Section 8

Recommended Treatment Process and Cost Estimates

This section presents the treatment process recommendations and cost estimates for a seawater reverse osmosis (SWRO) desalination plant in Santa Cruz. The recommendations are based on the pilot study results and information from existing desalination facilities operating worldwide.

8.1 Design Approach and Assumptions

Testing and subsequent recommendations in terms of treatment processes were based on information provided by **scwd²** as to the reliability required of a seawater plant. For example, the plant would need to reliably produce 2.5 mgd even when some equipment is off-line for maintenance or cleaning. These assumptions provided guidance as to the selection of the treatment processes recommended. However, subsequent design phases may choose to challenge these assumptions.

The goal of the treatment process recommendations is to provide a SWRO desalination plant with sufficient redundancy to reliably provide 2.5 mgd during a drought. The recommendations have been developed with input from both the SCWD and the SqCWD staff and assume that the plant will produce from 0.5 to 2.5 mgd of permeate with an average production of 1.6 mgd over the first 30 years of operation.

Table 8-1 provides a summary of the flow rates for the individual treatment processes based on plant production rates ranging from 0.5 to 2.5 mgd. The flow rates at 2.5 mgd of production were used to develop design criteria for each treatment process.

Table 8-1. Full-scale Desalination Facility Flow Rates for Equipment Sizing (mgd)

Plant Production	Source Water Flow(1)	RO Feedwater Flow after Pretreatment	RO Permeate & Post-treatment Flow	RO Brine Discharge Flow	Washwater Recycle Flow
0.5 mgd	1.2	1.1	0.5	0.6	0.1
1.0 mgd	2.4	2.2	1.0	1.2	0.2
1.5 mgd	3.7	3.3	1.5	1.8	0.4
2.0 mgd	4.9	4.4	2.0	2.4	0.5
2.5 mgd	6.3	5.6	2.5	3.1	0.7

(1) The source water design flow assumes that the pretreatment system will operate at a constant rate. This approach requires that the plant be designed to treat the design source water flow (i.e., RO Feedwater flow plus the washwater recycle flow) to account for downtime when individual pretreatment units are being backwashed or cleaned. Variable and constant rate design approaches may be further evaluated during the preliminary design phase of the project.

Because the production of 2.5 mgd is primarily required during drought conditions, the design approach assumes that the facility will need to achieve water quality goals under worst-case water quality conditions, which during a drought, are expected to be characterized by summer temperatures and red tide type water quality. Based on the pilot testing results, it is expected that designing the treatment systems for red tide type water quality conditions will allow the plant to meet water production and reliability goals during storm events.

Table 8-2 provides a summary of the assumed water quality conditions used to develop design criteria for a full-scale facility.

Table 8-2. Assumed Water Quality Conditions Used to Develop SWRO Plant Design Criteria

Description	Units	Design Criteria Range
Source Water TDS	mg/L	Average: 36,000 Range: 35,000 to 37,000
Average Daily RO feedwater temperature	Degrees Celsius	Average: 14 Range: 10 to 18
RO feedwater pH	pH Units	Average: 7.6 Range: 7.3 to 8.1
Source water turbidity	NTU	Average: 5 Range: 1 to 100
Source water TOC	mg/L	Average: 3.0 Range: 1 to 20
Source water chloride	mg/L	Average: 19,000 Range: 18,000 to 20,000
Source water bromide	mg/L	Average: 70 Range: 60 to 80
Source water boron	mg/L	Average: 4.5 Range: 4.0 to 5.0

8.2 Treatment Process Overview

It is recommended that the SWRO desalination plant include the following components. These recommendations are based on the assumption that the plant will be supplied from an open ocean intake.

- Intake and supply system: intake screens, piping, and pump station.
- Pretreatment system: a strainer, coagulation, rapid mixing, DAF clarification, and GMF or UF filtration with backwash systems; or a strainer, SSF filtration, and a harrowing type cleaning system.
- SWRO desalination system: an equalization basin, low-lift transfer pumps, cartridge filters, high pressure RO feed pumps, RO skids, energy recovery system, and a RO cleaning system (some components can be shared with a UF CIP system if UF is selected).
- Post-treatment system and distribution: calcite contactors, CO_2 system, a clearwell, and a high service pump station.
- Residuals handling system: a filter-to-waste/backwash water chamber, washwater clarification basins, a clarified washwater recycle pump station, solids equalization and thickening basins, and potentially a solids disposal pump station or solids mechanical dewatering system (if discharging solids to the SCWD's sewer system is not feasible).

- Brine disposal system: a brine equalization basin, potentially a brine disposal pump station (depending on the final plant elevation), and a pipeline to the existing WWTF outfall.

- Chemical systems: sodium hypochlorite, sodium bisulfate, ferric chloride, anti-scalant, corrosion inhibitor, CO_2, provisions for additional UF and RO cleaning chemicals including, citric acid, caustic soda, strong acid, and proprietary cleaners.

- Miscellaneous facilities: operations and maintenance rooms, electrical equipment room, yard piping, storm water detention/handling, and other miscellaneous items.

8.3 Recommended Treatment Process and Design Criteria

Figure 8-1 is a diagram of the recommended treatment process for a 2.5 mgd SWRO desalination plant using either GMF or UF pretreatment. Figure 8-2 is a diagram of the recommended treatment process for a SWRO plant using SSF pretreatment. All three alternatives are described in this section. The comparison of solids handling alternatives determined that discharging the SWRO plant's residual solids to the sewer is the preferred approach and this section describes the required facilities to do so. Additional information on the capacity of the sewer and the wastewater treatment facility is needed to finalize this recommendation. In the next phase of the project a decision will be made on whether SSF, UF, or GMF will be used and whether the solids will be discharged to the sewer.

8.3.1 Pretreatment Process

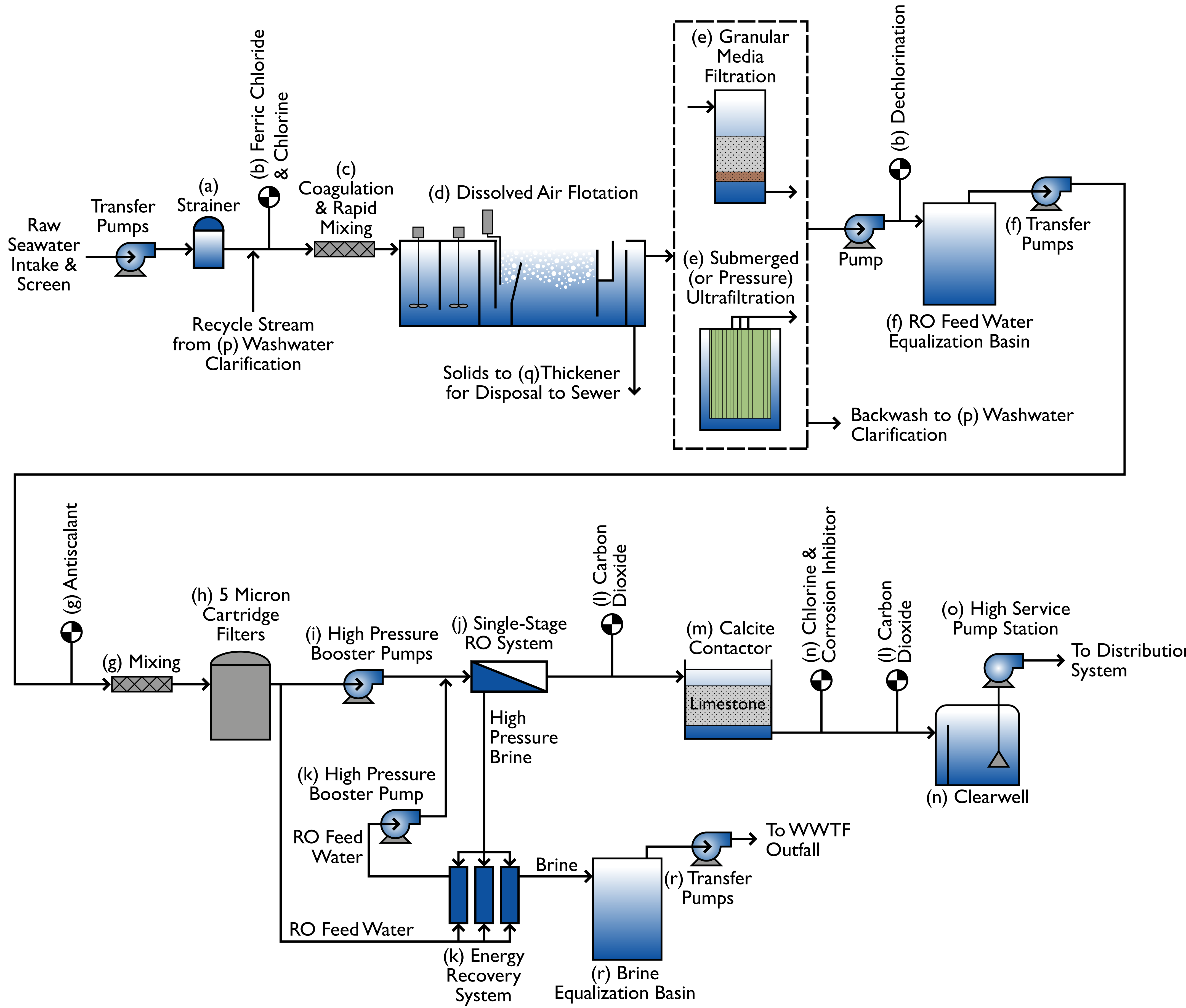
The recommended pretreatment process using GMF or UF includes a strainer, coagulation, intermittent pre-oxidation, DAF clarification, and either GMF or UF membrane filtration. The recommended pretreatment process using SSF includes a strainer and slow sand filters. Table 8-3 presents the design criteria and purpose for the process components and additional information on each component is presented after the table.

The following plant components are labeled "a" through "r" to correspond with the components shown in Figures 8-1 and 8-2.

(a) Strainer

A strainer with 100 to 120 micron nominal slot width is required by UF membrane vendors to protect the membranes from material which could damage the membrane material. 120 microns is considered the maximum effective size to remove larvae of barnacles, which have damaged membranes during pretreatment applications.

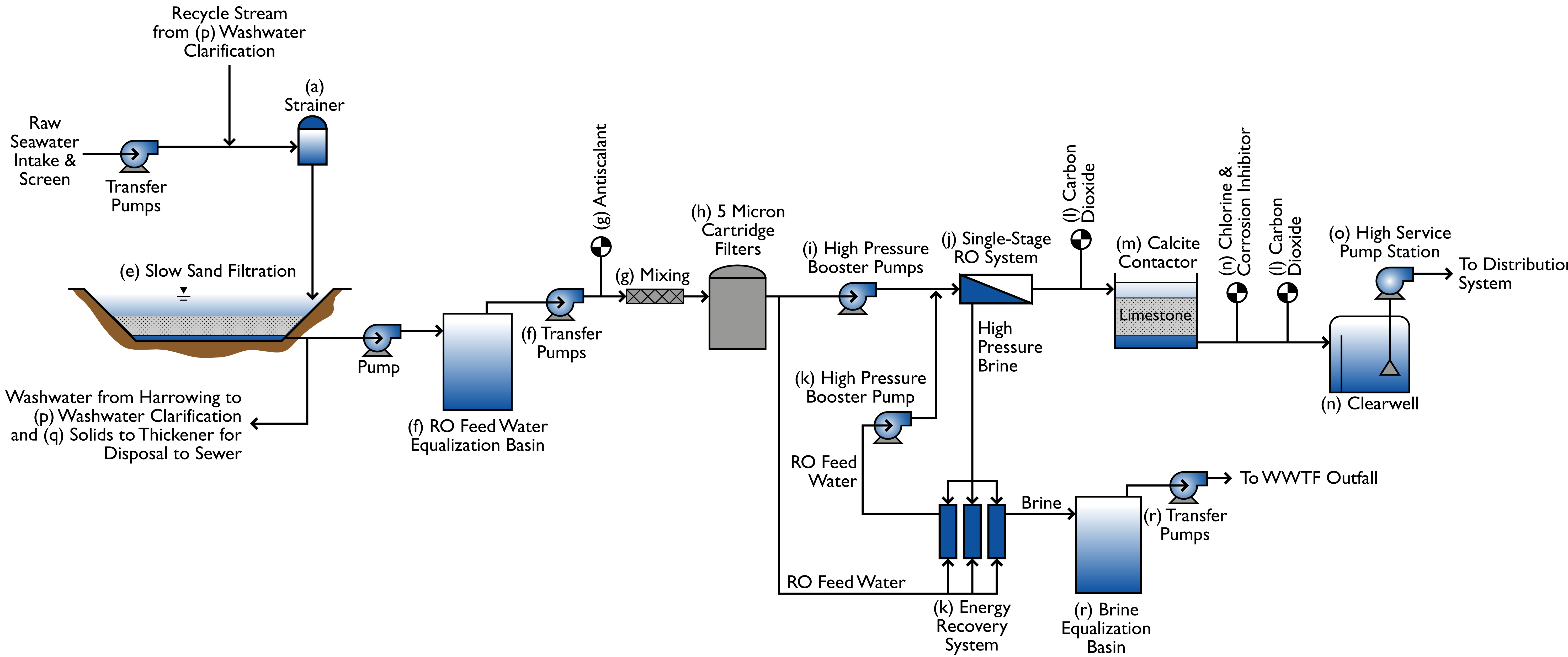
The strainers are recommended (but not required) upstream of SSF and GMF filters to reduce the amount of marine growth in the process piping, basins, and ancillary equipment upstream of the filters. Auto-backwashing strainers are being included for pretreatment at most large open intake desalination plants and are recommended for this project based on the growth observed in pipelines and systems downstream of both the Long Marine Laboratory intake in Santa Cruz and the Monterey Aquarium intake in Monterey.



W:\REPORTS\Santa Cruz City of\Desal Pilot_Final Report_09\Graphics\Figure 8-1_SWRO Desalination Plant Recommended Treatment Process_GMF or UF.ai 04/13/10 JJT

CDM

Figure 8-1
SWRO Desalination Plant: Recommended Treatment Process if GMF or UF is Selected for Pretreatment



CDM

Figure 8-2

SWRO Desalination Plant: Recommended Treatment Process if SSF is Selected for Pretreatment

Table 8-3. Pretreatment System Design Criteria

Component	Description	Purpose	Capacity	Design Rate/ Specification
Strainer	Auto-backwashing strainer	To remove barnacle larvae and minimize biological growth	6.3 mgd (provide two spare units)	Effective slot size: 100 micron Loading rate: <55 gpm/sf (varies w/ type)
Pre-oxidation	Sodium hypochlorite	To remove bio-growth via "shock chlorination" and to improve iron removal as necessary	6.3 mgd	Dose: 0.5 to 4.0 mg/L for pre-oxidation Dose: Up to 200 mg/L for shock cleaning
Coagulation	Ferric chloride or ferric sulfate addition	To remove algae and suspended material	6.3 mgd	Dose: 5 to 40 mg/L as $FeCl_3$
Rapid Mixing	Static mixer or pumped injection mixer	To provide adequate mixing for coagulation to improve removal of suspended solids	6.3 mgd	Greater than 95% mixed prior to clarification step
Clarification	High-rate dissolved air flotation clarifiers	To remove algae and suspended material prior to filtration	6.3 mgd (provide one spare unit)	Flocculation time: 20 minutes Surface loading rate: 6 gpm/sf
Filtration	Gravity Granular Media Filters	Designed to achieve pre-treated water quality goals, minimize filter-to-waste time, and reduce washwater requirements.	5.8 mgd (provide one spare filter)	Max. loading rate: 3 gpm/sf Recovery rate: ≥ 93% assuming air and water backwash and up to a 30 minute filter-to-waste time L/d ratio: ≥ 1400
	Submerged or Pressurized UF System	Pretreated water quality goals: SDI: ≤3.0 95% of the time; ≤4.0 99% of the time Turbidity: ≤0.1NTU 95% of the time; ≤0.5 NTU 100% of the time	5.8 mgd (provide one spare unit)	Recovery rate: ≥ 92% after backwash and chemical cleanings Flux rate: • Pressurized: ≤40 gfd • Submerged: ≤25 gfd
	Slow Sand Filters		5.8 mgd (provide two spare filters)	Recovery rate: ≥ 98% using harrowing to clean the filters Filtration rate: 0.1 gpm/sf

An Arkal disc type, auto-backwashing strainer was used at the pilot plant. Strainers from other vendors including Amiad, Hydac, and Bollfilter have also been used successfully at pilot-scale desalination systems in California. However, there are relatively few full-scale installations for seawater in the United States. Additional information on the operation at full-scale facilities should be considered in the preliminary design phase to select a strainer for the proposed facility. Extra strainer units are recommended for redundancy.

(b) Chemical Addition

Pretreatment chemicals are not added during slow sand filtration.

Pilot testing results indicated that a coagulant chemical was required to achieve pretreatment goals when using GMF filters.

A coagulant chemical is also recommended for UF pretreatment, especially during storm events and algal blooms. The pilot testing results indicated that a coagulant is not necessary for PVDF UF membranes during typical Pacific Ocean water quality conditions. This approach has also been demonstrated at other desalination pilot plants in California, including West Basin, Carlsbad, Marin, and Moss Landing. In general, the Pall, Memcor, and Zenon PVDF membranes have not required a coagulant while Norit PES membranes have consistently required a low dose of coagulant (e.g., <10 mg/L of ferric chloride) to achieve water quality and operational goals during typical conditions.

The ability to add a pre-oxidant such as chlorine or chlorine dioxide upstream of either GMF or UF is recommended as necessary to improve oxidation and removal of iron, especially for GMF filters. Shock-chlorination will also be required with all pretreatment options as a maintenance step to remove growth in process pipelines. A dechlorination agent is recommended at all times when adding a pre-oxidant due to the risks associated with damaging the RO membranes, even though the pilot test results indicated that a dechlorination agent may not be required if a low pre-oxidant dose (e.g., <1 mg/L of free chlorine) is added upstream of clarification.

(c) Rapid Mixing

Rapid mixing is required to enhance coagulation and clarification when chemicals are added upstream of GMF or UF. Static mixers or pump injection mixers are recommended for the full-scale facility. Multiple mixers are recommended for redundancy.

(d) Clarification

DAF clarifiers are recommended to remove algae, suspended solids, and other buoyant material prior to GMF or UF filtration. The removal of this material is expected to 1) improve water quality after filtration, 2) reduce the rupture of algal cells during filtration, and 3) minimize biofouling which has been linked to ruptured cells. A minimum of 20 minutes of flocculation time is recommended for adequate mixing time at colder temperatures based on both the pilot testing results and design experience. Multiple basins are recommended so that maintenance can be performed when one of the two is not being utilized.

(e) Filtration

Deep bed, gravity filters with media depth to media size (L/d) ratios of more than 1,400 are recommended to minimize coagulant breakthrough if GMF filters are selected. It is also recommended that filter-to-waste capabilities be provided because a filter-to-waste time of approximately 20 to 40 minutes was required to achieve the target SDI goal during pilot testing after the filters were brought back online following a backwash.

If UF filtration is selected, it is recommended that Zenon, Norit, Memcor, and Pall be considered for the facility because 1) they are well regarded in the industry for this type of application, 2) each has an existing full-scale installation for SWRO pretreatment, 3) each has been used successfully at pilot-scale SWRO desalination projects in California, and 4) to provide competitive pricing.

If SSF is selected, it is recommended that additional testing be performed to assess the need to cover the filters to improve long-term reliability (i.e., maintain a reasonable SSF cleaning frequency). A filtration rate of 0.1

gpm/sf, uniform sand at a depth of 24 to 30 inches, and a harrowing cleaning method are recommended based on pilot-testing results.

8.3.2 SWRO Desalination Process

The recommended SWRO process includes an equalization tank, a low-lift pump station, anti-scalant addition, cartridge filters, high pressure SWRO feed pumps, RO skids, and an energy recovery system. Table 8-4 presents the design criteria and purpose for the process components and additional information on each component is presented after the table.

Table 8-4. RO Desalination System Design Criteria

Component	Description	Purpose	Capacity	Design Rate/ Specification
EQ basin and low-lift pump station	A storage tank with a mixing chamber for dechlorination and a low lift pump station	To provide equalization to limit RO system shutdowns, mixing for adequate dechlorination, and to boost pressure to the high pressure pump suction	5.8 mgd (with one spare pump)	≥ 5 minutes of storage
Anti-scalant	Anti-scalant addition	To sequester dissolved iron	5.8 mgd	0.5 to 2.0 mg/L
Cartridge Filters	5 micron type sediment filters loaded in housings	To protect the RO membranes and pump from debris	5.8 mgd (with one spare filter)	5-micron nominal FRP housings Self-sealing
High Pressure Pump Station	High pressure pumps	To provide pressure to overcome osmotic pressure and system losses	2.9 mgd (with one spare pump)	High efficiency pumps and motors with VFDs 2.9 mgd at 750 to 1,100 psi Super-duplex stainless steel
RO skids	Single-stage, single-pass SWRO	To remove salts to achieve boron, bromide, and chloride goals	2.5 mgd (multiple skids)	Design recovery rate: 45% ; range: 43 to 50% Design flux rate: 8 gfd; range: 8 – 10 gfd Feed pressure: ≤1,100 psi
Energy Recovery	Pressure exchanger type	To provide energy recovery from the concentrate stream of each RO skid	2.9 mgd RO feed water; 3.3 mgd RO brine (with one spare unit)	>95% efficiency isobaric device Ceramic (low friction) materials

(f) Equalization Basin and Low-lift Pump Station

An equalization basin is required to equalize flows from the different pretreatment filter units and to provide contact time as needed for dechlorination. It would also be possible to use this basin as a backwash water supply tank, which would require additional storage. Multiple pumps are recommended for redundancy. Multiple basins are recommended so that maintenance can be performed while one is off-line; the equalization tanks at the pilot plant required cleaning and disinfection several times per year.

(g) Anti-scalant Addition

Anti-scalant is recommended to minimize long-term fouling from dissolved iron. Anti-scalant was not used at the pilot facility and was not necessary to minimize scaling at ambient water quality conditions. Scaling was only observed when the RO feedwater pH was increased to 9.0 at 50 percent recovery during enhanced boron rejection testing. However, long-term operations at full-scale SWRO facilities overseas have indicated that adding a low dose (e.g., <2 mg/L) of anti-scalant minimizes long-term iron-based fouling of RO membranes. This correlated with the pilot-scale autopsy results which found iron-based material on the surface of all membranes including the membranes downstream of SSF pretreatment, which did not use an iron-based coagulant.

(h) Cartridge Filtration

5-micron nominal cartridge filters are an industry standard to protect RO membranes from material which may damage the membranes. They also provide an additional treatment step, which can prolong the life of the RO membranes and are cheaper and more easily replaced than RO membranes.

(i) High Pressure SWRO Feed Pumps

High efficiency pumps and motors with VFDs are recommended to provide the maximum efficiency and operational flexibility given the range of flow rates at the facility. A spare pump is recommended for redundancy.

(j) RO Skids and Membranes

It is recommended that the SWRO skids be designed to operate as a single-stage, single-pass system that can use all high boron rejection SWRO membranes. This will provide a system that can operate reliably at high operating pressures. However, it is recommended that a combination of both high boron rejection SWRO membranes and low energy SWRO membranes be selected to achieve water quality goals with the lowest energy requirement. The selection of SWRO membranes should be re-evaluated during the design phase to take advantage of new membranes or advancements developed from on-going RO membrane research.

It is also recommended that the design allow the future addition of up to a 35 percent partial second pass in the event that more stringent water quality targets are selected in the future.

(k) Energy Recovery

The energy recovery device which is selected should provide the best combination of efficiency, footprint requirements, and operational flexibility given the desired range in production rates. It is recommended that the RO feedwater pumps be designed to operate as a single pumping system, that the RO skids be configured to operate as a single desalination system, and that the energy recovery units be designed to operate as a single system. This approach, which will maximize energy efficiency and operational flexibility, is called a "three center design" approach.

8.3.3 Post-treatment Process

The recommended post-treatment system includes calcite contactors, a carbon dioxide system, a clearwell, and a high-service pump station. Table 8-5 presents the design criteria and purpose for the post-treatment process components and additional information on each component is presented after the table.

Table 8-5. Post-treatment System Design Criteria

Component	Description	Purpose	Capacity	Design Rate/Specification
Calcite Contactors	Gravity flow contactors	To add calcium to improve taste and corrosion control	2.5 mgd (with one spare contactor)	Media filter underdrains Manual calcite loading NSF approved coarse limestone
Carbon Dioxide	Chemical system for pH adjustment	To adjust pH and add alkalinity	2.5 mgd	5 to 60 mg/L
Clearwell	Water storage tank to achieve contact time for disinfection	To provide contact time for 0.5 log *Giardia* inactivation and greater than 2.0 log virus inactivation	2.5 mgd	50,000 gallons to provide 28 minutes of contact time and storage at maximum flow
High Service Pump Station	High pressure pumps	To provide pressure to discharge conditioned permeate into the distribution system	2.5 mgd (with one spare pump)	Vertical turbine can pumps 2.5 mgd and existing HGL

(l) Carbon Dioxide Addition

Carbon dioxide is recommended as a cost-effective approach to 1) enhance calcium uptake from the calcite contactors, 2) add additional carbonate alkalinity, and 3) provide pH adjustment. Due to target alkalinity and pH goals in the product water, CO_2 addition will typically be required both before and after the calcite contactors.

(m) Calcite Contactors

Calcite contactors are recommended for the facility because they require less maintenance and optimization and produce less sludge than lime addition processes. Gravity flow contactors are recommended to minimize energy use. Relatively coarse limestone is recommended to minimize turbidity spikes after loading.

(n) Clearwell and Chemical Addition

A clearwell is recommended to provide 1) contact time to meet the DPH requirements for an additional 0.5 log *Giardia* inactivation, 2) settling to normalize turbidity after the calcite contactors, and 3) storage for the high service pump station. Upstream of the clearwell chlorine will be added for disinfection and a corrosion inhibitor will be added for corrosion control.

(o) High Service Pump Station

Distribution system modeling performed by SCWD has indicated that greater than 2.5 mgd can be pumped directly into the distribution system on the west side of Santa Cruz. Therefore, a high service pump station is recommended to provide pressure to match the hydraulic grade line (HGL).

8.3.4 Residuals Handling Process

The recommended residuals handling system includes washwater clarification, a solids equalization basin, gravity thickeners, a brine equalization basin, potentially a brine transfer pump station, and a pipeline to the tie-in point of the WWTF outfall pipeline. Table 8-6 presents the design criteria and purpose for the residuals handling process components and additional information on each component is presented after the table.

Table 8-6. Residuals Handling System Design Criteria

Component	Description	Purpose	Capacity	Design Rate/Specification
Washwater Clarification	High rate clarifiers	To remove solids from filter washwater for recycle back to the headworks of the plant	0.7 mgd (with one spare clarifier)	Surface loading rate: ≤0.4 gpm/sf
Solids Equalization Basin and Gravity Thickeners	Storage and gravity thickening tanks	To equalize storage and provide thickening of the solids for disposal to the sewer	0.1 mgd	Surface loading rate: ≤1 gpm/sf Solids loading rate: ≤5 pounds per day per sf
Brine Equalization Basins	Storage basins	To provide adequate storage and flow equalization for discharging the brine	3.3 mgd	500,000 gallons of storage
Brine Pump Station	Low pressure pumps	To provide pressure to convey brine to the WWTF outfall	3.3 mgd	To be determined during design phase

(p) Washwater Clarification

High-rate DAF or gravity settling type clarifiers are recommended to remove solids prior to recycling the washwater to the headworks of the plant. Multiple clarifiers are recommended for redundancy.

(q) Solids Equalization Basins and Gravity Thickeners

Equalization basins and gravity thickening basins are recommended to thicken the solids streams from the pretreatment DAF clarifiers and/or the washwater clarifiers prior to discharge to the sewer. Multiple equalization basins and thickeners are recommended for redundancy.

(r) Brine Equalization Basin and Potential Transfer Pump Station

Equalization basins are recommended to equalize the brine flow and to provide storage to achieve dilution requirements during low flow conditions at the WWTF. Initial calculations indicate that a minimum of 500,000 gallons of storage is required. Because the facility site and elevation have not been determined, a pump station may be required to transfer the brine to the WWTF outfall. Further evaluation is necessary during the design phase.

8.3.5 Additional Chemical Feed and Storage Systems

Ferric chloride, a pre-oxidant, an anti-scalant, calcite contactors, and carbon dioxide chemicals have already been discussed for the treatment plant. Additional chemicals recommended for the facility include bisulfite for de-chlorination as needed, sodium hypochlorite for post-treatment disinfection, corrosion inhibitor for corrosion control, and miscellaneous chemicals required for membrane cleaning. SSF will not require coagulant, pre-oxidant, or dechlorination chemicals. Although pretreatment and cleaning chemicals will be required for the GMF and UF pretreatment options, pilot-scale testing indicated that operators can reduce chemical use during typical water quality conditions and increase chemical use during algal blooms and storm events as needed.

It is assumed that the storage systems will be sized to store sufficient chemical to supply the maximum dose at maximum plant production capacity for a minimum of 14 days and the average dose at average plant production capacity for a minimum of 30 days. Table 8-7 summarizes the design criteria and purpose for the chemicals.

Table 8-7. Recommended Chemical Feed and Storage System Design Criteria

Chemical	Description	Design Flow Rate with one unit out of service	Dose Range
Coagulant	Ferric chloride to improve DAF clarification, pretreatment filtration, and washwater clarification	6.3 mgd	4 to 40 mg/L; note: not used with SSF pretreatment
Pre-oxidant, CEB chemical and disinfectant	Sodium hypochlorite for intermittent "shock-chlorination" to control biogrowth and as a pre-oxidant as needed to improve iron removal. Continuous addition for post-treatment disinfection.	6.3 mgd & 2.5 mgd	Pre-oxidant chlorine dose: 1 to 3 mg/L; note: not used with SSF pretreatment Shock-chlorination dose: 50 to 200 mg/L Chlorine dose after RO: 1 to 5 mg/L
De-chlorination agent	Bisulfite addition required upstream of the break tank as necessary to protect the RO membranes from damage due to free chlorine when added	6.3 mgd	Bisulfite dose before RO: 1 to 5 mg/L; note: not used with SSF pretreatment
Anti-scalant	Anti-scalant to sequester dissolved iron to reduce long-term iron-based fouling	5.8 mgd	Anti-scalant dose before RO: 1 to 5 mg/L
Post-treatment pH stabilization	Carbon dioxide for pH stabilization before and after the calcite contactors	2.5 mgd	CO_2 dose: 5 to 60 mg/L
Post-treatment corrosion control	Phosphate based corrosion inhibitor to minimize lead, copper, and iron release	2.5 mgd	Phosphate dose: 0.5 to 1 mg/L
Miscellaneous membrane cleaning	Citric acid for low pH CIP cleaning Sodium hydroxide for high pH CIP cleaning and acid neutralization Strong acids and proprietary cleaners if necessary	Varies	Dose recommended by membrane manufacturer

8.4 Estimated Costs and Energy Use

8.4.1 Cost Estimating Method

A construction cost estimate was prepared based on equipment unit prices provided by manufacturers and past projects costs, and unit costs for similar facilities. Total capital costs were estimated by adding costs for land, design and construction services, and escalation. Engineering design, engineering services during construction, and construction management costs were estimated to be 21% of construction cost based on actual percentages of recent projects similar in scope and effort.

Costs are not included for legal services, permitting, bond fees, financing services and labor costs for SCWD and SqCWD staff during design, permitting, and construction.

8.4.2 Key Assumptions

Cost estimates developed during conceptual level planning are based on the assumptions made prior to the site being selected and design drawings being developed. Table 8-8 lists the key assumptions used to develop the conceptual level planning costs.

Table 8-8. Summary of Key Assumptions

Category	Key Assumption	Description
Construction Costs	Construction costs estimated using unit costs from constructed facilities	Based on unit costs of similar systems and facilities for drinking water escalated to midpoint of construction
	Standard foundations, a flat site, and no site remediation	An allowance was not included for site-specific conditions
	Land costs: $1 million per acre	
	n+1 redundancy factor	Selected to improve plant reliability by providing 2.5 mgd of production with one unit out of service
	3% annual escalation	Assumed to be 3% yearly to construction midpoint of June 2014 based on historical escalation rates
Operation and Maintenance Costs	Electrical cost: $0.16 per kilowatt-hour	Assumes current rate escalated by 3% annually
	Source and treated water pumping power cost: $260,000 per year	Assumes 4.0 mgd at 70 feet for source water & 1.6 mgd at 283 feet for treated water; based on energy study estimates
	5 year RO membrane lifespan and 7% annual flux decline	Based on historical results at open intake SWRO facilities
	Labor cost: $410,000 per year; assumes 2 operators for one 8 hour shift and 1 operator for the other two shifts	Based on full-time equivalent hourly rates escalated by 30% of SCWD operations staff
	Landfill disposal cost: $75 per ton	Based on current landfill disposal cost
	Sewer disposal costs: $10 per 100 cubic feet plus a flat fee of $2,011 per month	Based on expected rate increase for disposal of solids WWTF rate schedule
	Financing for life-cycle costs: 30-year bond with a 5% interest rate	Based on typical California utility debt financing

8.4.3 Cost Estimates

The estimated capital costs are presented in Table 8-9, which shows the cost distribution among the treatment process components. The capital costs were escalated at 3% per year to 2014 dollars ($2014), assuming a construction midpoint of June 2014.

The estimated capital cost for a 2.5 mgd SWRO desalination is $59 million if the plant uses granular media filters for pretreatment. The plant's capital cost increases to $64 million if UF membranes are used for pretreatment. The estimated capital cost for SSF pretreatment ranges from $64 million if uncovered to $70 million if covered. Given the method for cost estimation (i.e. equipment cost quotes and experience from similar facilities) and the lack of design drawings from which to do quantity estimates, these estimates are for comparative purposes only. They are not for final budgetary considerations.

Table 8-9. Preliminary Capital Cost Estimate for a 2.5 mgd SWRO Desalination Plant ($2014)

Process Description	Design Capacity(1)	Facility Cost with SSF Pretreatment After Escalation(2,3)	Facility Cost with GMF Pretreatment After Escalation(2)	Facility Cost with UF Pretreatment After Escalation(2)
Strainer and Covered Slow Sand Filters	6.3 mgd	$13.0 M		
Strainer and DAF Clarification	6.3 mgd		$4.1 M	$4.1 M
Gravity GMF	6.3 mgd		$9.4 M	
Submerged MF/UF	6.3 mgd			$12.4 M
Single-pass SWRO(4)	2.5 mgd	$9.0 M	$9.0 M	$9.0 M
Calcite contactor, CO_2, clearwell & high service pump station	2.5 mgd	$5.4 M	$5.4 M	$5.4 M
Washwater clarification, thickening and discharge to sewer	0.5 mgd	$0.5 M	$0.9 M	$0.9 M
Brine storage and pump station	3.0 mgd	$1.2 M	$1.2 M	$1.2 M
Chemical systems	varies	$0.8 M	$0.9 M	$0.9 M
Ops building, yard piping, and other miscellaneous facilities		$0.9 M	$0.9 M	$0.9 M
General electrical, inst. & controls		$2.0 M	$2.3 M	$2.3 M
$1 million per acre of land		$12.0 M	$3.5 M	$3.5 M
30% contingency		$13.4 M	$11.3 M	$12.2 M
Total construction cost		**$58 M**	**$49 M**	**$53 M**
Engineering design, engineering services during construction, and construction management (21% of const.)		$12 M	$10 M	$11 M
Grand total(5)		**$70 M**	**$59 M**	**$64 M**

(1) Cost includes spare units so that the plant can produce 2.5 mgd of permeate during planned and unplanned equipment outages.
(2) Costs were escalated from $2009 at 3% per year to a construction mid-point of June 2014.
(3) Costs for slow sand filter include $6 million for a shade cover and additional land necessary to accommodate any potential expansion up to 4.5 mgd that would not be required for the other alternatives.
(4) SWRO assumes 45% recovery and 8 gfd flux at 2.5 mgd of production.
(5) Does not include costs for environmental review, permitting, or design and construction of other structures not located at the treatment plant site (e.g., intake, intake pump station, a source water pipeline, a brine discharge pipeline).

Construction cost estimates were developed using unit construction costs for similar processes from recently constructed projects. Costs for land were added at $1 million per acre. A 30% contingency was added to allow for additional costs that cannot be estimated without detailed engineering design drawings. Costs for engineering design, services during construction, and construction management were estimated at 21% of total estimated construction cost based on actual percentages of recent projects similar in scope and effort.

According to the Association of Advancement of Cost Engineering (AACE), planning level cost estimates have historically estimated the cost of proposed construction projects with an accuracy in the range of -30 to +50%.

The estimated operation and maintenance costs and distribution among cost categories are presented in Table 8-10.

Table 8-10. Preliminary Estimated Annual O&M Costs ($2014)

Cost Item	Annual O&M Cost with SSF Pretreatment(1) (2014 $ per year)	Annual O&M Cost with GMF Pretreatment(1) (2014 $ per year)	Annual O&M Cost with Membrane Pretreatment(1) (2014 $ per year)
In-Plant Power for the RO System	$830,000	$830,000	$830,000
In-Plant Power except the RO System	$104,000	$149,000	$228,000
Labor	$373,000	$410,000	$410,000
Raw and Treated Water Pumping Power	$211,000	$211,000	$211,000
Chemicals	$145,000	$253,000	$249,000
MF/UF & RO Membrane, Cartridge Filter, and Filter Media Replacement(2)	$283,000	$133,000	$199,000
Solids Disposal to the Sewer	$56,000	$120,000	$88,000
Annual O&M Sub-total	$2,000,000	$2,100,000	$2,200,000
General Maintenance and Miscellaneous (non-labor costs; estimated at 10% of subtotal)	$200,000	$210,000	$220,000
Annual O&M Total	**$2,200,000**	**$2,300,000**	**$2,400,000**

(1) Costs assume an average flow of 1.6 mgd and were escalated from 2009 at 3% per year to the mid-point of construction in June 2014.
(2) Assumes partial replacement each year.

Operations and maintenance (O&M) costs include estimates for labor; power; chemicals; cartridge filter, filter media, and RO and UF membrane replacement; maintenance/repairs; and solids disposal. The O&M costs were escalated at 3% per year to 2014 dollars ($2014).

The estimated annual O&M cost for a SWRO plant using SSF pretreatment is $2,200,000. The estimated O&M cost for a plant with GMF pretreatment is $2,300,000. The estimated O&M cost for a plant with UF pretreatment is $2,400,000.

Figures 8-3, 8-4, and 8-5 provide a summary of the estimated percentages for different O&M costs and activities for facilities using different pretreatment alternatives. Electrical power costs are the largest O&M expenditure cost, at approximately 38%, followed by labor at approximately 18%, source and treated water pumping at

12%, chemicals at 11%, and filter media/membrane replacement and general maintenance, each at approximately 10%.

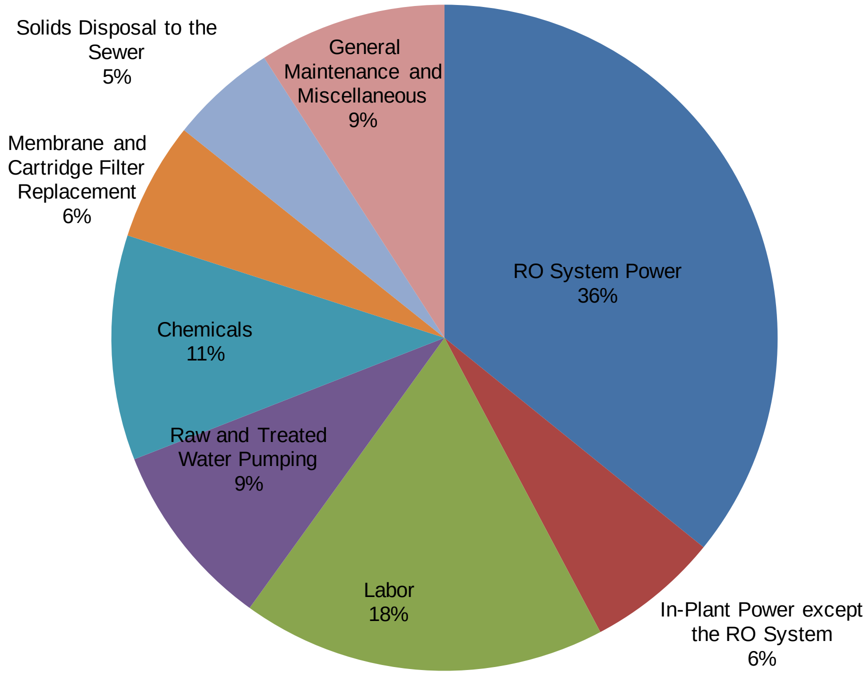


Figure 8-3. Annual O&M Costs for UF Pretreatment

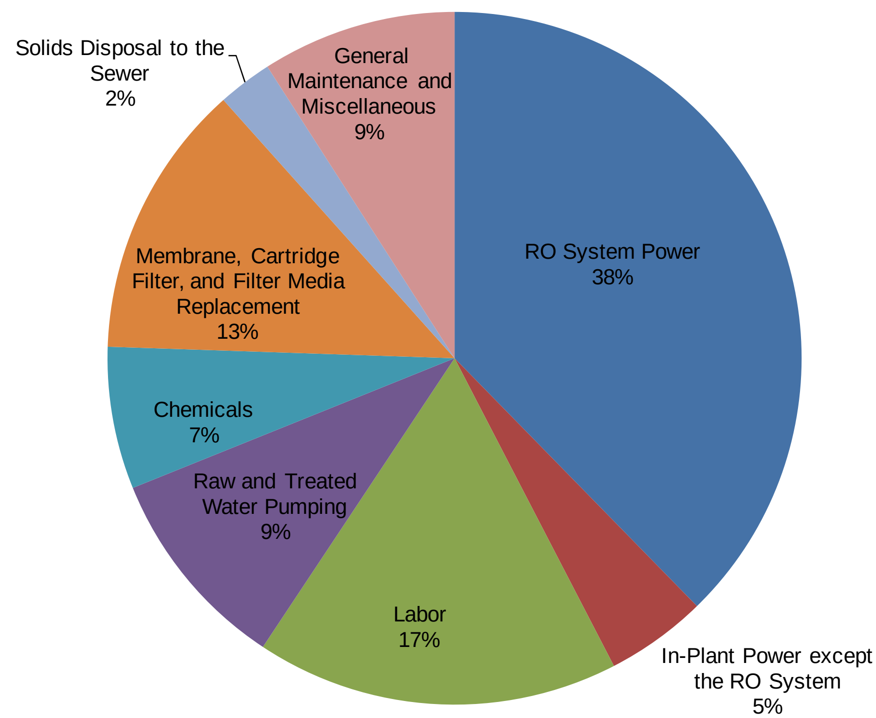


Figure 8-4. Annual O&M Costs for GMF Pretreatment

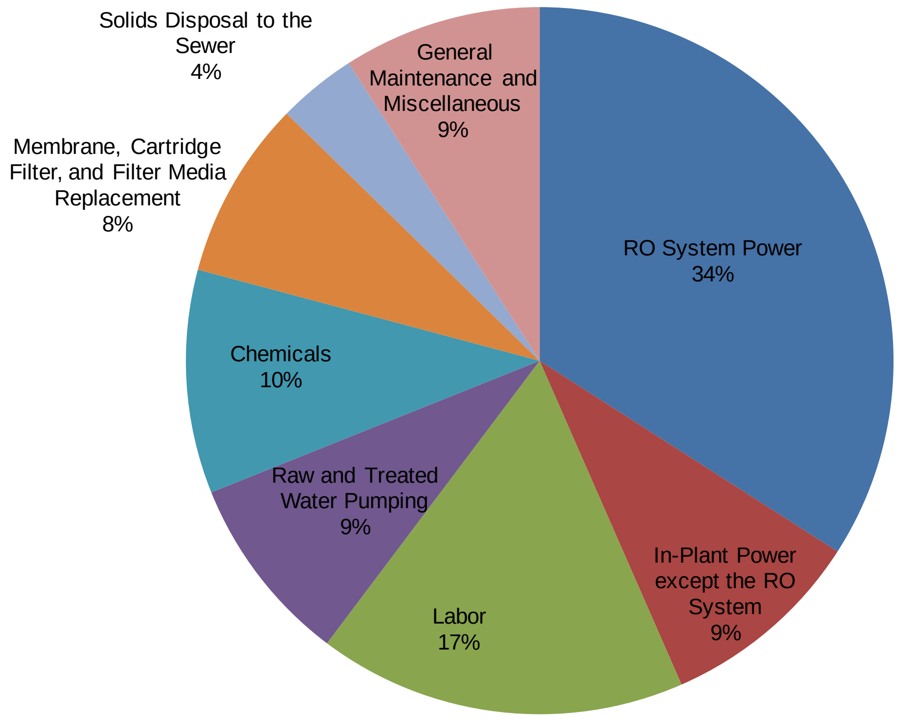


Figure 8-5. Annual O&M Costs for SSF Pretreatment

8.4.4 Energy Use

The estimated energy use for facilities with SSF, GMF, and UF pretreatment systems is presented in Table 8-11. This table does not include an estimate of the energy used during construction or for vehicle use associated with plant operation. The electrical power use of the SWRO plant with SSF pretreatment is estimated to be 12.9 kWh per 1,000 gallons, with GMF pretreatment is estimated to be 12.4 kWh per 1,000 gallons, and with UF pretreatment is estimated to use 13.8 kWh per 1,000 gallons.

Table 8-11. Preliminary Estimated Energy Use Per 1,000 Gallons of Water Produced at the Proposed Facility

Cost Item	Energy Use with SSF Pretreatment(1) (kWh/1,000 gallons)	Energy Use with GMF Pretreatment(2) (kWh/1,000 gallons)	Energy Use with UF Pretreatment(2,3) (kWh/1,000 gallons)
Pretreatment	0.1	0.6	1.4(3)
RO System(4)	9.0	9.0	9.0
Post-treatment System Including High Service Pump Station	1.5	1.5	1.5
Residuals handling assuming that solids and brine transfer pump stations will not be required	0.1	0.1	0.1
Miscellaneous facilities including source water pumping	1.8	1.8	1.9
Estimated Energy Use per Unit of Production	12.4	12.9	13.8

(1) Assumes the processes shown in Figure 8-2 and design criteria in Tables 8-3 through 8-7.
(2) Assumes the processes shown in Figure 8-1 and design criteria in Tables 8-3 through 8-7.
(3) A range of 0.9 for a submerged UF system to 1.4 for a pressurized UF system was estimated assuming average trans-membrane pressures of 10 psi and 30 psi respectively.
(4) Assumes an average RO membrane age of 3 years, a flux rate of 8 gfd, a recovery rate of 45%, an annual flux decline of 7%, and a pressure exchanger type energy recovery device.

8.5 Summary

This section summarized the design criteria and estimated costs and energy use for the proposed 2.5 mgd desalination facility with different pretreatment alternatives. The pretreatment alternatives, RO desalination process, and ancillary systems were selected based on the pilot testing results to provide a robust treatment process that will allow the plant to meet water production and reliability goals during algal blooms and storm events.

The estimated range of capital costs for the proposed 2.5 mgd facility is $59 to $70 million depending on the type of pretreatment selected. Assuming an average annual production of 1.6 mgd, the range of estimated annual O&M costs is $2.2 to $2.4 million and the range of estimated energy use is 12.4 to 13.8 kWh per 1,000 gallons assuming an average RO membrane age of 3 years.