when ozone is included in the process train because of the enhanced biological activity and contaminant removal it provides compared with anthracite. When ozone is included in the process train, the ozone breaks down organic molecules (e.g., TOC and SOCs) into smaller fragments that are more easily degraded by microbes on the media. Biological activity can be present in both anthracite/sand and GAC/sand filters, even without ozone, but removal of organics is substantially greater when ozone first breaks down the organic material making it more biodegradable. If chlorine is added ahead of an anthracite/sand filter, the chlorine is able to pass through the filter and will hinder biological growth and activity. With a GAC/sand filter, chlorine is removed by the GAC in the first few inches of the filter bed.

In terms of very general costs, a direct filtration treatment train with granular media is roughly 10% to 15% lower in capital cost than a conventional treatment train with granular media filtration.

3.3.1.2 Direct Filtration with Membrane Filtration

For direct filtration with membranes—either microfiltration or ultrafiltration membranes—the coagulation step may or may not be needed for effective filtration, but is often included. Flocculation, however, is not required for membrane filtration. A schematic of a membrane filtration process train is shown in Figure 9. Often a low dose of coagulant (i.e., 1 to 5 mg/L) is added to help reduce membrane fouling, increase the time between membrane cleanings, and possibly allow operation at a higher flux. If the TAC pursues membrane filtration, it is recommended that demonstration testing be performed (4 to 6 months) to investigate the effect of coagulant on membrane performance, as well as the optimum coagulant type and dose.

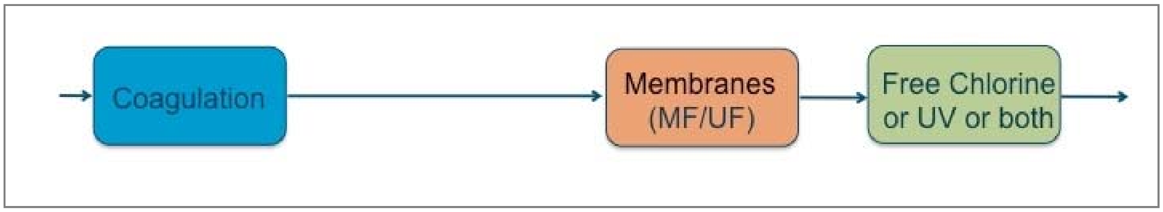

Figure 9. Direct filtration with membrane filtration

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 (CEB) 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. DDW has stated that CIP waste chemicals cannot be returned to the plant influent for blending with raw water, and must be either pumped to a sanitary sewer system for treatment at a nearby wastewater treatment plant (WWTP) or hauled off-site for proper treatment and disposal. Because of the remote location of the SRWA WTP, the CIP waste would have to be hauled off-site for disposal. It should be noted that some WWTPs do not accept citric acid waste because it chelates the iron in ferric chloride, which can interfere with the WWTP's performance.

Membrane filtration systems are exempt from the Enhanced Coagulation TOC removal requirements of the Disinfectants/Disinfection By-Products Rule (D/DBP), but the finished water must still meet the TTHM and haloacetic acids (HAA5) pMCLs in the distribution system. The pMCL for TTHMs is 80 µg/L and for HAA5 the pMCL is 60 µg/L. As mentioned previously, membrane filtration provides little or no TOC removal because only a very low coagulant dose, if any, is used. Given the uncertain TOC concentrations at the intake location and the fact that only a small fraction of the DBP precursor material will be removed through membrane filtration, it is likely that chloramines will have to be considered for secondary disinfection. Actual DBP formation in the source water in relation to TOC concentration can be estimated through bench-scale tests. Refer to Section 5 of this TM for further discussion of optional pilot- and bench-scale tests.

One advantage of membrane filtration is that it is considered an "absolute barrier" to *Giardia* and *Cryptosporidium*. The SWTR and subsequent Interim Enhanced Surface Water Treatment Rule (IESWTR) and LT2ESWTR require a specific amount of pathogen treatment be achieved through multi-barrier treatment (i.e., removal via filtration and inactivation via disinfection) when treating a surface water. 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 GMF, as summarized in Table 3 below; the additional required treatment credit, for multi-barrier treatment, is achieved through disinfection. Virus removal credit is awarded for direct filtration with GMF, but typically not for membrane filtration. For comparison, the credit achieved for conventional treatment with GMF—complying with filter effluent turbidity requirements—Is also shown in Table 3.

Table 3. Pathogen Removal Credit for Direct Filtration with a Granular Media Filter Compared to Membrane Filtration

Pathogen	Required Treatment	Direct Filtration with GMF	Direct Filtration with MF	Conventional Treatment with GMF
Cryptosporidium[(a)]	2-log	2-log	4-log	2-log
Giardia[b]	3-log	2-log	4-log	2.5-log
Viruses[b]	4-log	1-log	--	2-log

Footnotes:

a. Assumes Bin 1 classification
b. Regulations require multi-barrier treatment. The remaining required credit is achieved through disinfection

Membrane filtration does not provide treatment for pesticides, other SOCs, or algae-related tastes and odors. Therefore, if the TAC elects to pursue membrane filtration, they will have to make the following concessions with regard to regulated pesticides and SOCs:

- Not treat for regulated pesticides/SOCs and assume they will remain below their respective MCLs in the source water. Note that the historical pesticide/SOC data reported two contaminants above a DDW Notification Level but none above a primary MCL.
- Include the addition of powdered activated carbon (PAC) or the use of GAC adsorption in the treatment train. Activated carbon treatment would be required continuously because it is not possible to know if/when pesticides are above their respective MCL in the source water. Note that with GAC adsorption the GAC is regenerated once the carbon has exhausted its adsorption capacity; this is not the same as using GAC as a filter media in a GAC/sand (or BAC) filter where the filter is repeatedly backwashed and the media is never regenerated.
- Add a process such as ozone/BAC to the treatment train to breakdown (ozone) and biodegrade (BAC) the organic molecules. Note that addition of an ozone/BAC process to a treatment train with membrane filtration would necessarily result in redundant filtration processes.

When the TAC considers the viability of membrane filtration, the following should be kept in mind:

1. DDW is not a proponent of membrane filtration and permitting the WTP may be challenging
2. There have been two negative local experiences with membranes (i.e., MID and SSJID) and only one positive experience (i.e., Lodi)
3. The WTP design must include adequate protection for the membranes from the potential threat of Asian clams

3.3.2 Conventional Clarification and Filtration Treatment Options

A conventional treatment train for surface water treatment includes coagulation, flocculation, sedimentation, granular media filtration, and both primary and secondary disinfection. A conventional treatment train is generally 10% to 15% more expensive than a direct filtration treatment train.

A schematic of a conventional treatment train is shown in Figure 10. This subsection focuses on the clarification (i.e., coagulation, flocculation and sedimentation) and filtration components of conventional treatment; disinfection is addressed separately in Section 3.4.

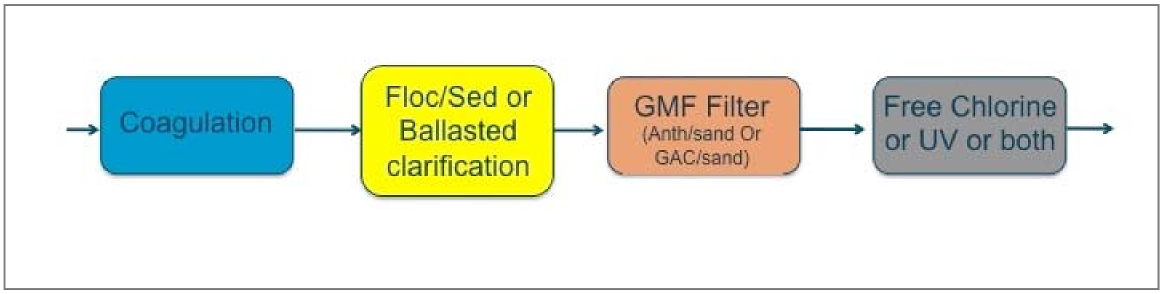

Figure 10. Conventional Treatment Train for Treatment of a Surface Water

<u>Coagulation and Flocculation</u>

In conventional treatment, a coagulant (e.g., ferric chloride or aluminum sulfate) is added to facilitate settling and removal of particulate material. In order to control DBP formation, the coagulant dose is generally high enough to also provide removal of TOC—typically 20 mg/L to 30 mg/L. In addition, the pH can be adjusted as needed to provide "enhanced coagulation" for DBP control, as coagulant performance is partially a function of pH.

Depending on the source water TOC concentration and alkalinity, the Enhanced Coagulation part of the D/DBP Rule requires a specific percentage TOC removal, or demonstration that the required removal cannot be reasonably achieved (Table 4). Enhanced coagulation is not required if the source water TOC is less than 2 mg/L. As stated previously, direct filtration is exempt from the Enhanced Coagulation requirements but the DBP MCLs must still be met.

Because conventional treatment is amenable to enhanced coagulation, TOC removal may be sufficient for DBP control, thereby allowing the use of free chlorine for secondary disinfection. Bench-scale jar tests can be done to evaluate a) TOC removal over a range of pHs, coagulant types and doses, and

b) the subsequent DBP formation in the settled water with both free chlorine and chloramines.

Due to the uncertainty about the Tuolumne River TOC concentrations at the infiltration gallery location (as discussed in Section 2.2), the upcoming source water monitoring program will be relied upon to clarify the expected range of TOC concentrations, and subsequent TOC removal requirements, for this source water.

The detention time for conventional coagulation/flocculation is 20 to 30 minutes (Crittenden, et al., 2012).

Table 4. TOC Removal Required Under the Stage 1 D/DBPR

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%

Sedimentation

There are several options for sedimentation. Conventional sedimentation uses large, rectangular, horizontal-flow basins and the detention time ranges from 1.5 to 4 hours (Crittenden, et al., 2012). As an alternative, high-rate sedimentation with lamella plate or tube settlers can be used. The detention time ranges from 6 to 10 minutes with tube settlers and 15 to 25 minutes with plate settlers (Crittenden, et al., 2012).

Another option which combines coagulation/flocculation/sedimentation into one unit process is sand ballasted clarification (SBC). With SBC, sand is added to provide nucleation sites for floc formation and growth. A high density sand is used and because of its density the sand/floc settles very rapidly. Plate settlers are generally incorporated into the SBC basins for high-rate clarification.

SBC is a very robust treatment process and generally is used when treating a surface water with highly variable raw water turbidity and TOC conditions. SBC also has a substantially smaller footprint than conventional coagulation/ flocculation/ sedimentation, but because of the proprietary nature of SBC systems, the capital cost may be more. However, under recent Design-Build or Design-Build-Operate procurement approaches, SBC has been shown to be a cost-competitive process.

Filtration

Both anthracite over sand and GAC over sand are appropriate filter media in a conventional treatment train. GAC is recommended for treatment trains which include ozone upstream of the filters, as GAC provides a more suitable adsorption / substrate environment for the microbial communities necessary to biodegrade the organic molecules broken apart during ozone treatment.

As discussed for direct filtration (Section 3.3.1.1), GAC is marginally more expensive than anthracite. Without the addition of ozone in the process train to break down the larger organic molecules making them amenable to biodegradation, there is not much benefit in using GAC rather than anthracite as a filter media. The adsorption capacity of the GAC for SOCs and TOC is rather quickly exhausted (typically within a few months), and without ozone there will not be significant biological degradation of organic material on the GAC filter media. So, without ozone/BAC, a conventional treatment train does not effectively address agricultural-related pesticides/SOCs or algae related T&O.

3.4 Disinfection

As required by drinking water regulations, surface water treatment must include both primary and secondary disinfection. Primary disinfection is included to meet the pathogen inactivation requirements of the SWTR (i.e., multi-barrier requirements), whereas secondary disinfection is required for the purpose of maintaining a detectible disinfection residual throughout the distribution system (i.e., required by the Disinfection/Disinfection By-Product Rule). The options for each are the following:

Primary Disinfection

- Free chlorine
- Ozone
- Ultraviolet radiation (UV)
- Chloramines

Secondary Disinfection

- Free chlorine
- Chloramines

Typically, only free chlorine or ozone are used for primary disinfection. Chloramines are not as effective for disinfection as free chlorine and therefore require a very long contact time to deliver equivalent treatment. UV provides good disinfection for *Cryptosporidium* and *Giardia*, but requires a high dose for virus inactivation. UV is an expensive option unless additional *Cryptosporidium* treatment credit is needed in the treatment train.

For secondary disinfection, each chemical has pros and cons. Free chlorine compared with chloramines is a stronger disinfectant and oxidant, and thus reacts with TOC to form higher concentrations of DBPs; it decays faster in the distribution system; and it is more easily detected by taste and smell. Chloramines are more stable than free chlorine, so they decay slower in the distribution system and form lower DBP concentrations when reacting with TOC; they require careful control of the chlorine to ammonia ratio; they can lead to nitrification issues; and chloramines require both ammonia feed and chlorine addition at well-heads for continued groundwater use.

The choice of final (i.e., secondary) disinfectant will be largely determined by TOC removal through the WTP, the TOC concentration of the finished water, and subsequent DBP formation potential. Due to uncertainty in TOC levels of the source water, all treatment alternatives should include the capability for chloramine addition. The source water monitoring program and bench testing will allow economical evaluation of DBP precursor removal through clarification and subsequent DBP formation with both free chlorine and chloramines.

3.4.1 Incorporating Ozone into the Process Train

Although incorporating ozone in a treatment train typically adds 8% to 10% to the capital cost of the facility, an ozone train provides more than just disinfection. Due to ozone's ability to break down larger organic molecules, it adds robustness to the process by addressing the following treatment needs:

- Treatment for low concentration pesticides, SOCs, and contaminants of emerging concern (CECs) (e.g., hormones, antibiotics, etc.)
- Treatment for algae related T&O, and algal cyanotoxins if present
- Enhanced filtration performance with granular media filters, such as longer filter funs and lower filter effluent turbidity

When ozone is added to the treatment train it is recommended that biologically active carbon (BAC) filtration—using GAC/sand filter media—be included after ozonation to reduce the assimilable organic carbon (AOC) concentration, making the water more stable before it is introduced into the distribution system. Higher AOC concentrations can lead to bacterial regrowth in the distribution system and potential difficulty maintaining a disinfectant residual throughout the system.

Although anthracite/sand filter media could be used in place of GAC/sand media, GAC is preferable because the GAC provides adsorption sites for organic material which promotes biological degradation of organic carbon. As the microbes degrade the organic carbon, additional sites are made available for further adsorption, effectively regenerating the GAC. Thus, GAC promotes better degradation of toxic compounds through adsorption and adaptation. By virtue of the biodegradation of the organic material, the combination of ozone and BAC filtration provides additional TOC removal capability—perhaps as much as 35% (Crittenden, et al., 2012)—resulting in lower DBP levels when free chlorine is used as a secondary disinfectant.

The following example illustrates the effect of adding ozone to a treatment train, in this case a membrane filtration process piloted by TID in 2008:

- The TID pilot study (Brown and Caldwell, 2008) found that even considering the very low raw water TOC concentrations being pilot tested (raw water TOC averaged 1.75 mg/L during the study) and membrane filtration, TTHM and HAA levels with 3 mg/L free chlorine disinfection and a 5-day sample holding time were close to or just above the regulatory limits. [Note: Membrane filtration can be considered a worst case filtration scenario for DBPs, since it does not provide biological activity for degradation of organics].

- With pre-ozonation ahead of membrane filtration, TTHMs were reduced 35% and HAAs were reduced 50%; resulting effluent TTHMs were below 50 µg/L and HAAs were below 30 µg/L.
- When alum coagulation was added after pre-ozonation, DBP levels were further reduced to TTHMs below 30 µg/L and HAAs below 10 µg/L. [It should again be noted that the source water TOC for the 2008 pilot study was substantially lower that the TOC measured during the same time period at the infiltration gallery location].

Ozone can be incorporated into both direct filtration and conventional treatment trains. The pros and cons of each of these options are discussed in the subsections below.

3.4.1.1 Adding Ozone to Direct Filtration

Ozone can be added to both the GMF and membrane direct filtration trains, as shown in Figure 11. The preferred choice for ozone addition in the **GMF train** is pre-ozonation, since adding ozone after floc formation can break apart the floc and potentially have a negative impact on particulate removal through the GAC/sand filter. In turn, pre-ozonation can enhance the performance of the GMF filter, resulting in longer filter runs and lower effluent turbidity. The ozone/BAC combination can also provide a moderate percentage (up to 35%) TOC removal.

The preferred choice for ozone addition in the **membrane filtration train** is after the membranes, particularly since pre-ozonation does not enhance membrane filtration. Ozone can be very damaging to the membrane and potting materials and as such it is critical to protect the membranes from exposure to ozone. Biofiltration is recommended following ozone for AOC removal. Including both membrane filtration and BAC filtration in the same treatment train is redundant. Therefore, the membrane filtration train with ozone is not justifiable.

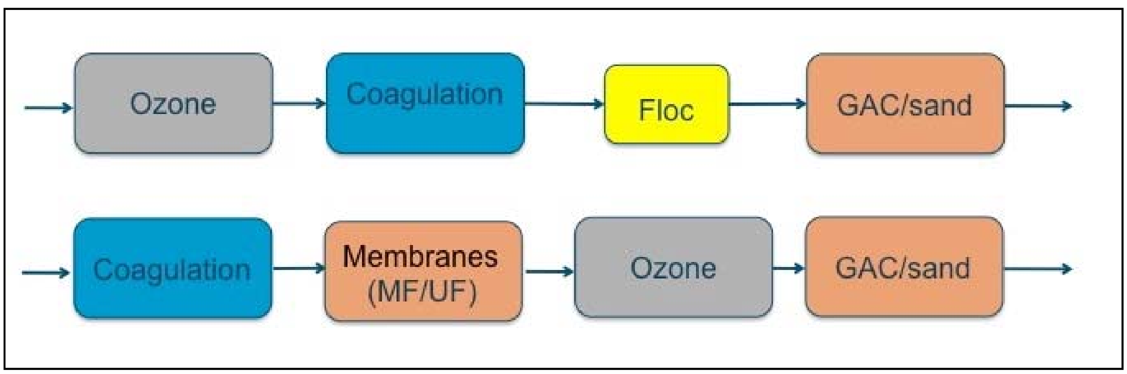

Figure 11. Options for Adding Ozone to Direct Filtration

3.4.1.2 Adding Ozone to Conventional Treatment

Ozone can easily be added to a conventional treatment train (Figure 12). Two locations should be considered for ozone, and each offers different advantages. Pre-ozone ahead of coagulation improves the coagulation process and reduces the coagulant dose. MID's conventional treatment train includes pre-ozone and MID has reported reduced coagulant usage. Intermediate ozone (after sedimentation) has a lower ozone demand because the TOC concentration is lower as a result of clarification.

Both ozonation locations are effective for disinfection, pesticide/SOC removal, and T&O mitigation. If the TAC elects to continue evaluation of a treatment train that includes ozone, bench-scale ozone demand tests can be done to evaluate the difference in ozone demand—and therefore ozone dose and treatment cost—between pre-ozone and intermediate ozone. Bench-scale tests can also be done to evaluate any difference in DBP formation between these two ozone location options.

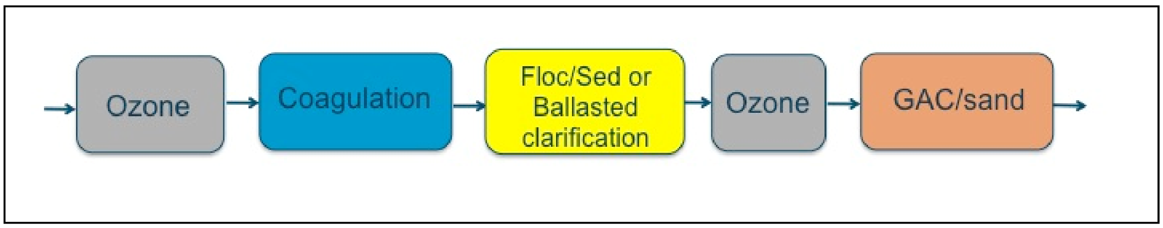

Figure 12. Addition of Ozone into the Conventional Treatment Process Train

4 - SUMMARY OF TREATMENT ALTERNATIVES

Considering the benefits offered by the addition of ozone—treatment for pesticides, SOCs and T&O compounds, while also providing disinfection—the candidate treatment trains are divided into two groups—those without ozone and those with ozone as shown in Figures 13 and 14 and listed below:

Treatment Trains without Ozone

Option A: Direct filtration with granular media filters and primary disinfection with free chlorine, UV or both

Option B: Direct filtration with membrane filters and primary disinfection with free chlorine, UV or both

Option C: Conventional treatment with granular media filters and primary disinfection with free chlorine, UV or both

Treatment Trains with Ozone

Option D: Direct filtration with pre-ozonation and biologically active granular media filters

Option E: Conventional treatment with pre- or intermediate ozonation and biologically active granular media filters

A brief summary of key considerations for these treatment alternatives is the following:

- TOC (i.e., DBP precursor material) at the infiltration gallery is high enough to cause concern over DBP formation with free chlorine, based on historical data. Chloramines form much lower DBP levels compared with free chlorine for secondary disinfection.
- Direct filtration without ozone (Options A and B) is unlikely to meet DBP requirements using free chlorine for secondary disinfection.
- Conventional treatment without ozone (Option C) may meet DBP requirements using free chlorine for secondary disinfection. More information about source water TOC is needed for consideration of this option, however.
- Treatment trains without ozone (Options A, B, C) will not address pesticides or T&O.
- Direct filtration with ozone (Option D) will address pesticides, and may meet DBP requirements using free chlorine. This train does not provide robust treatment for variable influent water quality, however.
- Conventional treatment with ozone (Option E) is the most robust train. It will provide treatment for pesticides/SOCs and T&O, and is expected to meet DBP requirements. Ozone\BAC will provide additional DBP protection by removing additional TOC beyond that removed through clarification.
- The choice of final (i.e., secondary) disinfectant will be determined by the amount of TOC removal provided by treatment. Due to uncertainty in TOC levels at the infiltration gallery, all treatment alternatives should include the capability for chloramine addition. Bench testing and additional source water monitoring will also inform this choice.

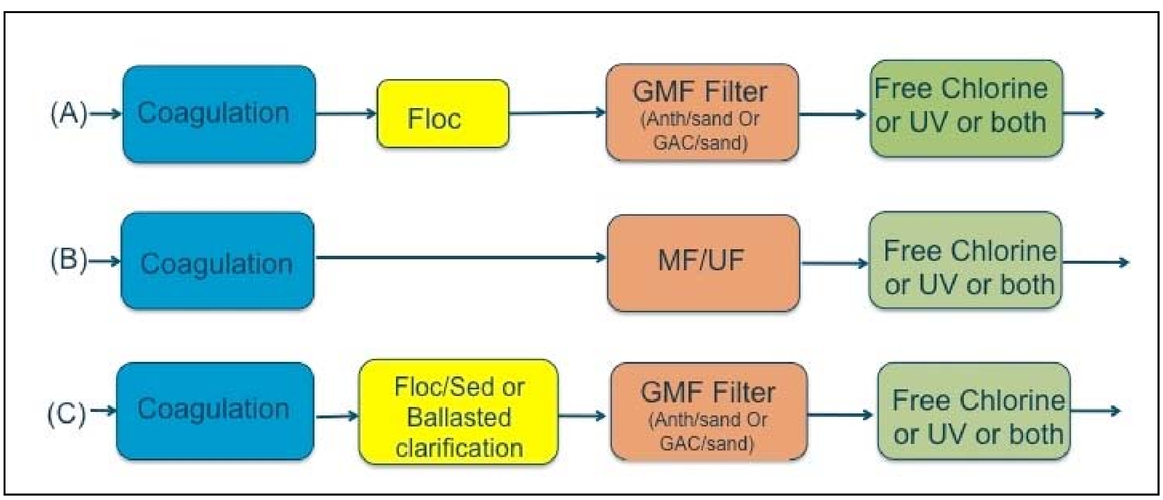

Figure 13. Candidate Treatment Trains without Ozone

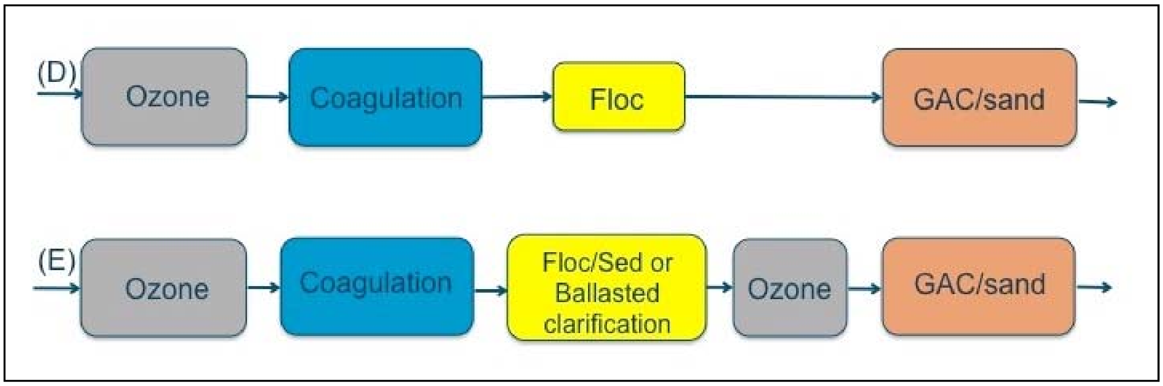

Figure 14. Candidate Treatment Trains with Ozone

A qualitative assessment of the above candidate treatment trains' ability to meet a selection of the TAC's most highly ranked treatment performance goals (i.e., goals with an importance ranking of five) is provided in Table 5. The intent of this summary table is to assist the TAC in selecting the candidate treatment alternative(s) that should be evaluated in greater detail and to justify the elimination of processes that do not provide appropriate treatment, based primarily on source water quality and treatment needs.

Table 5. Qualitative Ranking of Candidate Treatment Trains for Meeting Selected Treatment Performance Goals[1]

Treatment Train	Process Train Capabilities[2] for Addressing Selected SRWA Treatment Goals[1]				
	Meet Regulations with Safety Factor: **Regulated SOCs**	Meet Regulations with Safety Factor: **DBPs**	Reduce Aesthetic Concerns: **Tastes & Odors**	Robust Process for Variable Source Water **Turbidity**	Robust Process for Variable Source Water **TOC**
Option (A) Direct Filtration[3] with GMF, no Ozone	**1** – For anthracite/ sand, due to no adsorption **2** – For GAC/sand, due to limited adsorption; no ozone for SOC removal	**2 -** Limited by low coagulant dose; no ozone for precursor removal; chloramines may be necessary	**1** – For anthracite/ sand, due to no adsorption; no ozone for T&O removal **2** – For GAC/sand, due to limited adsorption;; no ozone for T&O removal	**1** – Unknown influence of infiltration gallery; difficult to find operators with experience	**2 -** Limited by low coagulant dose
Option (B) Direct Filtration[3] with MF, no Ozone	**1** – No ozone, no biological activity, no SOC removal	**2 -** Limited by low coagulant dose; no ozone for precursor removal; chloramines may be necessary	**1** – No Treatment	1 – Unknown influence of infiltration gallery; difficult to find operators with experience	**2 -** Limited by low coagulant dose
Option (C) Conventional Treatment with GMF, no Ozone	**2** – Possible adsorption onto floc; no ozone for SOC removal	**4** – Enhanced coagulation is an option; no ozone to reduce precursors	**3** – Powdered Activated Carbon can be added as needed; no ozone to remove T&O	**5** – SBC is potentially more robust for high turbidity levels	4 – Coagulant dose can be varied
Option (D) Direct Filtration[3] with Pre-Ozone and GMF	**4** – O_3/BAC provides treatment	**3** – Limited by low coagulant dose; O_3/BAC provides additional TOC removal	**4** – O_3/BAC provides treatment, but more information needed about ozone treatment for algal toxins	**1** – Unknown influence of infiltration gallery	**3 -** Limited by coagulant dose but O_3/BAC provides additional TOC removal
Option (E) Conventional Treatment with Pre- or Intermediate Ozone and GMF	**5** – Some additional removal may be provided by adsorption onto floc	**5** - O_3/BAC provides additional TOC removal	**4** – O_3/BAC provides treatment, but more information needed about ozone treatment for algal toxins	**5** – SBC is potentially more robust for high turbidity levels	**4** – Coagulant dose can be varied; O_3/BAC provides additional TOC removal

Notes:
[1] Goals listed include those identified as most important (ranking score of 5) to the TAC.
[2] Capability rankings: 1 = No ability to meet goal; 5 = Fully capable of meeting goal.
[3] Pilot testing is required for direct filtration options.

5 - INFORMATION GAPS

Information gaps identified at the June 30 workshop and discussed in this TM, as well as the available measures to provide the missing information, are summarized in Table 6 below.

Another important topic that was not discussed during the June 30 workshop, but is quite important to the success of this project, is integration of the new surface water into the Ceres and Turlock distribution systems that have historically seen only groundwater. Introducing a new water into a distribution system can be challenging and has potential for colored water events and more corrosive conditions. Some utilities have made this transition with few, if any, negative consequences, while others have experienced significant water quality and public perception issues related to “red water”, “black water”, or elevated lead levels. This TM was focused on describing the pros and cons of each candidate treatment train for the purpose of reducing the list of viable treatment alternatives; corrosion control was not considered at this point in time.

A future task should focus on understanding (1) the current and historical quality of the Cities groundwater, (2) the pipeline materials used in the distribution systems, (3) the history of customer complaints, and (4) water flow direction and detention times in the systems. The future WTP must include a corrosion control strategy for minimizing corrosion related issues when this new treatment facility comes on-line. This corrosion control strategy should encompass (1) finished water quality for maintaining a stable water chemistry in the distribution system, (2) addition of a corrosion inhibitor to stabilize existing corrosion scale, (3) distribution system preparation measures such as unidirectional flushing (UDF) to remove loose iron scale and manganese deposits, and potentially (4) a pilot-scale pipe loop study evaluating the effectiveness of corrosion control options. Corrosion control treatment and integration of surface water into the Cities existing distribution systems will be addressed either later in Phase 1 of this project, once the preferred treatment train has been selected, or during Phase 2 of this project. The timing and scope of this corrosion control evaluation will be discussed between the TAC and West Yost at an upcoming project meeting.

Table 6. Information Gaps and Available Measures to Provide Missing Information

Category	Information Gap	Available Measures to Provide Missing Information	Anticipated Outcome(s) of Available Measures	Current Disposition of Available Measures
Infiltration Gallery Performance	Ability of the infiltration gallery to reduce turbidity in the raw water to the WTP, under variable turbidity conditions in the River. Ability of infiltration gallery to remove grit and silt that would accumulate in downstream treatment	Pilot filter column testing using raw and spiked river water samples	Determination of feasibility of direct filtration	Optional task, pending review and direction from TAC
	Ability of the infiltration gallery to remove particles the size of Asian clam larvae, to keep the clams from entering basins at the treatment plant		Determination of likelihood of potential future Asian clam colonization in raw water pump station wet well and WTP basins	
Tuolumne River TOC Concentrations	Historical TOC data collected at the intake location indicate higher TOC concentrations than measured at the Modesto Reservoir influent or downstream near the Hughson WWTP where the TID pilot study was conducted	Measurement of raw water TOC concentrations	Determination of feasibility of direct filtration and disinfection with free chlorine. Determination of TOC removal requirements	24 months of measurement included in Sampling Plan
Pesticide Contamination	There are limited historical data regarding pesticide concentrations in the River, but several high use pesticides in the watershed.	Measurement of regulated pesticides in raw water	Determination of need for ozone or PAC treatment (if ozone is not included)	Quarterly measurements included in Sampling Plan
Potential for Algae-related T&O and Toxins	MID's water treatment plant includes ozone for T&O treatment. Other than detectable nitrate concentrations, there is little data to indicate whether or not T&O are a potential aesthetic issue for the influent water	Sample collection and analysis for Chlorophyll-a , algae species identification and enumeration, and subsequent 2-Methylisoborneol (MIB), geosmin and/or algal toxin analyses, as needed	Determination of need for ozone or PAC treatment (if ozone is not included)	Not a part of DDW-approved Sampling Plan. Included with additional recommended monitoring.

Category	Information Gap	Available Measures to Provide Missing Information	Anticipated Outcome(s) of Available Measures	Current Disposition of Available Measures
Potential TOC Removal through Enhanced Coagulation	It is unknown if there will be enough TOC removal to use free chlorine. Evaluate required coagulant dose and resulting TOC removal and DBP formation.	Jar testing of raw water samples to evaluate various coagulant, dose and pH combinations for optimum TOC removal and minimal DBP formation	Identification of optimum coagulant, dose and pH Determination of typical TOC removal and corresponding DBP formation through enhanced coagulation. Greater understanding if chloramines will or will not be necessary.	Optional task, pending review and direction from TAC
Ozone Demand of Raw and Clarified Source Water	An understanding of the ozone demand associated with the source water and the clarified water (based on optimal coagulant dose determined), along with an understanding of corresponding ozone byproduct formation. Evaluation of the optimum location for ozonation in the treatment train.	Bench testing to identify optimum ozone dose for required disinfection and T&O control using raw and clarified (i.e., coagulated and clarified) river water samples	Determination of optimum location for ozonation in conventional treatment train Identification of optimum ozone dose	Optional task, pending review and direction from TAC

6 - NARROWING THE FIELD OF VIABLE TREATMENT TRAIN ALTERNATIVES

Extrapolating from the historical water quality data, while concurrently recognizing and acknowledging limitations of the historical data, the TAC can begin to rule out some of the candidate treatment trains. This section of the TM reflects discussions at the June 30, 2016 workshop and attempts to provide justification for eliminating some of the initial five alternative treatment trains on the basis of source water quality and treatment needs. The following discussion centers on two primary questions:

1. Ozone/BAC or No Ozone/BAC?
2. Direct Filtration or Conventional Treatment?

Further narrowing the list of viable alternatives to just one or two treatment trains may require a combination of additional source water quality data, bench-test and/or pilot-test results described in Table 6.

6.1 First Decision – Ozone/BAC or No Ozone/BAC?

Ozone should be seriously considered in the selected treatment train(s) because of the enhanced treatment it offers as well as the robustness it provides for potentially variable and unknown water quality. Because of the large agricultural area and high pesticide usage in the Lower Tuolumne River watershed, ozone in combination with BAC provides excellent treatment for low levels of regulated pesticides that are likely to contaminate the river. Several pesticides and other SOCs were reported in the historical water quality data for the Tuolumne River.

Ozone with BAC is also effective treatment for algae-related T&O (i.e., aesthetic) considerations and, although there is not a lot of direct evidence of algal blooms in this source at this time and good data on algal blooms are often hard to come by, there is evidence of the presence of the nutrients that encourage algal blooms in this source water. Finally, the off-flavors associated with algal blooms are one of the principle complaints associated with surface water sources. Ozone/BAC also will provide additional TOC removal beyond what is achieved with conventional clarification. If ozone is used in the treatment train, GAC/sand filtration—referred to as BAC—should also be included because of the microbial activity on the filter media. This biological activity allows additional removal of SOCs, taste and odor compounds and TOC broken down by ozone, as well as lower AOC concentrations in the finished water. High AOC concentrations can lead to bacterial regrowth in the distribution system and potential difficulty maintaining a disinfectant residual.

Drinking water regulations require the finished water from a WTP to be in compliance with all enforceable standards. Per the treatment performance goals set out by the TAC during the May 12, 2016 Treatment Performance Goals Workshop and summarized in the ensuing technical memorandum (Trussell Technologies, July 21, 2016), the TAC desires a robust treatment approach for regulated contaminants, contaminants on the regulatory horizon (e.g., those with an NL, an aNL, or on a UCMR list) and aesthetic considerations, while at the same time being financially responsible regarding treatment for unregulated contaminants. Having a robust treatment train was ranked 5 (most important) by the TAC, while treatment for unregulated pesticides and CECs was ranked 2 (low importance). As discussed previously (Source Water Quality Assessment TM, Trussell Technologies, July 2016), several pesticides were measured in past river samples, but only two—diazinon and tert-butyl alcohol—were measured at a concentration above their respective regulatory notification level. The watershed around the infiltration gallery is a large agricultural area with several pesticides applied at an application rate greater than 5,000 lbs/yr. Thus, there is potential for low levels of pesticides in the source water for the WTP.

From a financial point of view, including ozone and in the treatment train will add 8% to 10% to the capital cost of the facility. Assuming the TAC decides that ozone is warranted on the basis of source water quality and treatment needs, the next consideration is whether or not the source water is amenable to direct filtration. As discussed earlier in this TM, direct filtration with membranes is not warranted because "double filtration" with a GAC/sand GMF would be required, resulting in a redundant and more costly alternative. So, **if ozone is chosen**, the two remaining candidate treatment trains are those shown in Figure 15.

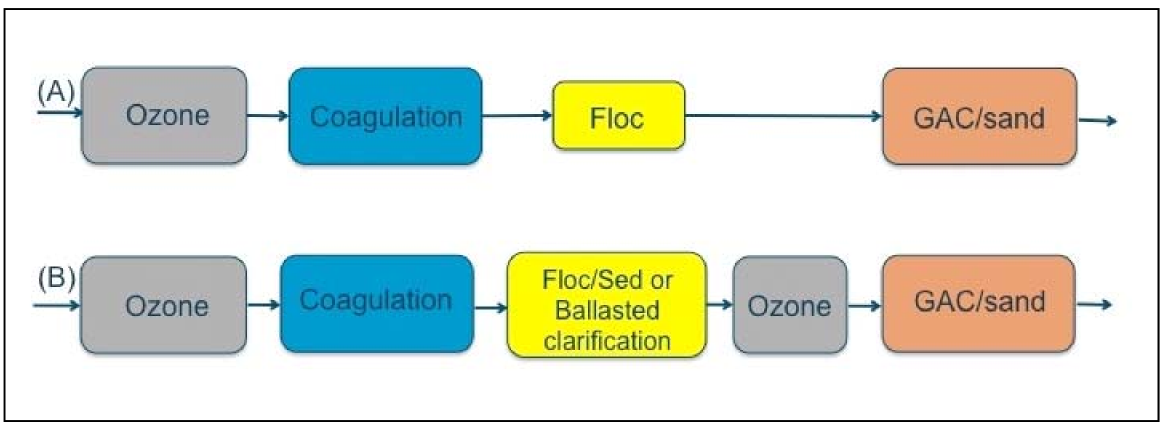

Figure 15. Feasible Treatment Trains if Ozone Treatment is Included

6.2 Second Decision – Direct Filtration or Conventional Treatment?

Notwithstanding the potential cost savings associated with direct filtration, deciding between direct filtration and conventional treatment comes down to the following treatment considerations:

- Will the turbidity of the influent water (after passing through the infiltration gallery) be consistently low enough to accommodate direct filtration?
- How much TOC removal will be required for DBP control with free chlorine for secondary disinfection?

- o Can this be achieved with the low coagulant doses used with direct filtration?
- o Should chloramines be considered for secondary disinfection rather than free chlorine?

Turbidity. The rule of thumb upper turbidity that direct filtration can accommodate is 10 NTU. Brief periods of elevated turbidity—up to roughly 20 NTU—can normally be tolerated without exceeding filter effluent turbidity limits. There are not enough raw water turbidity data to assess whether the turbidity will be consistently low—although the limited historical data are encouraging, indicating the turbidity of the raw water is consistently below 10 NTU. The historical data also do not allow assessment of the impact of storm events and associated high river flows on turbidity. In addition, improvement in influent turbidity provided by the infiltration gallery is unknown at this time. In general terms, conventional treatment is typically 10% to 15% higher in capital cost than direct filtration (with granular media filtration). If the TAC decides to continue investigating the viability of direct filtration, the following must be considered:

- Proper design of a direct filtration granular media filter (GMF) will require pilot testing (estimated 6 months) for proper media design.
- Pilot testing is required because the chemical requirements for particle destabilization are different with direct filtration, and experience has shown that the filter bed depth and filtration rate for proper depth filtration are different for each water with direct filtration.

TOC. A low coagulant dose must be used with direct filtration—less than 5 mg/L typically—so only a small amount of TOC removal will be achieved through coagulation. TOC is the precursor material for DBP (e.g., TTHMs and HAAs) formation during disinfection. The MCLs for TTHMs and HAAs are 80 µg/L and 60 µg/L, respectively. A rule of thumb for TTHM formation with free chlorine is 30 µg/L TTHMs for every 1 mg/L of TOC. Therefore, the estimated target TOC of the finished water from this WTP should be below 1.5 mg/L. Ozone/BAC will reduce TOC concentrations, by as much as 35% (Crittenden, et al., 2012). If the TAC decides to continue investigating the viability of direct filtration, they will need to consider the following:

- If the influent TOC is consistently low—say 2.0 mg/L or less—direct filtration with O_3/BAC may provide effective DBP precursor removal and allow the use of free chlorine for secondary disinfection in the distribution system. However, the historical data at the infiltration gallery location had an average concentration of 3.3 mg/L, with a maximum of 6.5 mg/L. *Therefore, given the uncertainty of the influent TOC concentrations, if direct filtration with O_3/BAC is selected, both Ceres and Turlock should be prepared to use chloramines for secondary disinfection in their distribution systems.* There may be public perception issues associated with switching to chloramines.

- DDW is not a proponent of direct filtration or chloramination. Pilot testing done for the filter design, though, should alleviate DDW's concerns if the TAC pursues direct filtration.
- Bench tests cannot be easily done to assess the TOC removal provided by O_3/BAC filtration, due to the time required to establish biological growth on a filter. Pilot scale testing with continuous feed of the source water is more appropriate for determining TOC removal from O_3/BAC filtration.

In summary, if the TAC decided to pursue direct filtration, the WTP will most likely need to employ chloramines for secondary disinfection, and the Cities will in turn have to switch to chloramines for disinfection in their distribution systems. Conventional treatment with ozone will be the more expensive option, but also the more robust system for variable influent water quality and will provide the greatest assurance of continuously meeting regulatory standards and the TAC's treatment goals.

7 - RECOMMENDED NEXT STEPS

This section outlines the recommended steps the TAC and program management team should take to begin narrowing the field of candidate treatment trains, fill information gaps and lay the groundwork for TM 1, Part 2 and the second treatment process alternatives workshop.

The TAC should review TM 1, Part 1 (this TM) and provide direction to the program management team on the following issues:

1. Is the TAC prepared to eliminate any of the five treatment train options described in Section 4 of this TM? If so, which options?

2. Does the TAC wish to move forward with available bench- or pilot-scale testing measures to filling information gaps? If so, which testing measures?

3. Based on the TAC's responses to the above questions, does the TAC wish to schedule the next process alternatives workshop before or after the results of any selected testing measures are available?

8 - REFERENCES

Brown and Caldwell (2008). *Turlock Irrigation District Watershed Sanitary Survey of the Lower Tuolumne River and Turlock Lake*.

Brown and Caldwell (2008b). *Turlock Irrigation District Regional Surface Water Supply Pilot Study Report*.

California Department of Pesticide Regulation (2016), Pesticide Use Reporting (PUR) Database, 2014 data for Lower Tuolumne River watershed, Stanislaus

County, California Pesticide Information Portal (CalPIP) <http://calpip.cdpr.ca.gov/main.cfm>, accessed May 11, 2016.

Crittenden, J. C., R. R. Trussell, D. W. Hand, K. J. Howe and G. Tchobanoglous (2011, In Press). Water Treatment: Principles and Design, Third Edition, John Wiey & Sons, Inc.

Trussell Technologies (September, 2016). *Tuolumne River Water Quality Assessment for the Stanislaus Regional Water Authority Water Supply Project*, Technical Memorandum.