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Technical Memorandum

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Technical Memorandum

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1. EXECUTIVE SUMMARY

The existing tertiary treatment system at the Sunnyvale Water Pollution Control Plant (WPCP) is used to produce both recycled water, which must have a turbidity less than 2 nephelometric turbidity units (NTU), and treated effluent for Bay discharge, which must have a turbidity less than 10 NTU. Switching between operation modes presents significant operational and compliance monitoring challenges. Under recycled water production operation, polymer dose is approximately 1.8 times greater than during Bay discharge mode. In addition, the dual media filters (DMF) are backwashed more frequently. We have evaluated a parallel recycled water system that would produce 4 million gallons per day (mgd) of recycled water (8 mgd, ultimate). A treatment capacity of 4 mgd (8 mgd, ultimate) is in line with the most recent recycled water master plan performed in 2000. We performed this evaluation for both the plant replacement and the plant rehabilitation scenarios. We identified several Title 22 approved filtration technologies and evaluated them on relative life cycle cost, energy consumption, footprint requirement, process maturity and resource consumption. Using these criteria, we selected DMF, cloth media filtration and membrane filtration for detailed evaluation which included planning level cost estimates. For the plant rehabilitation scenario, we recommend planning for new dissolved air flotation (DAF) units followed by DMF. This alternative has a higher present worth value than DAF followed by cloth media filters, however we do not recommend assuming that a cloth media system downstream of the oxidation pond will be feasible due to uncertainty regarding technology performance. Ultimately, pilot testing of this uncertain configuration could lead to a successful execution of the lower cost approach but, for prudent planning at this juncture, the cost and consequences of the DMF based system should be assumed. In addition, we recommend that the City pilot test DMF filtration (using chemical addition) downstream of DAF operating under Bay discharge mode (10-NTU). If successful, this would significantly reduce the capital cost by eliminating the need for dedicated DAF units. For the plant replacement scenario, where conventional activated sludge treatment could precede cloth filters and result in a proven treatment technology configuration, we recommend cloth media filtration, which had the lowest cost (capital and operating) of all alternatives. For the plant rehabilitation scenario, two new chlorine contact tanks (CCTs) would be required at 4-mgd recycled water capacity; four new CCTs would be required at 8-mgd recycled water capacity. For the plant replacement, we assumed that a new ultraviolet light (UV) disinfection system would be constructed.

2. INTRODUCTION

The tertiary treatment system at the Sunnyvale WPCP consists of: DAF and DMF, followed by disinfection. Currently, the fixed growth reactors (FGRs) are upstream of the DAF units, however we recommend operating them downstream of the DAF units to promote more stable operation as shown in Figure 2-1 (see "Nitrification Process Improvements TM"). Tertiary treatment is required for effluent disposal to the San Francisco Bay (Bay). During Bay discharge, the effluent turbidity cannot exceed 10 NTU on an instantaneous basis. The tertiary treatment system is also used to produce recycled water. During recycled water production, turbidity prior to disinfection cannot exceed 2 NTU on a daily average basis. Thus, the tertiary treatment system is operated in two distinct operational modes: 1) Bay discharge (or 10 NTU) and 2) recycled water (or 2 NTU). To meet the more stringent recycled water treatment requirements, polymer dose to the DAF and the chlorine dose to disinfection must be increased. Switching between these two operational modes has resulted in significant operational challenges for WPCP operations staff.

The purpose of this technical memorandum (TM) is to summarize the existing tertiary treatment system at the WPCP, discuss challenges with current operations, and investigate viable alternatives to increase recycled water production to meet future demand. Since recycled water demand is much less than Bay discharge, it

would be costly to produce 2-NTU water continuously. The recycled water system improvements presented in the Condition Assessment and Unit Process Improvements TM (Brown and Caldwell) consisted of a parallel process train to continuously produce 2-NTU recycled water. Table 2-1 summarizes recycled water flow projections presented in the Recycled Water Master Plan (EOA, Inc., 2000). The maximum total annual recycled water demand is predicted to range between 4.5 and 5.0 mgd if all projects were constructed. The current recycled water demand is approximately 1 mgd (approximately 2 mgd, maximum month). For this analysis, the parallel recycled water system was sized for 4 mgd with the possibility of expansion to 8 mgd. This sizing is in line with the most recent recycled water flow projections. We evaluated recycled water treatment technologies for both the plant rehabilitation scenario and the plant replacement scenario.

Table 2-1. Summary of Maximum Projected Recycled Water Demand (adapted from City of Sunnyvale Recycled Water Master Plan, EOA, Inc., 2000)

Description	Maximum Projected Flow (mgd)
Current Demand	0.64
Near-term Demand	0.34
Mid-term Demand	0.24
Long-term Demand (within Sunnyvale)	2.3
Long-term (outside Sunnyvale)	1.0 to 1.5
Total	4.5 to 5.0

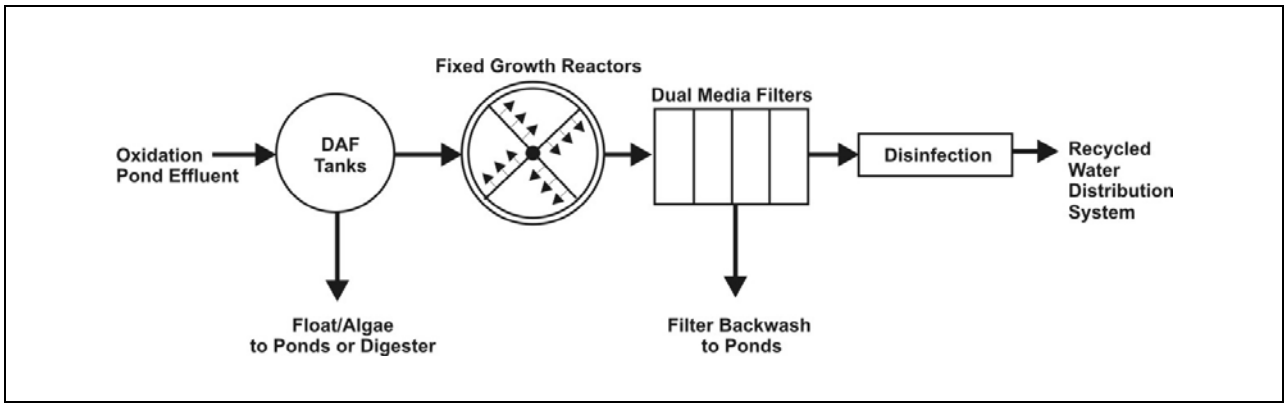

Figure 2-1. Process flow diagram for Sunnyvale WPCP tertiary treatment system. This configuration assumes that the FGRs would be downstream of the DAFs to promote more stable nitrification (see "Nitrification Process Improvements TM"). During recycled water operation, DAF polymer dose and chlorine dose are significantly higher than during Bay discharge operation.

3. EXISTING SYSTEM AND OPERATIONAL CHALLENGES

Recycled water represents a drought-resistant water source to the City of Sunnyvale and is one of the City's Level of Services (LOS). In addition, the use of recycled water reduces potable water consumption and the mass loading of pollutants to the Bay. This section provides an overview of the existing recycled water system at the WPCP; the recycled water distribution system is not considered in this analysis.

3.1 Overview of Existing System

Table 3-1 summarizes the elements of the tertiary treatment system at the WPCP. There are four DAF units that currently treat FGR effluent. Flotation is required prior to filtration due to the high algae content of oxidation pond effluent which passes through the FGRs. If not removed, algae will severely impede DMF performance and increase the frequency of backwashing (which will decrease overall recovery). Historically, polymer has been added to the DAF as a flocculation aid to improve solid-liquid separation. Polymer dosage is determined by the operation mode; recycled water operation requires higher polymer dose than Bay discharge mode.

DAF effluent is treated through four DMF units. The DMF units were designed for a flux of 5.8 gallons per minute per square foot (gpm/sf), equivalent to 8 mgd per unit, assuming all units in service. At 2035 flows (18 million gallons per day [mgd] annual average daily flow [AADF], 22.4 mgd maximum month flow), the loading would be 4.3 gpm/sf.[1] At ultimate flows (29 mgd AADF, 36 mgd maximum month flow[2]), one additional filter would need to be constructed to maintain a loading less than 5.8 gpm/sf.

DMF effluent is disinfected in four, serpentine CCTs using a liquid/gaseous chlorine system. The CCTs were designed for a 60-minute detention time for Bay discharge. At 2035 flows (using maximum month flow for sizing), the plant would need 3 of the 4 CCTs, and at ultimate flows (using maximum month flow for sizing) the plant would require 5 CCTs (all existing 4 CCTs plus 1 new CCT). Dechlorination prior to discharge to the Bay is performed by injecting sulfur dioxide. Dechlorination is not required for recycled water production; however treated effluent is partially dechlorinated with sodium bisulfite after disinfection to reduce the chlorine residual in the distribution system so as not to negatively impact end users. Two CCTs would be necessary for recycled water production at 4 mgd; four CCTs would be required for ultimate recycled water production (8 mgd).[3] If new CCTs were constructed, they would be designed specifically for recycled water production and would, presumably, eliminate the operational challenges associated with the existing units.

During recycled water production, the Recycled Water Pump Station (RWPS) pumps water to the distribution system. The RWPS has six pumps with a maximum total capacity of approximately 8 mgd. However, peak pumping is limited to approximately 6.5 mgd due to a pressure sustaining valve at the San Lucar storage tank (City of Sunnyvale 2008 Recycled Water Annual Report, March 13, 2009). The existing RWPS has sufficient capacity to meet future recycled water demand (4 mgd); no improvements are necessary. For the ultimate

[1] Filters were sized using maximum month flows increased by 6.7 percent to account for filter backwash.

[2] The maximum month flow for the ultimate flow was determined using the same maximum month to AADF peaking factor for the projected 2035 flow.

[3] For recycled water production, chlorine disinfection requires a 90 minute modal contact time in a CCT according to Title 22. A contact time of 120 minute is assumed to account for hydraulic inefficiencies in the CCTs. Each CCT has a volume of 111,300 gallons. Therefore, each CCT has 2-mgd of treatment capacity, or 4-mgd total. The CCTs may have more treatment capacity, but dye testing would be necessary to confirm this.

recycled water demand (8 mgd), the pressure sustaining valve would need to be repaired to increase distribution capacity.

Table 3-1. Summary of Existing Tertiary Treatment System Processes

Description	Value
DAF System	
Number of Tanks	4
Diameter, ft	60
Side Water Depth, ft	7
Filters	
Number of Units	4
Length, ft	32
Width, ft	30
Filter Media Depth. in	66
Anthracite, in	48
Sand, in	18
Pea gravel, in	7.5
Maximum Filtration Rate, gpm/sf	5.8
Maximum Backwash Rate, gpm/sf	35
Air Backwash Rate, cfm/sf	4
Chlorine Contact Tanks	
Number of Units	4
Number of Pass (per unit)	3
Width (per pass), ft	10
Length (per pass), ft	124
Depth (per pass), ft	12

3.2 Operational Challenges

The existing tertiary system was not designed to produce treated effluent for both Bay discharge and recycled water production. As a result this poses several operational challenges to plant staff. During recycled water operation, the DAF polymer dose is significantly higher (approximately 1.8 times) than during Bay discharge. As a consequence, DMF backwashing is performed daily, presumably due to the higher polymer dose. At elevated polymer doses, there is a higher possibility that DAF effluent (and therefore DMF influent) will contain residual polymer which can increase DMF headloss. Bay discharge operation results in DMF backwash approximately every 3 days, presumably due to the lower polymer dose. It is also important to note that filtration rates during recycled water operation are much lower than during Bay discharge.

Plant operations staff must routinely reconfigure the DAF polymer dosing depending on the operation mode. During peak recycled water demand periods, staff may reconfigure the process train on a daily basis. When operation is switched from Bay discharge to recycled production, for approximately 2 to 3 hours, DMF effluent does not meet 2-NTU recycled quality even though DAF polymer dose is increased. This represents an additional cost attributed to the current configuration. Plant staff have observed occasional upsets in

tertiary treatment performance, where DMF effluent turbidity has been greater than 10 NTU when switching to Bay discharge mode. Switching modes also poses challenges to disinfection. Recycled water production requires higher chlorine dosages so that when Bay discharge is resumed, it can be difficult to sufficiently dechlorinate before discharge. Needless to say, this is a cumbersome and labor-intensive way to operate. The inefficiencies associated with the mode switching can result in the use of potable water to supplement recycled water, which eliminates the benefits of recycled water use to Sunnyvale.

In addition to the operational challenges, there are challenges associated with compliance monitoring. When the plant is in recycled water production mode, it is not possible to collect effluent samples for compliance monitoring. This can pose problems for constituents that require frequent sampling events. Construction of a dedicated recycled water system that would operate in parallel with the tertiary treatment system would mean that Bay discharge would continue regardless of recycled water production.

4. OVERVIEW OF RECYCLED WATER REGULATIONS

Recycled water regulations in California are dictated by Title 22 California Code of Regulations. Recycled water for surface irrigation requires disinfected tertiary (i.e. filtered, nitrification is not required under Title 22) recycled water, which has been biologically oxidized and meets the following criteria:

1. Has been coagulated[4] and passed through natural undisturbed solids or a bed of filter media pursuant to the following:
    a. At a rate that does not exceed 5 gpm/sf in mono, dual or mixed media gravity or pressure filtration systems, or does not exceed 2 gpm/sf in traveling bridge automatic backwash filters; and
    b. The filtered wastewater turbidity does not exceed any of the following; a daily average of 2 NTU, 5 NTU more than 5 percent of the time within a 24-hour period, and 10 NTU at any time.

OR

2. Has been passed through a micro, nano, or reverse osmosis membrane following which the turbidity does not exceed any of the following: 0.2 NTU more than 5 percent of the time within a 24-hour period and 0.5 NTU at any time.

AND

3. Has been disinfected by either:
    a. A chlorine disinfection process that provides a CT of 450 mg-minutes/L with a modal contact time of not less than 90 minutes, based on peak dry weather design flow, or
    b. A disinfection process that, when combined with filtration, has been demonstrated to achieve 5-log inactivation of virus.

There are several alternative technologies to conventional filtration that can meet the filtration requirements and have been documented as accepted by the California Department of Public Health (see Treatment Technology Report for Recycled Water, February 2009). This TM does not cover all filtration technologies in exhaustive review but provides a review of select technologies. For the plant rehabilitation scenario, we assumed that chlorine disinfection would be used for disinfection because of the impact algae could have on the efficiency of UV disinfection. The green color of the water could reduce UV transmittance.[5] For the plant replacement scenario where the pond system would be replaced with an activated sludge process, we assumed that UV disinfection would be used which would eliminate potential disinfection by-products discharge problems that are associated with chlorine based disinfection methods.

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[4] Coagulation may be waived if the filter effluent does not exceed 2 NTU, the filter influent is continuously measured, the filter influent turbidity does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and automatically activated chemical addition or diversion facilities are provided in the event filter effluent turbidity exceeds 5 NTU.

[5] Membrane (either microfilter or ultrafilter) filtered effluent could have less color than other filtration technologies. However, pilot testing would be necessary to confirm. To be conservative, we assumed chlorine disinfection would be used for membranes for the plant rehabilitation scenario.

5. OVERVIEW OF SELECT FILTRATION TECHNOLOGIES

This section includes an overview of five main types of filtration technologies including: conventional depth filtration, continuous backwash filters, fuzzy filters, membrane filters and cloth media filters.

5.1 Conventional Depth Filtration

In the conventional depth filtration process, water filters down through a bed of filter media. Particulates are removed in the filter bed by several mechanisms which include straining, adhesion, impaction, sedimentation, flocculation and interception. Filter media typically rests on top a layer of gravel. An underdrain system, which collects filter effluent, is typically under the layer of gravel. Over time, the accumulation of material in the filter bed will increase head loss, and can eventually result in particle breakthrough in the effluent. Backwashing is performed where flow is reversed through the filter media (using filter effluent) to remove particles. An air scour can also be performed. After backwash, the filter is returned to service. The DMF process is one type of depth filtration process. In the DMF process, two layers of media (typically anthracite and sand) are used.

5.2 Continuous Backwash Filtration

The continuous backwash filter is a granular filter, similar to the DMF process. However, it continuously produces treated effluent since it is never out of service for backwashing. There are currently nine suppliers of Title 22 certified upflow continuous backwash filtration technologies; the Dynasand filter (Figure 5-1), manufactured by Parkson Corp. (Fort Lauderdale, FL), is one example. It is Title 22 approved for a flux of 5 gpm/sf, which is the same flux as DMF. Influent enters the bottom of the sand bed and flows upward. A portion of the sand is continuously washed so that a backwash cycle is not necessary, and the filter is never out of service for backwashing. Continuous backwash filters will have similar footprint requirements to DMF, but will have higher energy costs associated with the continuous backwashing.

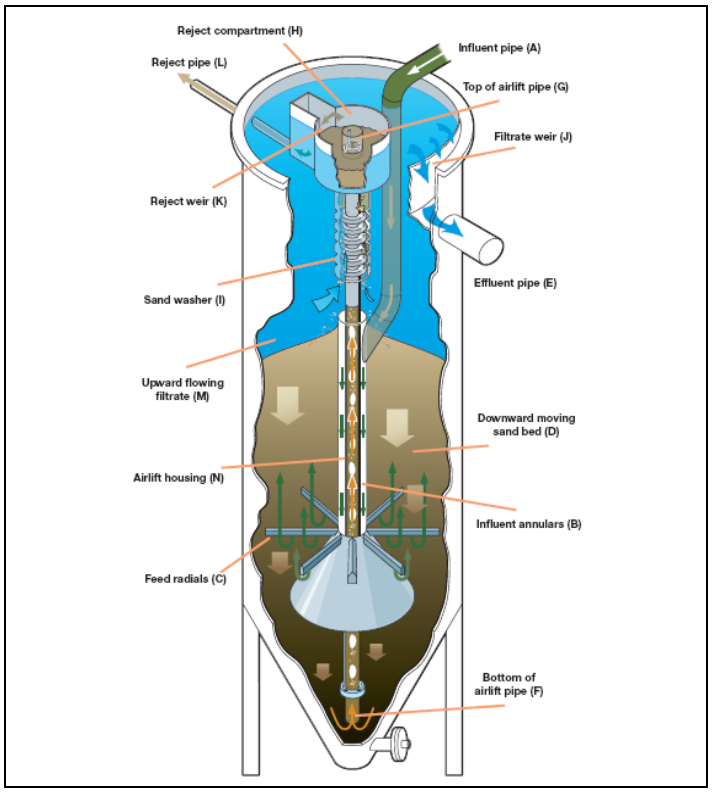

Figure 5-1. Dynasand filter manufactured by Parkson Corpororation. (Source: Parkson website - http://www.parkson.com/files/Product%20Brochures/PC%20FbrglsTankOilWtrSep/PC%20DynaSand.pdf)

5.3 Fuzzy Filter

The Fuzzy Filter (Figure 5-2), manufactured by Schreiber LLC (Trussville, AL), uses a low-density, high-porosity synthetic media. The process is Title 22 certified for a flux of 30 gpm/ft^2. Because the media is compressible, the porosity can be altered for different applications by compressing it between two porous plates. Influent enters the bottom of the filter and travels up through the media. During the backwash cycle, the unit is taken out of service and an air scour and wash cycle using filtered effluent is performed to remove solids from the media. The Fuzzy Filter process will have a smaller footprint than a DMF or continuous backwash system due to the higher flux rates. The Fuzzy Filter has mostly been used in smaller plants; there are currently no installations larger then 1 mgd in California.

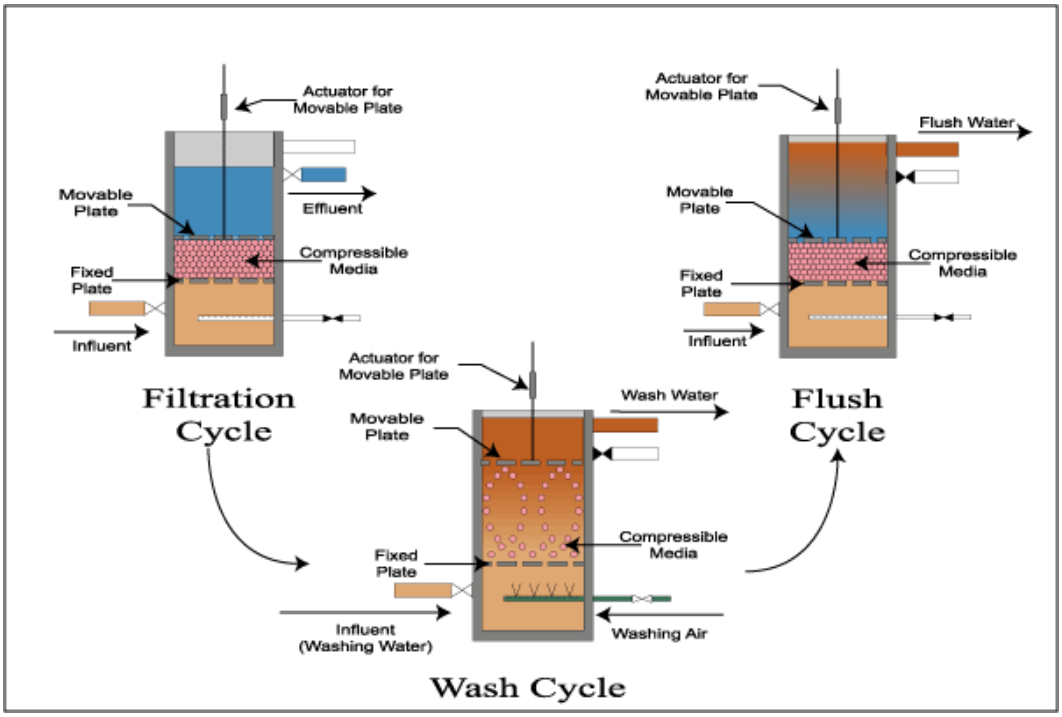

Figure 5-2. Fuzzy Filter manufactured by Schreiber LLC. (Source: Schreiber website - http://www.schreiberwater.com/html/equipment/fuzzyfilter.html)

5.4 Membrane Filtration

Membrane processes for recycled water are typically either ultrafilters (UF) or microfilters (MF). The pore size of MF units is typically 0.1 to 0.4 microns; UF pore size is typically 0.01 microns. Membranes can be operated in either pressure-driven or vacuum-driven modes. For pressure-drive systems, water is filtered through the membrane using feed pumps. The membrane is routinely backwashed (approximately every 10 to 30 minutes) to remove accumulated debris. For a vacuum system, membranes are immersed in a process tank, and water is pulled through the membranes using a vacuum pump. Similar to pressure-driven membranes, vacuum membranes must be backwashed frequently; a relax cycle can be used in lieu of backwash where the vacuum pumps are turned off to allow the membrane to recover. Membrane aeration is typically used with vacuum systems to mitigate membrane fouling. Either membrane configuration eventually will require a chemical cleaning to remove material that is not removed from backwashing or relaxing, typically after several months. Chemical cleaning is typically performed with sodium hypochlorite; acid cleaning may also be necessary in some instances. Membrane lifetime will vary depending on operation and cleaning frequency. Typically, membranes are replaced approximately every 5 to 10 years.

There are currently 17 membrane suppliers that are Title 22 approved for recycled water production. However, there are only a few that have multiple installations in California. Membrane systems represent a small footprint technology that, in general, will be more expensive than traditional tertiary filtration. In addition, the energy costs associated with pumping and the chemicals necessary for cleanings will increase operations and maintenance (O&M) costs. Figure 5-3 presents a picture of a full-scale (7.8 mgd), pressure driven MF system manufactured by Pall Coporation (East Hills, NY).

Figure 5-3. Full-scale Pall MF system (Source: Pall website - http://www.pall.com/water_8149.asp)

5.5 Cloth Media Filtration

Cloth media filtration is a low energy process that uses cloth media to filter out solids. The cloth media is submerged in a process tank and water filters through the cloth media. The media is routinely cleaned using vacuum headers that remove solids from the cloth media surface. Aqua Aerobic Systems, Inc. (Rockford, IL) is one of six Title 22 approved cloth media suppliers. The AquaDisk manufactured by Aqua Aerobic Systems, Inc. is an example of a submerged fixed cloth-media filter. The cloth media is Title 22 approved for a flux of 6 gpm/sf. Figure 5-4 presents an example of the AquaDisk system. Water flows through the media by gravity, and over time the solids will accumulate on the outside of the cloth while water flows to the inside. Solids will also settle out in the tank, and can be routinely removed through a sludge valve. As solids continue to accumulate, the tank level rises and, once a set level is reached, the backwash cycle will initiate. During backwash, a vacuum pump removes solids from the surface of the cloth media as disks are slowly rotated. Similar to membranes, cloth media will need to replaced approximately every 5 to 10 years.

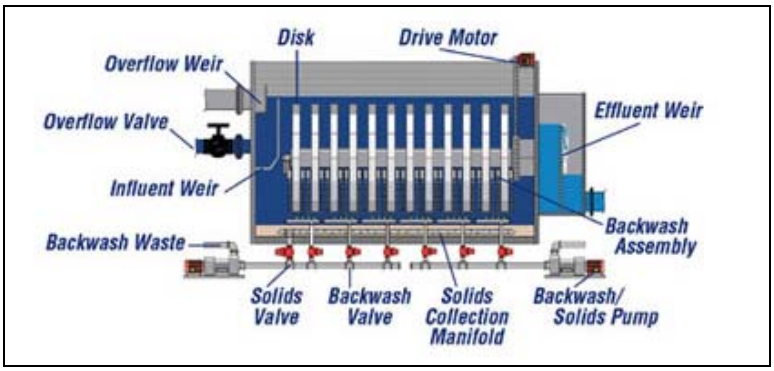

Figure 5-4. Cloth media filter (AquaDisk) manufactured by Aqua Aerobic Systems, Inc. (Source: Aqua Aerobic Systems, Inc. website - http://www.aqua-aerobic.com/aquaDisk.asp)

6. ALTERNATIVES ANALYSIS

6.1 Evaluation of Technologies

Table 6-1 provides a comparison of the five filtration technologies identified in section 5. With the exception of membranes, all filtration technologies are low energy systems. The DMF and continuous backwash filters have the highest footprint requirements due to limiting the filtration flux rate to 5 gpm/sf. Cloth media filters will have lower footprint requirements than DMF due to the higher flux rate and stacking of treatment surface area. Membranes will also have lower footprint requirements than DMF despite the lower filtration flux rates. This is because membranes have much more area in a smaller space than DMF. Membranes will have the highest cost of all technologies both due to capital, chemical and energy costs. Membranes and granular filtration are mature processes that have several full-scale installations in California. The fuzzy filter and cloth media filtration technologies are newer technologies. Of the two, cloth media filtration has more installations.

Of the five technologies identified in Table 6-1, DMFs, cloth media and membranes were considered for subsequent evaluation. DMFs were selected over continuous back wash filters because DMFs will have lower energy costs. In addition, the City has direct experience with DMF technology. The fuzzy filter process was eliminated because it has limited installations in California. Currently, there are no fuzzy filter installations greater than 1 mgd in California.

Table 6-1. Summary of Filtration Technologies that were Considered for the WPCP for the Production of Recycled Water

Technology	Life Cycle Cost	Energy Consumption	Footprint Requirement	Process Maturity	Resource Consumption
DMF	Med	Low	High	Mature	Low
Continuous Backwash Filters	Med/High	Low	High	Mature	Low
Fuzzy Filters	Low	Low	Low	Evolving	Low
Membranes	High	High	Low	Mature	High
Cloth Media Filters	Low	Low	Med	Evolving/Mature	Low

6.2 Alternatives Analysis – Plant Rehabilitation Scenario

The technologies identified in Table 6-1 were evaluated for implementation into the plant rehabilitation scenario.

6.2.1 Evaluation of Feedwater Quality – Plant Rehabilitation Scenario

For the plant rehabilitation scenario, there are four potential feed water locations for the recycled water system.

- Oxidation pond effluent– this would represent the worse quality feed water because effluent suspended solids and algae would not be removed prior to filtration.
- Bay Discharge DAF effluent –DAF effluent under the current polymer dosing would be better than oxidation pond effluent. However, this effluent would not meet the Title 22 regulations for granular

filtration that requires an influent turbidity less than 5 NTU. If turbidity is greater than or equal to 5 NTU, coagulation is required. Use of coagulation could produce a suitable feed water for DMF, but testing (full-scale or pilot-scale) would be necessary to confirm. There is no limit for influent turbidity if membranes are used.

- DMF effluent – The DMF effluent at current polymer dose would be 10 NTU or less. In order to meet Title 22 requirements, an additional filtration step would be necessary.
- Dedicated DAF effluent – this configuration would provide the highest quality feedwater for the processes. Presumably, the new DAF would be operated with polymer dosing similar to current dosing strategies for producing recycled water.

Table 6-2 presents an analysis of each previously identified recycled water filtration technology (with the exception of fuzzy filter and continuous backwash filters) and each feedwater location. DMF is only recommended using the effluent from a new, dedicated DAF. For the cloth media filters, a high-quality feed water will improve process performance. Therefore, a new, dedicated DAF would also be used upstream of the cloth media filters. Aqua Aerobic Systems, Inc., (manufacturer of cloth media technology) has expressed concern with using their technology downstream of a DAF unit due to potential media blinding from polymer use; pilot testing would be necessary to confirm process performance because of the presence of algae and residual polymer in the influent. The membrane could be placed downstream of the existing DAF or DMF, or downstream of a new DAF. Similar to the cloth media, we recommend a pilot test due to the potential for fouling from the residual polymer and algae.[6]

Table 6-2. Recommendations for Feedwater for each Tertiary Filtration Technology for the Plant Rehabilitation Scenario for the Production of Recycled Water

Technology	Oxidation Pond Effluent	DAF Effluent (Operating at 10 NTU Bay Discharge)	DMF Effluent (Operating at 10 NTU Bay Discharge)	Dedicated DAF Effluent (Operating at 2-NTU Recycled Water Discharge)
Dual Media Filters	Not Recommended	Existing Process Testing Would be Required	Not Recommended	Proven
Membranes	Not Recommended	Pilot Testing Would be Necessary	Pilot Testing Would be Necessary	Pilot Testing Would be Necessary
Cloth-Media Filters	Not Recommended	Not Recommended	Not Recommended	Pilot Testing Would be Necessary

6.2.2 Alternative Identification – Plant Rehabilitation Scenario

As a result of the preliminary screening (filtration technology and feedwater source), we identified three potential treatment alternatives. A process flow diagram of each alternative is shown in Figure 6-1. For Alternative 1, a new DAF and DMF would be installed. For Alternative 2, a new cloth media filter would be located downstream of a new DAF. For Alternative 3, new membrane filters would be located downstream of the tertiary DMFs. Both Alternative 2 and 3 would require pilot testing to confirm required performance.

[6] Membrane fouling due to algae is a common concern. Huang et al., 2009 provide a critical review of membrane pretreatment to mitigate membrane fouling.

The DAF units were sized for a loading of 6 gpm/sf.[7] Each filtration technology was de-rated to account for the difficulty associated with filtering pond effluent. We sized the DMF filters using the existing filter loading rates during recycled water production (2 gpm/sf).[8] We sized the cloth media filters for a filter flux of 3.25 gpm/sf, which is considerably less than Title 22 rated filter flux (6 gpm/sf). We assumed there would be three cloth media units (2 duty/1 standy). The membrane filters were sized at a flux of 35 gallons per square foot per day (gfd) with 3 trains total (2 duty/1 standby).

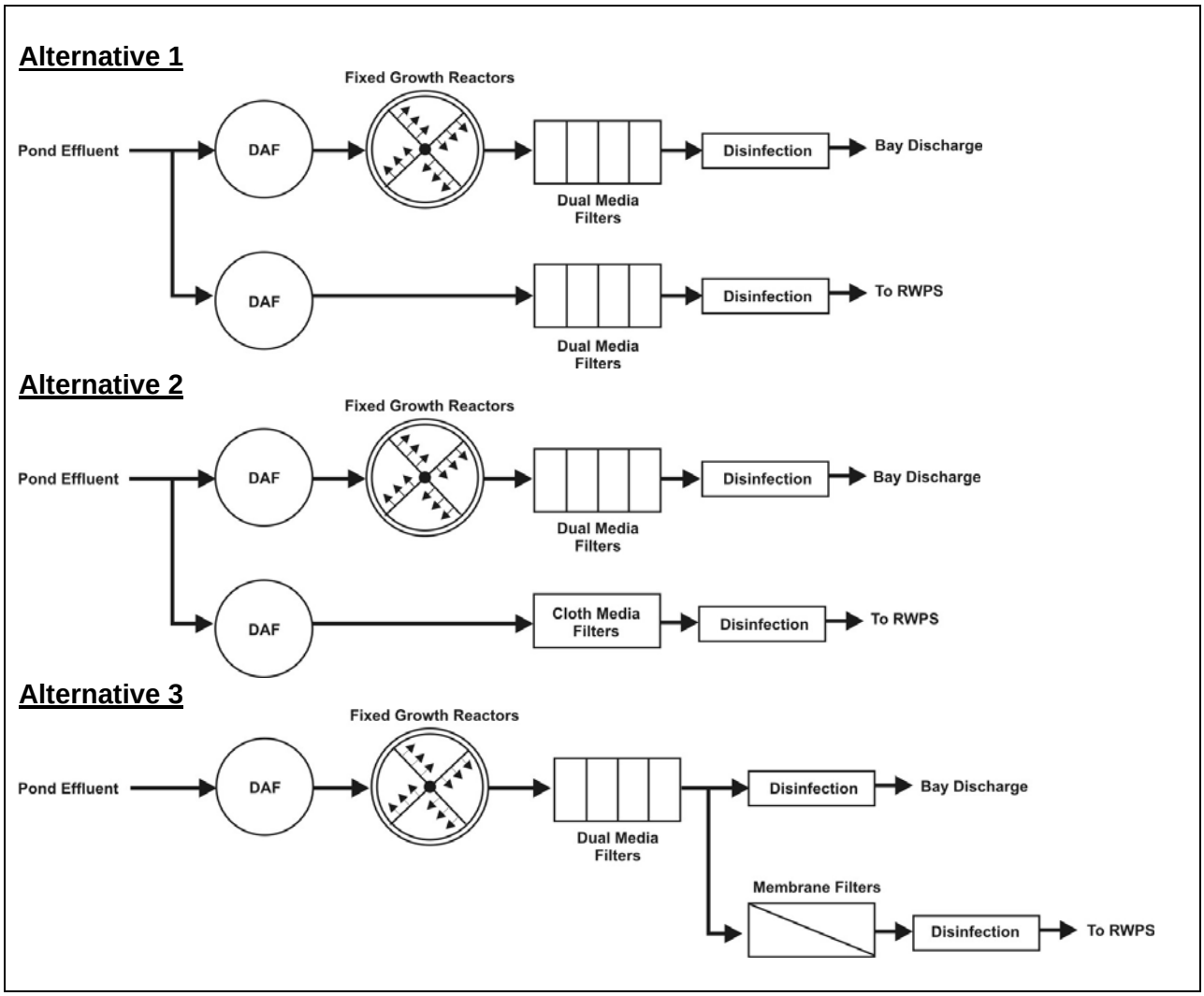

Figure 6-1. Process flow diagram for each recycled water alternative for the plant rehabilitation scenario.

[7] This DAF loading rate is consistent with the value used in the TM: Upgrade Alternatives for the Air Flotation Tanks (AFT) at the Sunnyvale WPCP

[8] Higher flux rates may be possible with continuous coagulant addition upstream of the DMF. However, testing (either pilot-scale or full-scale) would be necessary to confirm.

6.2.3 Cost Analysis – Plant Rehabilitation Scenario

Planning level cost estimates were determined to estimate capital and selected operating costs. The cost estimate was performed assuming the DMF, DAF and cloth media filters would be constructed with concrete tanks; membrane filter equipment would be located on a concrete pad. These costs are meant to be used to compare technologies and should not be used to estimate actual project costs. Table 6-3 presents the capital costs associated with each alternative.[9] Alternative 3 had the highest capital cost ($5.5 million) followed by Alternative 1 ($4.8 million) and Alternative 2 ($3.6 million).

Table 6-3. Comparable Capital Costs for 4-mgd Recycled Water System for the Plant Rehabilitation Scenario

Parameter	Alternative 1 DAF Followed by DMF	Alternative 2 DAF followed by Cloth Media	Alternative 3 Membrane Filters
DAF	$1,928,000	$1,928,000	---
Filtration	$2,864,000	$1,715,000	$5,495,000
Total	$4,792,000	$3,643,000	$5,495,000

Selected operating costs were determined assuming that 730 million gallons of recycled water would be produced per year (or 4-mgd production for 6 months per year which represents projected near-term operating condition) (Table 6-4). All alternatives include DAF; therefore, DAF operating costs were not included (with the exception of polymer use). The difference in operational costs between the alternatives will be determined by the polymer cost, electrical cost, chemical cost for membrane cleaning, and replacement cost. The difference in the polymer costs between alternatives is due to the difference in dose; Alternatives 1 and 2 require a higher dose than Alternative 3. Electrical costs were calculated assuming $0.20/kWhr.[10] All alternatives have a replacement cost. We assumed 10-year replacement for the membranes; 7-year replacement for the cloth media; and 10-year replacement for the granular media. Replacement costs represent installed costs, but do not include costs associated with disposal of spent equipment. Maintenance costs and parts replacement were not included.

Alternative 2 has the lowest operation cost ($177,000/yr) due to the low electrical cost and replacement cost associated with the cloth media filtration. Alternative 1 operation costs are higher ($206,000/yr) and are due to the higher replacement costs associated with the granular media. We assumed a 10-year replacement cycle. In reality, this replacement may be less frequent; the existing DMF media is over 20 years old. Alternative 3 has the highest operating cost ($215,000/yr) because of the chemical requirements and replacement costs

[9] Table 6-3 does not include costs for startup, contingency, insurance or bonds. There is no significant civil work included (i.e. piles, cut and/or fill, yard piping, demo, landscape, etc.). Allowances were made for above-ground interconnecting piping as required.

[10] Electrical costs were determined by estimating the additional natural gas that would be required to operate equipment. Current gas costs $1.04/Therm. Assuming a 30 percent efficiency for the engines, this equates to $0.12/kWhr. Increase to $0.20/kWhr to account for costs associated with equipment operation and maintenance and to impose additional burden on alternatives requiring more electric power, reflecting a Level of Service objective to minimize power use.

$$Cost = \frac{\$1.04}{Therm} * \frac{1 Therm}{100{,}000 BTU} * \frac{3412 BTU}{kWhr} * \frac{1}{0.3}$$

$$Cost = \frac{\$0.12}{kWhr}$$

associated with the membrane filters. There will be a reduction in chlorine requirements for disinfection with Alternative 3 because the membrane filtered effluent will be free of particles. Particles present in filter effluent will increase chlorine requirements because they exhibit a chlorine demand. However, the savings in sodium hypochlorite that could be realized with Alternative 3 is not expected to reduce the operating costs enough to be competitive with Alternatives 1 or 2.

Table 6-4. Opinion of Select Operating Costs for 4-mgd Recycled Water System in the First Year Assuming an Annual Production of 730 Million Gallons for the Plant Rehabilitation Scenario

Parameter	Alternative 1 DAF Followed by DMF	Alternative 2 DAF followed by Cloth Media	Alternative 3 Membrane Filters
Chemical Costs			
Polymer Use[1]	$170,000	$170,000	$96,000
Membrane Cleaning[2]	---	---	$6,000
Electrical Costs			
Dual Media Filters[3]	$3,000	---	$3,000
Cloth Media Filters[4]	---	$1,000	---
Membranes	---	---	$41,000
Replacement Cost			
Dual Media Fitlers[5]	$33,000	---	---
Cloth Media Filters[6]	---	$6,000	---
Membranes[7]	---	---	$69,000
Annual Cost	$206,000	$177,000	$215,000

[1] Assuming $7.74/gallon of polymer ($0.9/lb at 8.6 lb/gal). Bay discharge requires 17 gallons per million gallons treated; recycled water requires 30 gallons per million gallons treated

[2] Includes costs for chemicals used for clean in place and maintenance washes

[3] Includes cost of backwash pumps and air scour

[4] Includes cost for drive motors and backwash pumps

[5] Assume 10-year replacement. 2,900 cu.ft. of sand at $22/cu. ft. (installed); 7,740 cu. ft. anthracite at $30/cf (installed). Include 11.5-percent markup for tax and shipping.

[6] Assume 144 units at $220/unit. Include 26.5-percent markup for tax, shipping and installation.

[7] Assume $1,600 per module at 342 modules. Assume 10 year replacement. Include 26.5-percent markup for tax, shipping and installation

The present worth value of each alternative is shown in Table 6-5. We assumed a 5-percent interest rate, 2-percent inflation, and a 10-year life cycle. Alternative 3 had the highest present worth value ($7.3 million) followed by Alternative 1 ($6.6 million). Alternative 2 had the lowest present worth value ($5.2 million).

Table 6-5. Opinion of Present Worth Value for 4-mgd Recycled Water System for Plant Rehabilitation Scenario (10-year life cycle, 5-percent interest, 2-percent inflation)

Parameter	Alternative 1 DAF Followed by DMF	Alternative 2 DAF followed by Cloth Media	Alternative 3 Membrane Filters
Capital Cost	$4,792,000	$3,643,000	$5,495,000
Annual Operations Cost in the First Year	$206,000	$177,000	$215,000
Life Cycle Cost	$1,757,000	$1,510,000	$1,834,000
Present Worth Value	$6,549,000	$5,153,000	$7,328,000

6.3 Alternatives Analysis – Plant Replacement Scenario

The technologies identified in Table 6-1 were evaluated for implementation into the plant replacement scenario.

6.3.1 Alternative Identification – Plant Replacement Scenario

A process flow diagram of each alternative for the plant replacement scenario is shown in Figure 6-2. For this scenario, the oxidation ponds would be replaced with an activated sludge process. The effluent from the activated sludge alternative would be fully nitrified, which would eliminate the need for the FGRs. In addition, there would no longer be a need for the DAF for algae removal. For each alternative, we assumed that the secondary effluent could be used as a feedwater. For Alternative 1, a new DMF would be installed. For Alternative 2, a new cloth media filter would be installed. For Alternative 3, new membrane filters would be installed. Neither Alternatives 2 nor 3 would require pilot testing to confirm performance since both cloth media and membranes have been shown to operate treating activated sludge effluent. However, pilot testing would determine site specific operating information that could optimize process design.

We sized the DMF filters for a filter loading rate of 5 gpm/sf. The cloth media filters were sized assuming a filter flux of 6 gpm/sf. We assumed 2 cloth media filters (1 duty/1 standby). The membrane filters were sized for 4 mgd and a filter flux of 35 gfd.

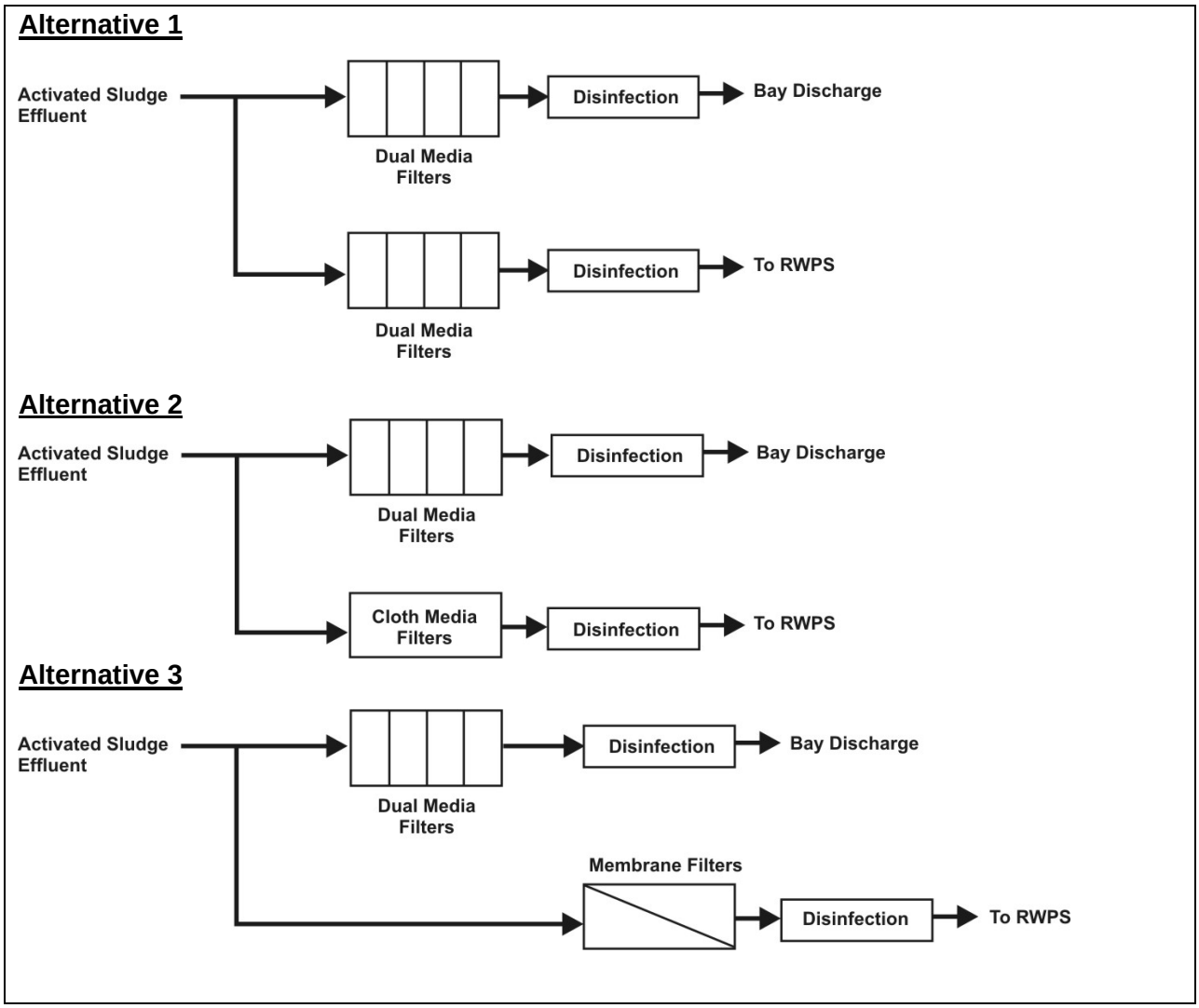

Figure 6-2. Process flow diagram for each recycled water alternative for the plant replacement scenario.

6.3.2 Cost Analysis – Plant Replacement Scenario

Planning level cost estimates were determined to estimate capital and selected operating costs. The cost estimate was performed assuming the DMF and cloth media filters would be constructed with concrete tanks; membrane filter equipment would be located on a concrete pad. These costs are meant to be used to compare technologies and should not be used to estimate actual project costs. Table 6-6 presents the capital costs associated with each alternative.[11] Alternative 3 had the highest capital cost ($3.7 million) followed by Alternative 1 ($1.5 million) and Alternative 2 ($1.2 million). The larger capital cost of Alternative 3 is due to the equipment costs associated with the membranes.

[11] Table 6-3 does not include costs for startup, contingency, insurance or bonds. There is no significant civil work (i.e. piles, cut and/or fill, yard piping, demo, landscape, etc.). Allowances were made for above-ground interconnecting piping as required.

Table 6-6. Comparable Capital Costs for 4-mgd Recycled Water System for Plant Replacement Scenario			
Parameter	Alternative 1 DMF	Alternative 2 Cloth Media	Alternative 3 Membrane Filters
Total	$1,494,000	$1,205,000	$3,707,000

Similar to the plant rehabilitation scenario, selected operating costs were determined assuming that 730 million gallons of recycled water would be produced per year (Table 6-7). The difference in operational costs between the alternatives will be determined by the chemical cost for membrane cleaning, and replacement cost. As before, electrical costs were calculated assuming $0.20/kWhr. We assumed 10-year replacement for the membranes; 7-year replacement for the cloth media; and 10-year replacement for the granular media. Replacement costs represent installed costs, but do not include costs associated with disposal of spent equipment. Maintenance costs and parts replacement were not included.

Alternative 2 has the lowest operation cost ($4,000/yr) due to the low electrical cost and replacement cost associated with the cloth media filtration. Alternative 1 operation costs are higher ($17,000/yr) and are due to the higher replacement costs associated with the granular media. We assumed a 10-year replacement cycle. In reality, this replacement may be less frequent; existing DMF media is over 20 years old. Alternative 3 has the highest operating cost ($80,000/yr) because of the chemical requirements and replacement costs associated with the membrane filters.

Table 6-7. Opinion of Select Operating Costs for 4-mgd Recycled Water System in the First Year Assuming an Annual Production of 730 Million Gallons for the Plant Replacement Scenario

Parameter	Alternative 1 DMF	Alternative 2 Cloth Media	Alternative 3 Membrane Filters
Chemical Costs			
Membrane Cleaning[1]	---	---	$4,000
Electrical Costs			
Dual Media Filters[2]	$3,000	---	$3,000
Cloth Media Filters[3]	---	$1,000	---
Membranes	---	---	$27,000
Replacement Cost			
Dual Media Fitlers[4]	$14,000	---	---
Cloth Media Filters[5]	---	$3,000	---
Membranes[6]	---	---	$46,000
Annual Cost	$17,000	$4,000	$80,000

[1] Includes costs for chemicals used for clean in place and maintenance washes

[2] Includes cost of backwash pumps and air scour

[3] Includes cost for drive motors and backwash pumps

[4] Assume 10-year replacement. 1,180 cu. ft.f of sand at $22/cf. (installed); 3,140 cu. ft. anthracite at $30/cu. ft. (installed). Include 11.5-percent markup for tax and shipping.

[5] Assume 72 units at $220/unit. Include 26.5-percent markup for tax, shipping and installation.

[6] Assume $1,600 per module at 228 modules. Assume 10 year replacement. Include 26.5-percent markup for tax, shipping and installation

The present worth value of each alternative is shown in Table 6-8. We assumed a 5-percent interest rate, 2-percent inflation, and a 10-year life cycle. Alternative 2 has the lowest present worth value ($1.2 million). The present worth value of Alternative 3 was higher ($1.6 million), and Alternative 3 had the highest present worth value ($4.4 million).

Table 6-8. Opinion of Present Worth Value for 4-mgd Recycled Water System for Plant Replacement Scenario (10-year life cycle, 5-percent interest, 2-percent inflation)

Parameter	Alternative 1 DMF	Alternative 2 Media	Alternative 3 Membrane Filters
Capital Cost	$1,494,000	$1,205,000	$3,707,000
Annual Operations Cost in the First Year	$17,000	$4,000	$80,000
Life Cycle Cost	$145,000	$34,000	$682,000
Present Worth Value	$1,639,000	$1,239,000	$4,389,000

7. PLANNING LEVEL RECOMMENDATIONS

7.1 Plant Rehabilitation Scenario

For the plant rehabilitation scenario, we recommend Alternative 1 (DAF followed by DMF). Although Alternative 1 has a higher capital cost and life cycle cost than Alternative 2 (cloth media filtration), we do not recommend operating cloth media on oxidation pond water due to the uncertainty in performance. A pilot study of cloth media filtration is required before the technology could be further considered for this application.

Figure 7-1 presents a conceptual layout for Alternative 1 for the plant rehabilitation scenario. The DAF and DMF units would be designed to be modular to meet the future recycled water demand (8 mgd). Two new CCTs are included. Table 7-1 summarizes the requirements for Alternative 1. It may be possible to operate the DMF units treating DAF effluent (operated in Bay Discharge mode) if chemical were added upstream of the DMF units. If possible, this would eliminate the need for new, dedicated DAF units and could reduce the size of the DMF units. We recommend that chemical addition upstream of the DMF units while the DAF is operated in Bay discharge mode is tested to determine if this is possible.

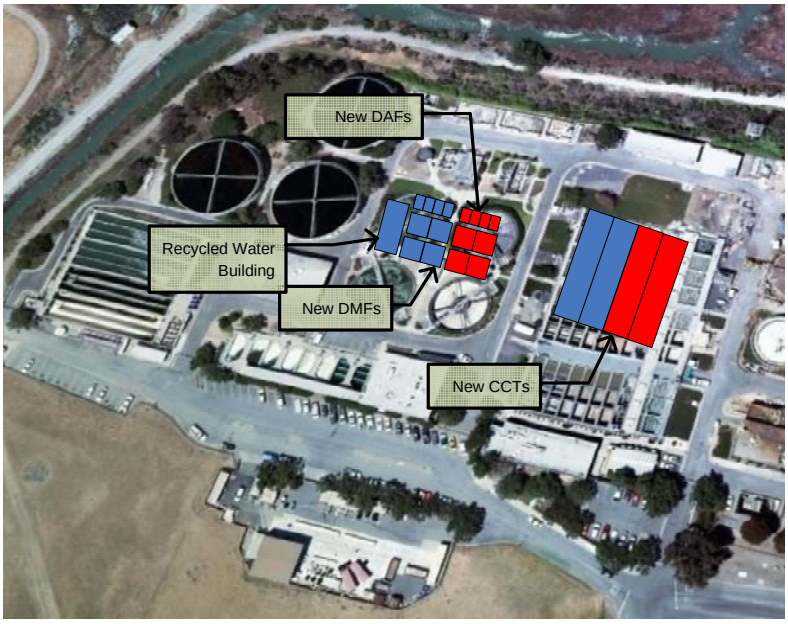

Figure 7-1. Conceptual layout of Alternative 1 for the plant rehabilitation scenario at buildout flows. (Additional footprint requirements for ultimate flows are indicated in red).

Table 7-1. Summary of Alternative 1 Requirements for the Plant Rehabilitation Scenario		
Description	Value (4 mgd)	Value (8 mgd)
DAF System		
Number of Tanks	4	8
Length, ft	15	15
Width, ft	10	10
Filters		
Number of Units	4	8
Length, ft	22	22
Width, ft	22	22
Filter Media Depth, in	66	66
Chlorine Contact Tanks		
Number of Units	2	4
Number of Pass (per unit)	3	3
Width (per pass), ft	10	10
Length (per pass), ft	124	124
Depth (per pass), ft	12	12

7.2 Plant Replacement Scenario

For the plant replacement scenario, we recommend Alternative 2 (cloth media). Alternative 2 had the lowest capital and operating costs of the three alternatives. Conversion of the plant to an activated sludge process would produce a suitable feedwater to the cloth media process.

Figure 7-2 presents a conceptual layout for Alternative 2 for the plant replacement scenario. Similar to the plant rehabilitation scenario, the cloth media filters and UV system would be designed to be modular to meet the future recycled water demand (8 mgd). UV disinfection may or may not be the final recommendation for plant replacement scenario; chlorine contact could be used in place of UV disinfection. Table 7-2 summarizes the requirements for Alternative 2 using UV disinfection.

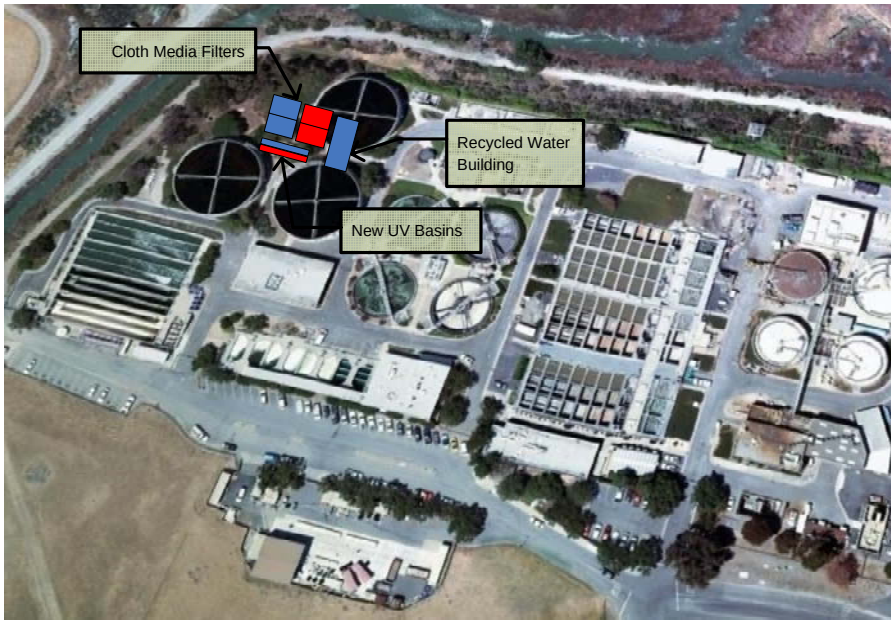

Figure 6-2. Conceptual layout of Alternative 2 for the plant replacement scenario at buildout flows and ultimate flows. (Additional footprint requirements for ultimate flows are indicated in red).

Table 6-2. Summary of Alternative 2 Requirements for the Plant Replacement Scenario

Description	Value (4 mgd)	Value (8 mgd)
Cloth Media Filters		
Number of Units	2	4
Number of Disk Filters per Unit	8	8
Length, ft	18	18
Width, ft	10	10
Height, ft	12	12
UV Disinfection		
Number of UV Channels	2	4
Length, ft	42	42
Width, ft	2	2
Depth, ft	6	6

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