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Innovative One Water Solutions for a Sustainable Water Supply

Alex Waite[1], Sunny Wang[1], Chris Aguillon[1] and Alex Nazarchuk[2]

1. City of Santa Monica Public Works: Water Resources Division, Santa Monica, CA 90404, United States

2. City of Santa Monica Public Works: Engineering Division, Santa Monica, CA 90404, United States

Abstract: Climate change impacts, such as higher average temperatures and prolonged drought conditions, have affected regional and local water supply reliability. The City of Santa Monica has long been a leader in promoting sustainability and is implementing several innovative water supply projects to develop alternative water supplies—including stormwater, dry weather urban runoff, and municipal wastewater—to provide a diverse, sustainable, and drought-resilient local water supply. The City is developing the first MBR (Membrane Bioreactor) system and cartridge filtration system to receive log removal credits for potable reuse in the State of California, the first stormwater treatment project in the State of California that will augment groundwater supplies via direct injection, and the first municipal flow reversal RO (Reverse Osmosis) system in the United States. Collectively, these alternative water supplies sources will reduce the City's reliance on imported water supplies and meet as much as 99% of its water demands through local water resources.

Key words: Self-sufficiency, sustainability, MBR, flow reversal RO.

1. Introduction

The City of Santa Monica (City) has long been a leader in promoting sustainability and implementing innovative solutions to address climate change. In 2018, the City updated its SWMP (Sustainable Water Master Plan) that refined the pathway to achieve water self-sufficiency by 2023 through establishing a diverse, sustainable, and drought-resilient local water supply aimed to provide water supply security and long-term cost benefit to the community. Currently, the City's water supply portfolio consists of primarily local groundwater (~65%-75%), imported water supplies (25%-35%) from the Metropolitan Water District of Southern California, and a small non-potable supply (<1%) from the City's SMURRF (Santa Monica Urban Runoff Recycling Facility).

Recognizing the potential impacts of climate change on the City's water supply, the SWMP's "one water" approach aims to diversify and enhance resiliency of its water supply portfolio through three key components: (1) increase water conservation, (2) develop alternative water supplies, and (3) restore impaired local groundwater supplies and increase drinking water production efficiencies. The City aims to complete this integrated approach to maximize local water supplies creating an improved water supply portfolio (see Fig. 1) by 2023.

This article summarizes groundbreaking achievements within two projects integral to the SWMP's "one water" vision: the SWIP (Sustainable Water Infrastructure Project) and Olympic Well field Restoration and Arcadia WTP (Water Treatment Plant) Expansion Project.

2. SWIP

The SWIP will leverage stormwater, dry weather urban runoff, and municipal wastewater to produce advanced treated recycled water for non-potable uses and potable reuse—groundwater augmentation via subsurface application. The SWIP will provide a sustainable and drought resilient water supply by

Corresponding author: Alex Waite, PE, MSc, research fields: high-recovery reverse osmosis, sustainable design.

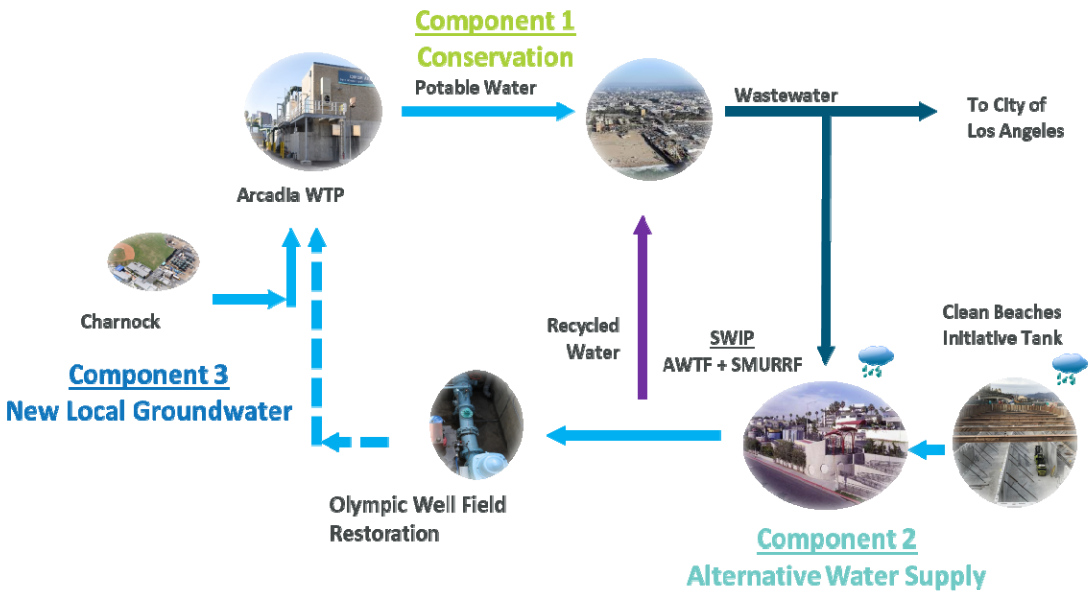

Fig. 1 City's future integrated water supply portfolio.

producing up to 1.5 mgd (million gallons per day), or 1,680 AFY (acre-feet per year), of advanced treated water to recharge the local groundwater aquifer. Through a progressive design-build-operate delivery method, Kiewit (contractor), Arcadis and PACE (designers), and Perc Water (operators) are delivering a new advanced water purification facility, upgrades to the City's SMURRF, and operations for both facilities.

2.1 New SWIP Advanced Water Treatment Facility

A new 1 mgd SWIP AWTF (Advanced Water Treatment Facility) will be constructed to produce advanced treated recycled water for non-potable uses and potable reuse—groundwater augmentation via subsurface application. Typical influent to the AWTF will consist of a mixture of raw wastewater and dry weather runoff/stormwater, when available. A new stormwater harvest tank will be constructed adjacent to the SWIP AWTF capturing stormwater and dry-weather urban runoff from the City's municipal separate storm sewer system (MS4) and Civic Center parking lot. The Civic Center stormwater harvesting tank will be plumbed to the AWTF and treated at a controlled rate, up to 30% contribution to the total feed water, to avoid upset of the biological treatment processes at the AWTF.

The AWTF is designed to meet the State of California's Title 22 GRRP (Groundwater Replenishment Reuse Project) 12, 10, 10 LRV (log removal value) requirements for enteric virus, Cryptosporidium, and Giardia, respectively [1], as tabulated in Table 1. The treatment train at the AWTF consists of MBRs (Membrane Bioreactors), cartridge filters, RO (Reverse Osmosis), UV/Cl_2 AOP (Ultraviolet with Free Chlorine Advanced Oxidation Process), and chlorine disinfection, as shown in Fig. 2. The SWIP AWTF will be one of the first facilities in California to obtain log removal credits for the MBR system and cartridge filtration for potable reuse, in addition to log removal credits received for RO, UV AOP, and chlorine disinfection. The SWIP AWTF will also be completely buried beneath the Civic Center parking lot (see Fig. 3) making it the first completely underground potable reuse facility for groundwater augmentation in California.

2.1.1 MBR System

The AWTF utilizes an MBR to fully oxidize the raw wastewater, provide nitrogen reduction, and remove suspended solids. Following a technology provider analysis, Suez Zee Weed^{TM} 500d-422 membranes were

Table 1 SWIP AWTF log reduction values per process.

Process	Virus	Cryptosporidium	Giardia
MBR	1.0	2.5	2.5
Cartridge Filters	-	2.0	2.5
RO	1.5	1.5	1.5
UV-AOP	6.0	6.0	6.0
Chlorine	6.0	-	-
Total	14.5	12.0	12.5
Required[a]	12.0	10.0	10.0

[a] Required log reduction values per DDW Title 22 §60320.208 [2].

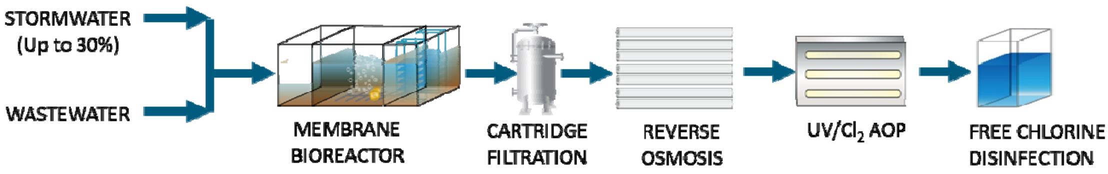

Fig. 2 SWIP AWTF process flow diagram.

Fig. 3 SWIP AWTF rendering showing treatment plant facilities located below Civic Center parking lot.

selected, to be installed in 52-module cassettes, two cassettes per train. The membranes used for the MBR system are ultrafiltration, hollow fiber membranes that have a nominal pore size of 0.04 µm. Maximum filtrate flow will be based on a maximum instantaneous flux of 17.6 gfd (Gallons per Square Feet per Day) which is the maximum flux allowed per the Australian Water Val^{TM} Tier 1validation protocol for MBR LRV requirements [3]. However, during the course of design, WRF (Water Research Foundation) Project 4997was published establishing the United States tiered validation protocol [4]. Per WRF Project 4997, a conservative Tier 1validation was developed to meet 1.0-log reduction virus and 2.5-log reduction of both Giardia and Cryptosporidium including continuous analytical membrane integrity validation by maintaining a filtrate turbidity of <0.2 Nephelometric Turbidity Units (NTU). After coordination with the California SWRCB (State Water Resources Control Board) DDW (Division of Drinking Water), the US Tier 1 Validation was approved for the SWIP AWTF MBR system as long as monitoring requirements are met.

2.1.2 Cartridge Filtration System

Cartridge filters have been accepted for use as an alternative filtration technology to meet the physical removal requirements of the California SWTR (Surface Water Treatment Rule) [5] but have not previously been accepted for potable reuse applications. After coordination with the SWRCB DDW, the Harmsco HC/170-LT2NSF/ANSI Standard 61 certified pleated microglass cartridge filters were approved to be granted the 2.0-log reduction of both Cryptosporidium and Giardia for the AWTF, as long as monitoring requirements are met. The monitoring requirements include continuous monitoring of the differential pressure across the filter vessel (< 30 psi), the turbidity of the effluent of the filters (< 0.3 NTU), and flow rate (based on capacity of installed filter vessel). The filter vessels will have a 1-duty plus 1-standby arrangement per train so that even flow splitting is not required for pathogen reduction credits.

2.2 Upgrade to the SMURRF

The SMURRF was originally designed to serve as an advanced BMP (Best Management Practice) facility for treating dry weather urban runoff for non-potable uses such as irrigation and toilet flushing. The existing treatment processes at SMURRF consist of drum screens, grit removal, dissolved air flotation, submerged ultrafiltration, open channel UV disinfection, and chlorine addition. The SMURRF will be upgraded with the addition of RO (see Fig. 4) to meet diluent water quality requirements under the State of California's guidelines for a GRRP [6].

Since the source water for SMURRF is not of wastewater origin, the City worked closely with the California State Water Resources Control Board's Regional Water Quality Control Board—Los Angeles Region and the Division of Drinking Water to develop a comprehensive source water sampling and characterization program in order to convert SMURRF from a BMP facility to a permitted facility. The addition of RO to the SMURRF will ensure it meets diluent water quality requirements, including removal of perfluorooctanoic acid and perfluorooctanesulfonic acid, to be the first stormwater treatment system that will directly inject treated stormwater for groundwater augmentation in California.

3. Olympic Well-field Restoration and Arcadia WTP Expansion Project

The City's existing Arcadia WTP is a brackish groundwater desalination facility that uses a traditional three-stage RO system that operates between 82%-83% recovery and has an RO bypass stream between 17%-23%. The existing treatment train consists of greensand pretreatment filtration, cartridge filtration, RO, post-treatment stabilization (decarbonation towers and chemical addition), and chlorine disinfection. The Arcadia WTP receives influent from the Charnock, Arcadia, and Olympic Well-field. Concentrations of 1,4-dioxane, trichloroethylene, tetrachloroethylene, and other containments were identified in the Olympic Well-field as a result from industrial pollution. The Olympic Well-field is now identified as an extremely impaired drinking water source under the SWRCBDDW 97-005 Policy Memorandum [7]. The existing WTP does not include the treatment processes necessary to effectively remove these contaminants, thus production from the Olympic Well-field is significantly limited. The Olympic Well-field Restoration Project

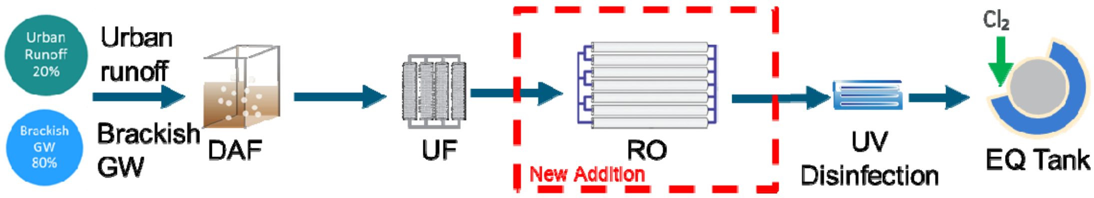

Fig. 4 SMURRF process flow diagram with addition of RO.

will restore the well-field to its full production capacity, creating 3,200 acre-feet per year of local groundwater, by adding an ultraviolet light with hydrogen peroxide advanced oxidation process (UV/H_2O_2-AOP) followed by GAC(Granular Activated Carbon) to treat groundwater from Olympic Well-field prior to blending with flow within the Arcadia WTP.

In addition to restoring the Olympic Well-field and in support of the City's goal to achieve water self-sufficiency, the City pilot tested two production efficiency enhancement projects to increase the overall RO recovery to 90% or greater and reduce the RO concentrate waste stream. The City conducted side-by-side pilot testing of two high-recovery RO technologies ultimately selected one technology for full-scale installation. Through a progressive design-build delivery method, Walsh Construction (contractor) and Brown and Caldwell (designer) are delivering the new advanced water treatment facility and innovative high-recovery technologies.

3.1 CCRO (Closed Circuit Reverse Osmosis)

CCRO™ system by DuPont (formerly Desalitech) is a high-efficiency semi-batch RO system that could treat RO concentrate and/or feed water to traditional RO systems (e.g., greensand filtrate at Arcadia WTP) to increase overall membrane system recovery to potentially 98% [8]. The CCRO process operates by cycling between two operational modes: closed-circuit and plug-flow RO. Much of the time, the system operates in closed-circuit mode and the concentrate is recirculated back to the feed side of the membranes. The high-pressure feed pump adds additional feed water at an equal rate to the permeate production, thereby maintaining the total volume in the system. Once a set recovery is achieved (as indicated by a set point for maximum feed pressure, concentrate conductivity, or volume), the system switches to plug-flow mode and the concentrate is purged from the system. The system is replenished with a volume of fresh feed water to match the displaced concentrate, and the permeate production is uninterrupted.

Desalitech manufactures two types of CCRO™ systems: ReFlex™ and ReFlex Max™ systems. While the ReFlex™ system purges the CCRO™ concentrate to atmosphere, the ReFlex Max™ system uses a side-conduit to isolate the CCRO™ concentrate before purging it to waste without breaking pressure. The side conduit also provides flexibility to operate at sequence time as low as 90 s, compared to the ReFlex™ minimum sequence time of 6 min [8]. The CCRO ReFlex Max™ system (see Fig. 5) was pilot tested in this work.

Based on a desk-top modeling analysis performed by the City in 2018, projections and cost evaluation showed operating in concentrate recovery mode was cost prohibitive. Alternatively, a blended feed stream of greensand filtrate plus RO concentrate minimized life-cycle cost. Therefore, the CCRO ReFlex Max™ was piloted on a blend of 40% existing 83% recovery RO concentrate with 60% greensand pressure filter filtrate.

3.2 FRRO (Flow Reversal Reverse Osmosis)

FRRO by ROTEC Ltd. employs two techniques to increase recovery compared to a traditional RO system [9] (see Fig. 6). First, periodically the FRRO system switches the flow direction of the saline stream in RO pressure vessel arrays to increase recovery by minimizing the time period in which scale can form on membranes surfaces before being swept away by under-saturated feed solution conditions. Second, in RO systems where more than one stage is required, stage rotation is employed. Individual pressure vessels or blocks of pressure vessels are periodically rotated from the more challenging stage (for instance, second stage in a two-stage system) into the first stage array while those are replaced by other vessels rotating to take their place. This reduces the load on any one set of vessels treating the most challenging water quality.

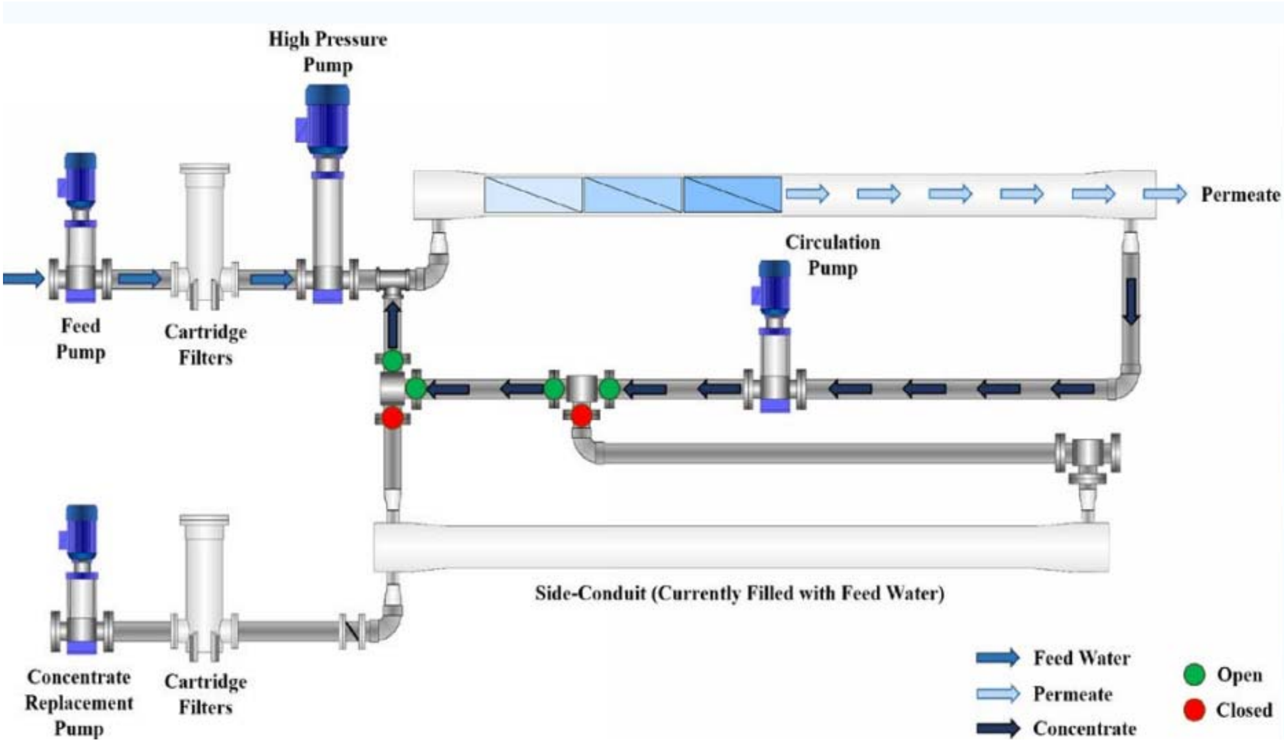

Fig. 5 CCRO ReFlex Max™ process flow schematic shown in closed circuit mode (brine flush valve closed) [8].

Benefits of FRRO include increased permeate production and reduced concentrate volume with reduced chemical consumption, CIP (Clean-in-Place) frequency, and membrane replacement. The FRRO system was piloted as a three-stage system modeling a retrofit of the existing conventional RO system.

3.3 Pilot Testing Results

Both pilot systems were tested side-by-side and evaluated based on various performance criteria including operating at >88% recovery for at least 4 months and operating on a chemical CIP frequency of no greater than every one month, triggered by the following criteria:

- Decline of normalized specific flux of less than 15%;
- Increase of normalized salt passage of less than 15%;
- Increase of normalized differential pressure of less than 15%;
- Decline of normalized flow rate decline of less than 15%;
- Increase of normalized feed pressure of less than 15%.

Side-by-side pilot testing began on June 2, 2020. As shown in Fig. 7, FRRO pilot testing proceeded from June 2 to December 2, 2020. CCRO™ pilot testing proceeded from June 2 to September 6, 2020. The CCRO™ pilot testing was discontinued after September 16, 2020. Table 2 provides a summary of pilot performance for each system.

Pilot testing allowed the City to gain useful insights about how each high-recovery RO technology operates, optimize recovery versus life-cycle cost, and identify potential risks in a full-scale system that the City may need to take on. The City ultimately selected the FRRO technology for full-scale implementation based its ability to meet the performance criteria outlined for the pilot program, its ability to maximize operation of the City's existing RO skids, smaller overall footprint, lower acid/antiscalant consumption and life cycle cost, and has the lower risk profile of the two technologies for the City since either technology would be the first municipal installation in the United States.

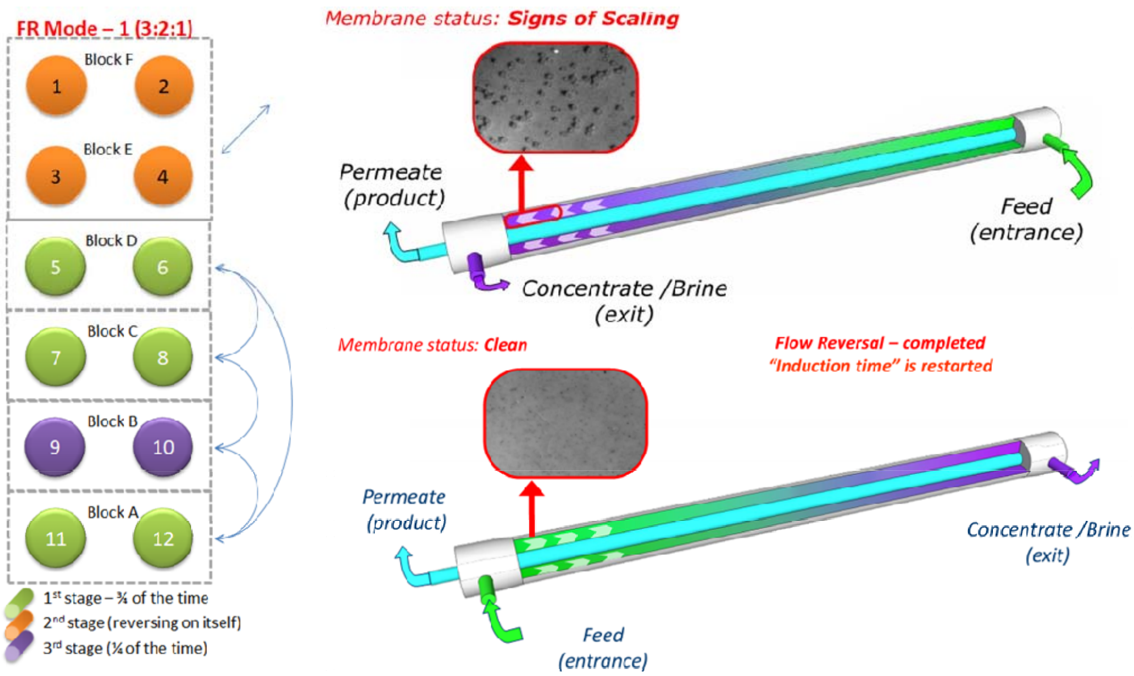

Fig. 6 Picture of FRRO process flow schematics illustrating stage rotation (left) and flow reversal processes (right).

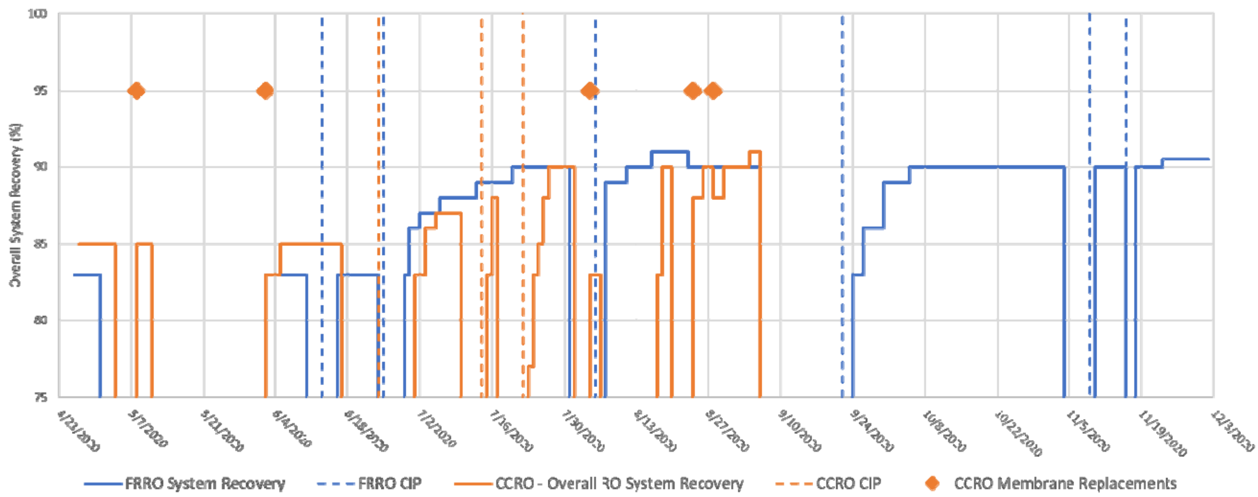

Fig. 7 Pilot testing summary of FRRO and CCRO™ recoveries, CIPs, and membrane replacements.

Table 2 FRRO and CCRO™ pilot performance summary.

Pilot	FRRO	CCRO
Operations	Primary RO in high recovery mode	Concentrate minimization system = 62% greensand filtrate/38% RO concentrate
Online time	Total online time of 144 days 106 days at 89% or greater recovery 15 consecutive days at 91% recovery	Total online time of 86 days ~22 days at 89% or greater overall recovery <5 non-consecutive days at 91% overall recovery
# of CIPs	Five CIPs; typical pilot operation between CIP events was over 30 days, longest operation was 42 days	Three CIPs; no typical pilot operation between CIP events
Membrane replacements	Membranes never replaced	Membranes replaced five times
Chemical consumption	pH of 6.3 (depressed from 7.5 with sulfuric acid) Antiscalant dose of 1 ppm of American Water Chemicals A-119 (6/3-9/4/20) or 2.5-3.0 ppm of Avista Vitec-4000 (9/24-12/4/20)	pH of 6.8 (depressed from 7.5) Antiscalant dose of 3 ppm of AWC A-119 + 1 ppm antiscalant from conventional RO system

3.4 Full-Scale Design of FRRO

Retrofitting the existing RO train to FRRO involves modifying the current conventional RO 3-stage array of static pressure vessels into an alternating sequence of rotating blocks. To keep the existing pressure vessels in place without modifying their locations or skid frame, the FRRO provider devised a concept of separating the existing 1st stage into 11 horizontal blocks of three pressure vessels each, and three of those blocks will rotate into 3rd stage. New manifolds and pneumatic valve configurations will allow flows to be redistributed throughout the system based on the automatic control system.

Retrofitting the existing RO skids with the FRRO technology will increase the RO recovery to 90% or greater, increase local potable water production (~1,200 acre-feet per year) without having to extract additional groundwater, and reduce concentrate waste discharge to the sanitary sewer. In addition, the FRRO technology also eliminated the need for the City to build a 5th RO skid as the higher recovery allows the City to still meet water production needs when one RO skid is down for CIP. Once complete in 2023, the FRRO retrofit will be the first full-scale municipal installation in the United States.

4. Alternative Delivery Method

All of the above projects are being implemented through progressive design-build as the City typically uses this delivery approach on its larger infrastructure projects to have a single point of responsibility and collaborate with the design and construction team throughout the entirety of the project. The progressive design-build delivery approach also allows the City to have direct input on treatment system design (e.g., operation preferences), performance guarantees, warranties, and system supplier selection on major process equipment including the membrane systems. With several first of its kind membrane applications and technologies being implemented by the City, a design-build delivery approach allows the City to minimize its risk profile through the collaborative delivery process where the design, construction, and equipment supplier are all at the table together.

In addition to the project delivery teams, owner's engineers provide significant insights on these large infrastructure projects based on expertise outside the City's experience. Stantec, for the SWIP, and GHD, for the Olympic Well-field Restoration and Arcadia Expansion Project, have assisted the City throughout design and construction to achieve the project's quality objectives.

5. Conclusion

The City of Santa Monica is nearing completion on several ambitious and innovative projects. These projects will produce multiple benefits for the City, including:

- Supplying as much as 99% of water demands through local water resources;
- Creating new drought resilient water supplies;
- Improving beach water quality;
- Diversifying the City's water supply;
- Augmenting local groundwater supplies;
- Restoring contaminated drinking water supplies;
- Reducing carbon footprint; and,
- Providing long-term cost benefits to ratepayers.

Successful, collaborative engagement with state regulators, funding partners, local leaders, owner's engineers, and design-build team partners has propelled the City towards water self-sufficiency.

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