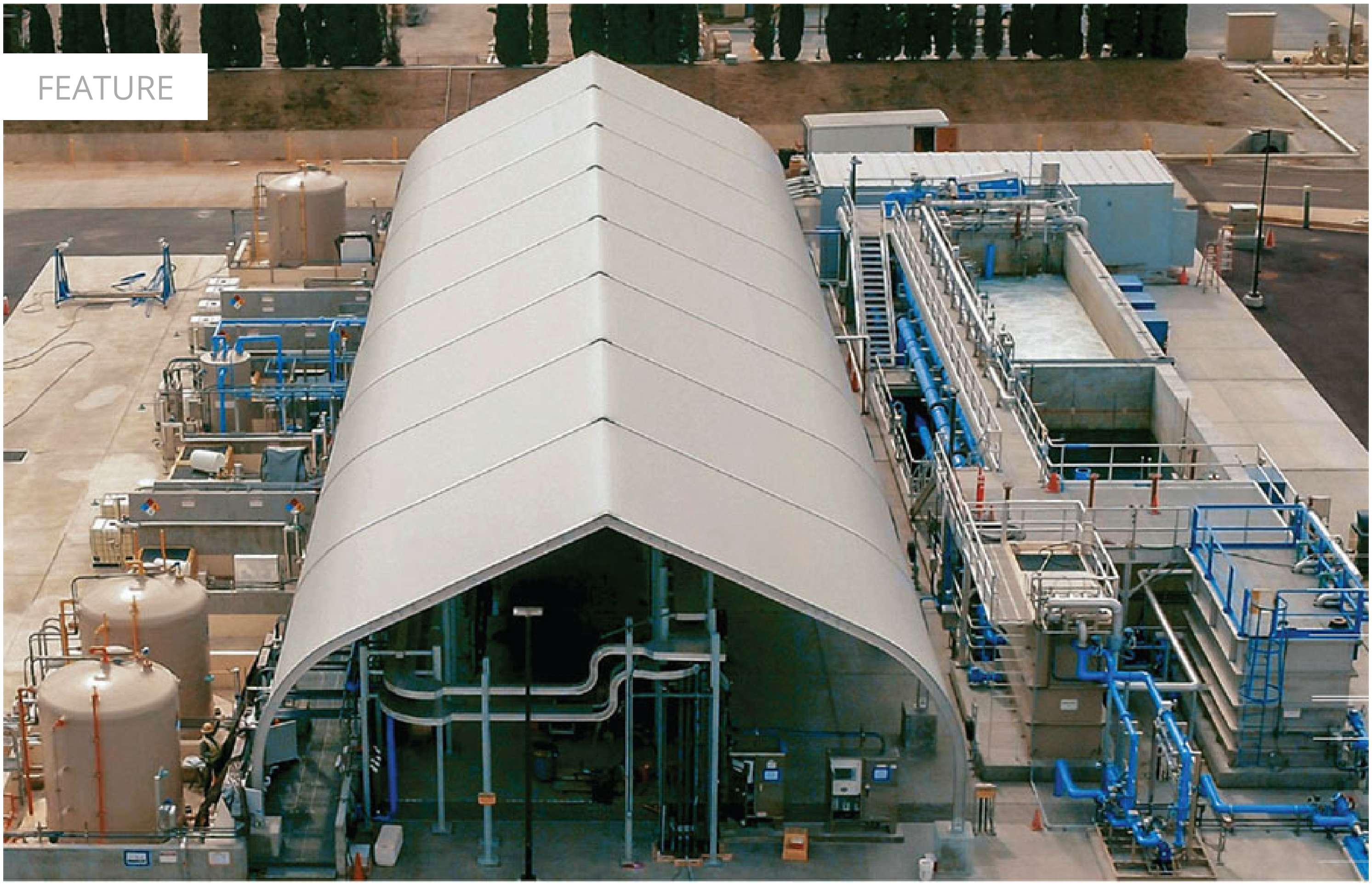


An Indirect Route with Direct Results

Forging a path to reuse for Southern California pushes through a pandemic

Sun Liang, Joyce Lehman, Heather Collins, Mickey Chaudhuri, Gloria Lai-Bluml, Bruce Chalmers, and John Bednarski

The Metropolitan Water District of Southern California (Metropolitan) and the Los Angeles County Sanitation Districts (Sanitation Districts) are partnering on a regional recycled water program to develop a drought-resistant new water source for Metropolitan's member agencies. For Metropolitan and all Southern California, the program offers potentially significant regional benefits. The production of up to 568 million L/d (150 mgd) of purified water for indirect potable reuse (IPR) can help to maintain groundwater production in Los Angeles and Orange counties.

This new supply has the potential to complement other Metropolitan water supply initiatives by providing reliable replenishments, freeing up imported water to be placed in storage as a drought buffer. The program also prepares Southern California for a catastrophic earthquake by developing a new reliable water supply wholly within the region. Furthermore, the program can be integrated into the existing regional system and become part of Metropolitan's network of facilities.

While originally conceived as an IPR-only program, Metropolitan will continue to monitor and engage in the research, technical assessments, and regulatory development of direct potable reuse (DPR) applicable for this program. Upon promulgation of such regulatory guidance for DPR applications, it is envisioned that future application of this new supply could be feasible in its service area, such as through raw water augmentation at two Metropolitan water facilities as represented by the future options shown in Figure 1 on p. 36.

The program includes an advanced water treatment (AWT) facility that would be located adjacent to the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) in Carson, California, and a new conveyance system. The conveyance system would consist of approximately 96 km (60 mi) of 213-cm (84-in.) diameter pipeline and at least three pumping facilities. Also shown in Figure 1, the system would deliver up to 568 million L/d (150 mgd) of purified water as far east as the Orange County Spreading Basins in Anaheim and as far north as the Santa Fe Spreading Grounds in Irwindale. Delivery points would consist of either groundwater spreading basins or injection wells. The program is anticipated to deliver advanced treated recycled water in 2032.

Regulatory Framework

The use of recycled water for IPR is regulated in California to ensure protection of public health and water quality. IPR refers to the augmentation of groundwater or surface water with highly treated recycled water. IPR through groundwater replenishment, which is the focus of the program, has been conducted for decades in California.

The draft criteria used to evaluate projects evolved over time. The revised groundwater replenishment regulations were incorporated into Title 22 of the California Code of Regulations in June 2014. The state's Water Recycling Criteria and Groundwater Replenishment Regulations are implemented and enforced through water reclamation requirements (WRRs) and waste discharge requirements (WDRs) that are imposed by the individual Regional Water Quality Control Boards (RWQCBs).

For projects involving surface water discharge, a National Pollutant Discharge Elimination System (NPDES) permit is also required. The RWQCB prescribes WRRs and/or WDRs that reasonably protect all beneficial uses and implement relevant water quality control plans and policies. Any entity proposing to recycle water would file a Title 22 Engineering Report with the State Water Resources Control Board (SWRCB) Division of Drinking Water (DDW) and the RWQCB on the proposed use. Figure 2 (p. 37) summarizes the permit approval process for a water recycling project in California.

AWT Demonstration Facility

A significant first step for this program is the construction of a 1.9 million L/d (0.5 mgd) AWT demonstration facility, located within the Sanitation Districts' JWPCP, as shown in the photo on p. 34. The process train consists of a membrane bioreactor (MBR), a reverse osmosis (RO) system, and an ultraviolet light with an advanced oxidation process (UV/AOP) for disinfection and organic contaminant removal as shown in Figure 3 (p. 38).

Most AWT facilities in California use a microfiltration (MF)-RO-UV/AOP treatment train to meet required IPR regulations for groundwater replenishment. Because of the need to manage nitrogen in the JWPCP source supply, an MBR has been proposed as the optimal process in a potential full-scale AWT treatment train.

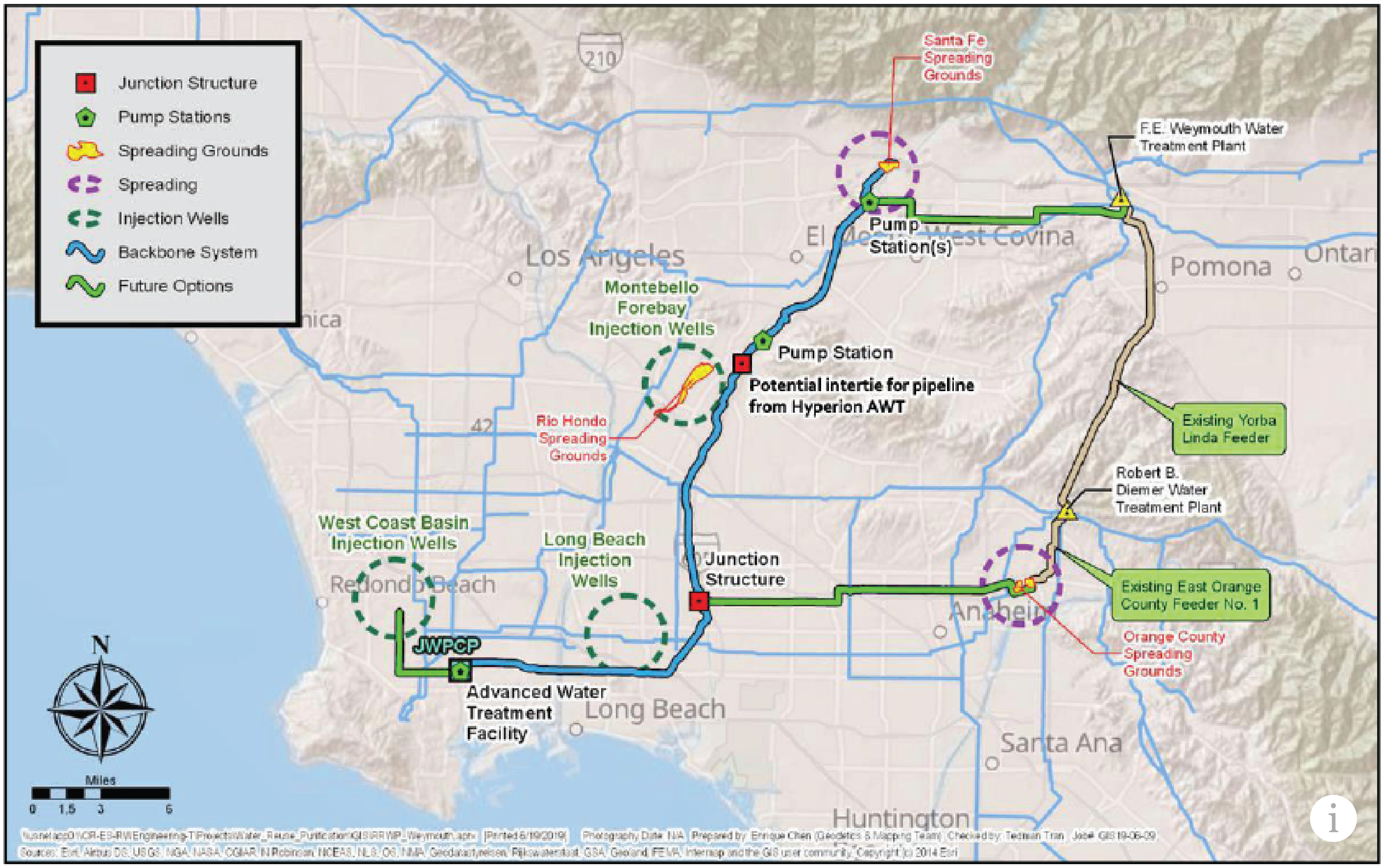
Metropolitan and the Sanitation Districts conducted a 2-year pilot study between 2010 and 2012. It revealed an MBR-RO-UV/AOP process could be used to meet the draft IPR regulations available during the time of the study, and significant benefits could be observed by employing an MBR with a biological treatment process as opposed to an MF process alone upstream of RO. However, DDW currently does not grant pathogen removal credits for MBRs, so the challenge of implementing IPR using MBR is obtaining conservative log reduction credits for MBR. A regulatory strategy for pathogen removal must be developed to enable incorporation of an MBR into a potable reuse advanced treatment train.

The biological treatment basins of the demonstration facility can be configured to treat secondary or primary wastewater effluent resulting in a tertiary or secondary MBR, respectively. The RO system is equipped to run as either a single-pass or a double-pass system, with each pass having two stages.

The UV/AOP system uses low-pressure/high-output lamps and hydrogen peroxide or sodium hypochlorite to drive the AOP process. All product water and waste streams including RO concentrate are routed back to the head of JWPCP. The demonstration facility can also be expanded in the future to incorporate additional treatment processes to assess potential treatment requirements for DPR. The demonstration facility will provide the water quality data needed for the Title 22 report and be used to develop the design and operating criteria for the full-scale AWT.

Coordination and Demonstration

Metropolitan and the Sanitation Districts are collaborating on treatment technology acceptance with regulatory agencies, including DDW and the Los Angeles and the Santa Ana RWQCBs, concurrent with the development and operation of the demonstration facility.



The panel. Starting in 2016, Metropolitan and the Sanitation Districts have met with regulatory agencies, seeking input and guidance on the program, including the treatment process for the demonstration facility. In April 2018, the National Water Research Institute (NWRI) formed an independent science advisory panel — experts in the fields of microbiology, toxicology, chemistry, potable reuse, hydrogeology, corrosion, and water treatment technology. The panel's objective is to provide an independent review of the technical, scientific, regulatory, and public health aspects of the demonstration project. Its members are evaluating alternative approaches to meeting existing regulations, reviewing data and regulatory submittals, and helping to guide the technical aspects of the overall program. Under California's groundwater recharge reuse regulations (Title 22 CCR §60320.130), projects such as Metropolitan's that may seek alternatives to existing regulations require the review by such a panel.

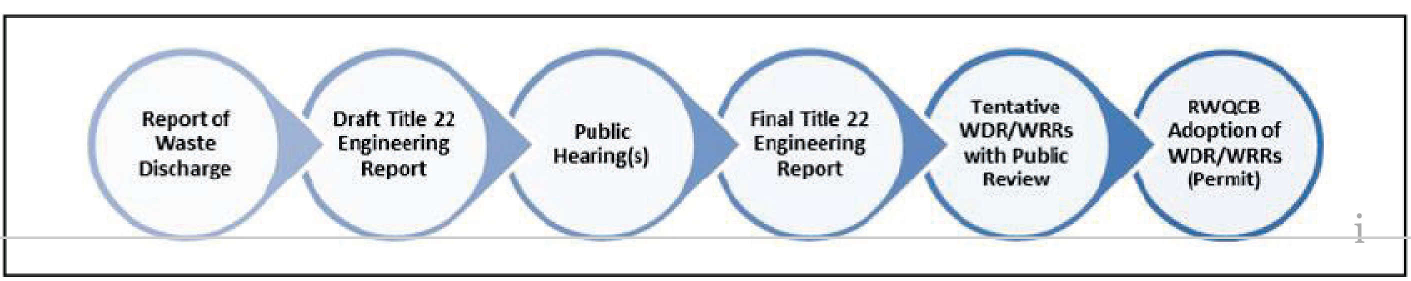
In August 2018, Metropolitan and the Sanitation Districts met with the advisory panel and regulatory agencies to discuss the regional recycled water program concept, groundwater basin analyses, demonstration facility process train, and demonstration testing strategy.

The plan. Due to the need to demonstrate pathogen removal through the MBR process, a testing and monitoring plan was developed that summarized the testing period during which pathogen removal data could be gathered from the MBR system, as well as provide overall water quality performance. Metropolitan and the Sanitation Districts incorporated the panel's initial feedback, they submitted a draft testing and monitoring plan for the demonstration project to regulatory agencies in October 2018. The Los Angeles RWQCB and DDW submitted comments to Metropolitan and the Sanitation Districts in November 2018. The water partners responded to the comments in January 2019, and a final plan submitted shortly thereafter received approval from DDW in February 2019.

The demonstration. Demonstration facility operations commenced in October 2019, and following several months of pre-testing, the advisory panel and regulatory agencies met a second time to discuss the operational and treatment performance observed during startup, microbiological analytical method development, the proposed testing and monitoring approach for IPR treating primary wastewater effluent, and the concept of a downstream satellite AWT facility for future raw water augmentation.

In April 2020, after 7 months of equipment testing and process acclimation, a virtual meeting (due to COVID-19 access restrictions) was held to review the demonstration operational results, preliminary MBR bypass results, and proposed MBR challenge test conditions.

Metropolitan and the Sanitation Districts will continue to engage the advisory panel and regulatory agencies in the review of the tertiary MBR testing results and the development of secondary MBR testing and monitoring protocols, and the secondary MBR testing results. Potential DPR applications for raw water augmentation at a conceptual level, as well as future work to be developed for ultimate permitting of the program, will also be discussed with the panel and regulatory agencies.



Demonstration Testing

While the primary objective of the testing and monitoring plan is to obtain technology acceptance for the MBR process, additional objectives are to ensure that the final product water would meet all regulatory requirements. Metropolitan will routinely monitor numerous locations throughout the demonstration facility treatment train to assess the efficacy of the proposed unit processes.

For the Sanitation Districts, the main monitoring objectives for the plan can be grouped into three categories: NPDES and Ocean Plan compliance, effect of residual waste streams on JWPCP operation, and source control. In order to assess the potential full-scale AWT quality and effect of waste streams on JWPCP, Sanitation Districts monitor the JWPCP influent, JWPCP secondary effluent, and residual streams at various frequencies at both the demonstration facility and JWPCP.

Pathogen removal. For an IPR project, the treatment system must achieve 12-log enteric virus reduction, 10-log *Giardia* cyst reduction, and 10-log *Cryptosporidium* oocyst reduction using at least three treatments. Table 1 (p. 38) describes the pathogen log removal credits that are typically granted for an MFRO-UV/AOP train, as well as the minimum 2.5-log for MBR that would be needed to meet California's requirements of 10-log removal of *Cryptosporidium* and *Giardia* with an MBR-RO-UV/AOP train. These additional pathogen removal credits through the MBR will be pursued through demonstration testing.

It should be noted that demonstrating pathogen removal can be difficult as analytical challenges exist for detection of *Cryptosporidium* and *Giardia*. This is partly due to the lack of standardized methods for the quantification of *Cryptosporidium* in large volumes of advanced treated wastewater, such as MBR filtrates or RO permeates. Although U.S. Environmental Protection Agency (EPA) Method 1693 was developed for the quantification of *Cryptosporidium* and *Giardia* in 1- to 10-L samples of disinfected wastewater, some studies have reported very poor recoveries for spiked secondary effluent samples. Fortunately, the drinking water and regulatory communities can build upon prior research to help address these challenges. Metropolitan is investigating *Cryptosporidium* analytical challenges within the context of potable reuse, including exploring the application of previously developed research methods, such as cell culture infectivity assessment and genotyping to potable reuse.

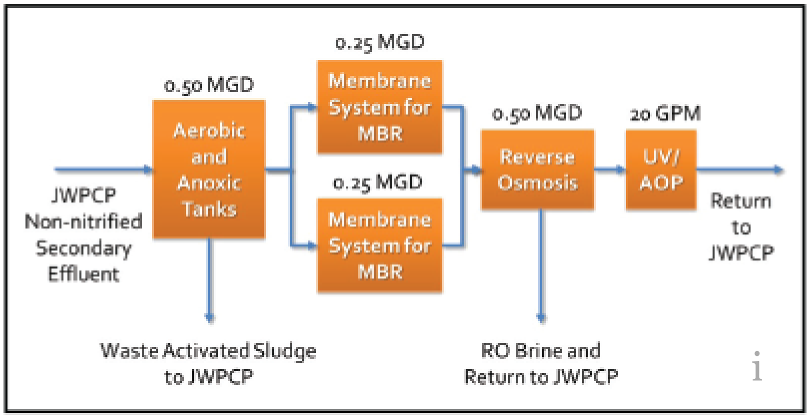
Water quality. Since the AWT product water is intended to recharge multiple groundwater basins in Los Angeles and Orange counties, it must meet the strictest Water Quality Control Plan (Basin Plan) limits of those groundwater basins. Those limits are set by the local RWQCBs. The product also must satisfy all drinking water maximum contaminant levels and notification levels. While IPR regulations require that the concentration of total nitrogen in recycled water must not exceed 10 mg/L, the most stringent limit that must be considered is the Orange County Basin Plan requirement for nitrate, which is 3.4 mg/L-N.

Therefore, the demonstration facility must achieve product water well below this requirement. The demonstration facility will also be used to evaluate the impact of MBR filtrate water quality on RO fouling rates, determine the suitability of tertiary MBR biological nitrification/denitrification (NdN), and to evaluate hydrogen peroxide and sodium hypochlorite as oxidants that drive the UV/AOP process.

Testing and monitoring plan. The plan outlines the three phases of testing work to be conducted at the demonstration facility. The first phase of testing included 9 months of equipment testing, process acclimation, and analytical methods development as part of a "pretesting" initial shakedown period.

The next two phases of testing are expected to be completed over 12 months of testing, including a steady-state baseline phase. A challenge testing phase will follow, during which the MBR will be intentionally compromised to evaluate the robustness and overall tolerances of the system under worst-case conditions, as well as evaluate fouling observed on the RO system.

For the UV/AOP system, collimated beam testing and 1,4-dioxane spiking tests will occur during baseline testing, whereas nitrosamine formation potential studies and UV testing with peroxide or sodium hypochlorite will be conducted within both baseline and challenge testing phases. The plan includes simultaneous testing of the unit processes to maximize the time and the amount of useful data produced during the test period.



Biological Nutrient Reduction

During the pretesting phase starting in October 2019 through May 2020, the demonstration facility operated in a process acclimation mode to establish NdN. The goal during NdN operations was to achieve complete nitrification resulting in an ammonia concentration of less than 0.5 mg/L, followed by partial denitrification resulting in MBR filtrate nitrate of 10 to 12 mg/L. After startup at the demonstration facility, nitrification of ammonia to nitrate was successful. However, partial denitrification of the nitrate into nitrogen gas resulted in accumulation of nitrite in the system that could not be addressed with the operational configurations and process flow options available at the demonstration facility.

Then, efforts turned to achieving the NdN goal. During this period, MicroC 2000 was added to the anoxic tank, typically at dosages between 125 and 275 mg/L to provide the organic carbon necessary for denitrification. Phosphoric acid up to 6.5 mg/L was added to the demonstration facility influent to ensure adequate nutrients to foster NdN. Sludge retention times of 8 and 15 days were tested while the target dissolved oxygen (DO) concentration in the aerobic tank was 2 mg/L. The return-activated sludge flow was set as high as 5.7 times the filtrate flow for testing. The MLSS concentration in the aerobic tank was up to 7,000 mg/L under high chemical oxygen demand (COD) conditions. The MBR membranes were operated at a flux of 18.7 Lmh (11 gfd). While the bioreactor operated in an NdN mode for 8 months, water resource recovery experts from the Sanitation Districts provided input and assistance with optimization efforts to minimize nitrite buildup observed at the demonstration facility.

Table 1. Approaches to Achieving Pathogen Log Reduction Credits

Unit Process	Currently Approved AWT Train			Alternate AWT Train Using MBR[1]		
	Virus	Cryptosporidium	Giardia	Virus	Cryptosporidium	Giardia
Membrane bio-reactor	—	—	—	0	2.5[2]	2.5[2]
Microfiltration/Ultraviolet filtration	0	4	4	—	—	—
Reverse osmosis	1.5	1.5	1.5	1.5	1.5	1.5
Ultraviolet light with advanced oxidation process	6	6	6	6	6	6
Free chlorine	6	0	0	6	0	0
Total	13.5	11.5	11.5	13.5	10	10
Regulatory requirement	12	10	10	12	10	10

[1]Pathogen log removal credits currently not granted for MBRs by regulators.
[2]Requires demonstration and approval by regulator.

As shown in Table 2 (p. 39), with MicroC 2000 added at the design dose of 210 mg/L, total inorganic nitrogen removal was only 40% to 50% (15.8±2.8 mg/L nitrate-nitrogen and 6.2±1.9 mg/L nitrite-nitrogen at MBR filtrate versus 43.5±2.3 mg/L ammonia-nitrogen at AWT influent). That level is below the 80% removal goal (10 to 12 mg/L nitrogen at MBR filtrate). In addition, the median nitrite concentration under these operational conditions was 6.2±1.9 mg/L in MBR filtrate.

Subsequently, it was determined that operation of the biological reactors under a nitrification-only (N-only) mode would alleviate concerns of nitrite on downstream treatment processes, yet still allow the project to proceed while maintaining the approved testing and monitoring plan objectives. Since switching to a N-only mode of operation in June 2020, no nitrite accumulation in MBR filtrate has been observed.

Nitrite and nitrate are continuously removed by the RO process. However, studies show a decline will occur over time in nitrate rejection by RO membranes. Nitrate concentrations in a tertiary MBR NdN mode with a single-pass RO and a tertiary MBR N-only mode with a double-pass RO were 1.1±0.5 and 1.8±0.5 mg/L-N, respectively. This demonstrates that both process combinations could achieve the overall nitrate goal of less than 3.4 mg/L nitrate for the final water product. However, nitrate levels under a tertiary MBR N-only mode with single-pass RO resulted in an RO permeate nitrate concentration of 5.0±0.4 mg/L-N, which exceeds the nitrate goal. As such, it was determined that under a tertiary MBR N-only mode, the overall water quality goals could not be achieved with single-pass RO. Therefore, a tertiary MBR N-only mode would need the RO system to operate in a double-pass configuration.

Future Plans

Secondary MBR testing. Following completion of testing according to the testing and monitoring plan for tertiary MBR treating non-nitrified secondary wastewater effluent, the demonstration facility will transition to treatment of primary wastewater effluent with a secondary MBR for another approximately 14 months. The plan for secondary MBR testing would be patterned after the tertiary MBR testing and monitoring plan, including revisions to account for lessons learned.

DPR testing. With respect to DPR testing, additional treatment processes may be required to be constructed at the demonstration plant. While DPR regulatory requirements in California are to be finalized by 2024 at the latest, the "Proposed Framework for Regulating Direct Potable Reuse in California" (DPR Framework) provides DDW's current thinking on DPR regulation in California.

While initially issued in April 2018, a second edition was issued in August 2019. It is envisioned that the DPR test objectives would build upon those outcomes from tertiary and secondary MBR testing and seek to achieve the following:

(1) Demonstrate the efficacy of additional treatment processes for pathogen and contaminant removal;

(2) Demonstrate the appropriate treatment train that can satisfy groundwater basin requirements for IPR and anticipated regulatory requirements for DPR through raw water augmentation;

(3) Develop water quality acceptance criteria and blending strategies for advanced treated water placed upstream of drinking water treatment plants; and

(4) Develop, evaluate, and optimize analytical methods for detecting microbial and chemical contaminants.

Table 2. Operational Conditions and Water Quality Performance

Biological Reactor Operational Conditions and Performance				
Operational Mode	NDN		N-Only	
Sludge retention time (day)	15		9	
Aerobic chemical oxygen demand (COD) (mg/L)	62-75 (20-30% total COD)		—	
Anoxic chemical oxygen demand (mg/L)	210		—	
Mixed liquor suspended solids concentration (mg/L)	6,397±226		1,370±202	
Dissolved oxygen (mg/L)	1.9		1.8	
Return activated sludge Q	5.1Q		1.6Q	
Phosphate dose (mg/L)	1.4		—	
Location	AWT Influent	MBR Filtrate	AWT Influent	MBR Filtrate
Nitrate (mg/L-N)	—	15.8±2.8	0.31±0.11	41.4 ± 3.5
Nitrogen dioxide (mg/L-N)	—	6.2±1.9	0.07±0.11	<0.015
Ammonia (mg/L-N)	43.5±2.3	0.018±0.003	40.5±2.2	0.017±0.006

Reverse Osmosis (RO) Performance						
Operational Mode	NDN		N-Only			
RO configuration	Single-Pass		Single-Pass		Double-Pass	
Location	MBR Filtrate	RO Permeate	MBR Filtrate	RO Permeate	MBR Filtrate	RO Permeate
Nitrate (mg/L-N)	13.9±5.1	1.1±0.5	43.0±2.6	5.0±0.4	40.7±2.1	1.8±0.5
Nitrogen dioxide (mg/L-N)	7.4±4.8	0.5±0.4	<0.015	<0.015	<0.015	<0.015
Ammonia (mg/L-N)	0.016±0.002	0.235±0.125	0.017±0.005	—	0.017±0.003	—

It is anticipated that following the initial testing period, demonstrating pathogen removal through the MBR process and meeting established treatment goals for water quality from all unit processes, a future testing phase will focus on treatment process optimization. After optimization, the development of full-scale design criteria can begin.

Metropolitan and the Sanitation Districts will continue to coordinate with regulatory agencies and the independent science advisory panel throughout testing at the demonstration facility. They also will continue to monitor and engage in research, technical assessments, and regulatory developments of additional forms of potable reuse — evaluating future opportunities for DPR.

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