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Developing a regional recycled water program in Southern California

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Abstract

The Metropolitan Water District of Southern California (Metropolitan) and the Sanitation Districts of Los Angeles County (Sanitation Districts) are exploring the potential of a Regional Recycled Water Program (RRWP) to beneficially reuse water currently discharged to the Pacific Ocean. The program would consist of a new advanced water treatment (AWT) facility at the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) in Carson, California, USA, capable of producing an ultimate flow of 581 MLD (150 MGD). The full-scale facility would treat effluent from the JWPCP using an AWT train comprising a membrane bioreactor (MBR), followed by reverse osmosis (RO) and ultraviolet light advanced oxidation (UV/AOP). After MBR-RO-UV/AOP treatment, the treated water would be distributed to groundwater basins in Los Angeles and Orange counties to recharge their aquifers. This program would diversify the region's water resources and significantly contribute to long-term water supply targets outlined in Metropolitan's Integrated Water Resources Plan. A feasibility study for the RRWP was completed in 2016, confirming its technical viability. Currently, Metropolitan and the Sanitation Districts recently completed conceptual planning studies to investigate implementation options for a full-scale program, and constructed a 1.9 MLD (0.5 MGD) AWT demonstration facility. Although large facilities employing membrane filtration (MF)-RO-UV/AOP are currently permitted and operating in California, there are no facilities using an MBR-RO-UV/AOP train. The AWT demonstration facility – the Regional Recycled Water Advanced Purification Center – will build on recent research in Australia and the USA to develop a regulatory strategy to incorporate MBR into a potable reuse advanced treatment train.

Key words: advanced treatment, membrane bioreactor, nutrient removal, potable reuse, reverse osmosis

INTRODUCTION

The Metropolitan Water District of Southern California (Metropolitan) is one of the world's largest water suppliers. Metropolitan is a regional agency that delivers a supplemental water supply for domestic and municipal uses by importing water from the Colorado River and Northern California. It provides more than half of the water used by 19 million Southern Californians. The Sanitation Districts of Los Angeles County (Sanitation Districts) is a regional agency that collects, treats, recycles, and disposes of wastewater, and generates recycled water, electricity, and biosolids as products of its treatment processes. Jointly, Metropolitan and the Sanitation Districts are contemplating the development of a Regional Recycled Water Program (RRWP) to beneficially reuse up to 568 MLD (150 MGD) of water from the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) in Carson, California. The JWPCP is a 1,514 MLD (400 MGD), high-purity, oxygen-activated sludge

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(HPOAS) facility that discharges un-nitrified secondary effluent to the Pacific Ocean. This new source of regional supply could be used to replenish local groundwater supplies, which are facing significant challenges due to years of drought. The RRWP can help to maintain groundwater yields across several Southern California counties and provide significant regional benefits.

PROGRAM DEVELOPMENT

Initially, the RRWP would produce treated water to provide a reliable recharge source for regional groundwater basins that serve a vital function in the region's diversified water resource portfolio. In the future, the facility may provide resources for other direct and indirect potable reuses. In addition to a new advanced water treatment (AWT) facility at the JWPCP, the program would include an extensive new network of pipelines and pump stations, to deliver treated water to recharge four groundwater basins across the region via existing spreading grounds, and new and/or existing injection wells. A Metropolitan feasibility study report completed in 2016 (Metropolitan Water District of Southern California 2016) determined that the RRWP is feasible, and recommended that additional work be conducted to delineate and refine the major program elements, including: (1) construction and operation of an AWT demonstration facility; (2) development of institutional and financial arrangements for program management and operation; (3) evaluation of potential cost allocation within Metropolitan's rate structure, and (4) completion of a public outreach plan associated with the demonstration facility.

Due to its scale and technical challenges, development of the RRWP requires extensive planning in all major elements. An initial step is to gain regulatory acceptance of processes that may be considered for the AWT to produce water meeting the pathogen reduction and groundwater recharge requirements. After a two-year pilot study evaluating two treatment trains, Metropolitan has designed and is currently constructing a 1.9 MLD (0.5 MGD) demonstration facility. This Regional Recycled Water Advanced Purification Center (RRWAPC) will start operating in early 2019 to evaluate a treatment train consisting of a membrane bioreactor (MBR), reverse osmosis (RO), and ultraviolet light with advanced oxidation (UV/AOP), to treat un-nitrified secondary effluent from the JWPCP. The Advanced Purification Center will be used to demonstrate the ability of MBR treatment in both pathogen reduction and nitrogen removal.

VALIDATION OF MBR TREATMENT FOR POTABLE REUSE

MBR treatment is an alternative to the conventional activated sludge system used in wastewater treatment, in which biosolids separation through the clarifier is replaced by membrane filtration. The MBR process is used widely in non-potable reuse applications such as toilet flushing and golf course irrigation. Its advantages include high biodegradation efficiency and complete retention of microorganisms, allowing disinfection of treated water (Çiçek *et al.* 1998; Le-Clech *et al.* 2006; Sipma *et al.* 2010); reduced sludge production (Bouhabila *et al.* 2001; Na *et al.* 2017); and low turbidity product water (Hirani *et al.* 2013). Although a membrane performs the solid-liquid separation in an MBR, disinfection is commonly required in the USA for reuse applications to ensure adequate virus removal and there is concern amongst regulators that microorganism concentrations may increase with time as the membranes age. Regardless, MBRs are widely applied in non-potable applications and membrane fouling poses the most significant disadvantage to existing MBR installations, lowering filtration efficiency and treated water output flow (Bouhabila *et al.* 2001; Bagheri & Mirbagheri 2018). Various techniques are used to control membrane fouling potential – e.g., air bubbles in submerged bioreactors, chemical cleaning, and periodic backwashing (Bouhabila *et al.* 2001; Le-Clech *et al.* 2006).

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Indirect potable reuse (IPR) projects continue to expand in California due to increasing interest in local water supplies and population growth. IPR uses advanced treated wastewater for applications such as surface water augmentation (e.g., rivers, lakes), and artificial groundwater recharge through direct injection, or surface-spreading and percolation. In the United States, the California Division of Drinking Water (DDW) is one of the few state agencies that has issued regulations about potable reuse. They are in Title 22 of the California Code of Regulations (CDPH 2014). For direct injection of potable reuse water into aquifers, DDW requires the treatment train to include RO and advanced oxidation, to remove chemical contaminants and inactivate pathogens. In the past, treatment trains have included microfiltration (MF) or ultrafiltration (UF) prior to RO, to provide pre-treatment and remove protozoa. Although MBRs are used in non-potable reuse applications, DDW has not yet granted pathogen log-removal values (LRVs) for the MBR process in recycled water applications.

Typically, MBRs are used to treat raw sewage or primary effluent (Melin *et al.* 2006), but studies have shown that incorporating them as RO pre-treatment can produce high quality secondary effluent, due to effective filtration and biological nitrification (Hirani *et al.* 2012; Branch & Le-Clech 2015; Salveson & Fontaine 2016). Biological activity in the MBR may lower the concentration of organic matter and other compounds of concern, and can provide higher quality water to the RO and UV/AOP processes. Consequently, this technology offers potential advantages over regular membrane filtration (i.e., MF and UF), which is usually used in advanced treatment. Additional research is needed, however, to demonstrate to DDW the pathogen LRVs that MBR can achieve, before it can be incorporated into an AWT facility.

To assist with regulatory approval, Metropolitan's Advanced Purification Center will be used to demonstrate compliance with the water quality requirements associated with the groundwater basins that would be proposed for recharge in a full-scale program. Treatment must also meet all drinking water maximum contaminant levels (MCLs) and notification levels, while providing at least 12 logs pathogen removal for viruses and 10 logs for *Cryptosporidium* and *Giardia*. Although DDW has not yet granted pathogen LRVs to MBR systems, an Australian approach for crediting MBR with LRVs (WaterSecure 2017) provides useful guidance.

The main objectives of the Advanced Purification Center are to: (1) build on industry knowledge to maximize the LRVs awarded to the MBR process in artificial groundwater recharge; (2) demonstrate that an MBR-RO-UV/AOP treatment train can satisfy groundwater basin plans and other regulatory requirements for groundwater recharge; (3) develop data for the Title 22 Engineering Report, on which DDW would approve a full-scale permit; (4) determine optimum design and operating criteria for a full-scale AWT facility; and (5) provide a vehicle for public outreach and acceptance. In order to accomplish these objectives, the Advanced Purification Center will be used to evaluate MBR pathogen inactivation. Researchers will measure water quality parameters relevant to the groundwater basins likely to receive the treated water, while operating and water quality data will be generated to develop both the Title 22 Engineering Report and the full-scale AWT facility design criteria.

Australian tiered approach for MBR

An extensive study investigating pathogen removal in MBR systems was conducted in Australia by the Australian Water Recycling Centre of Excellence (Branch & Le-Clech 2015). The study concluded that membrane integrity testing techniques, such as a pressure decay tests (PDT), are not favorable to MBR systems for several reasons, including the lack of correlation between PDT and LRV because pathogen removal is not limited to size exclusion. It was also noted that poor LRV frequently correlates with low hydraulic retention time (HRT), high flux, high permeability, low transmembrane pressure (TMP), high turbidity, low mixed liquor suspended solids (MLSS), and high dissolved oxygen (DO) content.

The study's results were used in Australia to develop the Membrane Bioreactor Validation Protocol (WaterSecure 2017), a three-tiered approach for granting LRV credits to MBR systems for viruses,

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bacteria, and protozoa. Tier 1 grants a default LRV of 1.5, 2.0 and 4.0 for viruses, protozoa, and bacteria, respectively, for submerged MBR systems with nominal pore sizes of 0.04 to 0.1 μm and operating within the envelopes defined in Table 1. Although DDW has indicated that it is comfortable awarding pathogen Tier 1 LRVs for a potable reuse project in California, the MBR must be designed and operated within the ranges presented in Table 1 to meet the validation protocol.

Table 1 | MBR operating envelope for adoption of Tier 1 conservative LRVs. (HRT is calculated on the basis of total influent volume over the last 24 hours of operation.)

	Operating Envelope	
Parameter	**Minimum**	**Maximum**
Bioreactor pH	6.0	8.0
Bioreactor DO, mg-O_2/L	1	7
Bioreactor temperature, °C	16	30
Solids Retention Time (SRT), hours	11	–
HRT, hours	6	–
MLSS, mg/L	3,000	–
TMP, bar	0.03	–
Flux, LMH	–	30
Turbidity, NTU	–	0.2

In Tier 2, MBR systems are validated with a different operating envelope through initial challenge testing, to demonstrate the MBR's base performance before installation, followed by confirmation of pathogen reduction performance by analyzing paired feed water, mixed liquor, and permeate samples during and after commissioning. Tier 2 targets specific water quality goals, including LRVs superior to the default levels in Tier 1. An MBR validated under Tier 2 must always operate under the validated operating envelope to receive the approved LRVs (WaterSecure 2017).

Tier 3 involves a specific investigation to demonstrate the correlation between parameter(s) that can be monitored constantly online and the MBR's pathogen removal performance. It allows critical limits to be established specific to LRVs claimed. According to WaterSecure (2017), Tier 3 remains hypothetical until peer-reviewed and tested in full-scale settings.

Table 2 describes the LRVs attributed to individual unit processes in California, and compares the predicted removal by the treatment train in this study (MBR-RO-UV/AOP) to that of an advanced MF-RO-UV/AOP treatment train, the most common potable reuse treatment train in the state. MBR LRVs in the

Table 2 | Currently approved pathogen LRVs in California, by unit process and treatment train

	Log Removal Values		
Unit Process	**Virus**	***Cryptosporidium***	***Giardia***
MBR*	0.0	0.0	0.0
MF	0.0	4.0	4.0
RO	1.5	1.5	1.5
UV/AOP	6.0	6.0	6.0
Free chlorine	6.0	0.0	0.0
Total LRV granted in treatment trains:			
MF-RO-UV/AOP	13.5	11.5	11.5
MBR-RO-UV/AOP	13.5	7.5	7.5

*Metropolitan's study seeks to demonstrate for MBR minimum LRVs of 1.5/3/3 for virus, *Cryptosporidium*, and *Giardia*, respectively.

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table (i.e., 0 LRV) are assumed because DDW has not yet granted credits to a full-scale project. As shown, the MBR-RO-UV/AOP scenario does not earn sufficient LRVs to satisfy the minimum 10 LRV required for either *Cryptosporidium* or *Giardia*. Thus, the demonstration project at the Advanced Purification Center will seek to improve the LRVs through the MBR process to secure regulatory approval.

ADVANCED TREATMENT CENTER TESTING STRATEGY

Feed water

Data collected from unchlorinated secondary effluent at JWPCP show typical water quality as in Table 3 – presented as average concentrations (SDLAC & MWDSC, 2012; SDLAC, 2014). These data are provided to inform the water quality that has been used for planning and designing the RRWAPC, which represents a high quality non-nitrified secondary effluent in Southern California.

Table 3 | Typical secondary effluent water quality from JWPCP

Analyte	Concentration	Unit
Alkalinity	373	mg-$CaCO_3$/L
Ammonia	41.3	mg-N/L
Boron	0.89	mg/L
N-nitrosodimethylamine (NDMA)	433	ng/L
1,4-dioxane	9.4	μg/L
Total dissolved solids (TDS)	1,410	mg/L
pH	7.2	–
Total phosphorus	0.59	mg/L
Chemical oxygen demand (COD)	55	mg/L
Total organic carbon (TOC)	12.3	mg/L

Treatment train description and layout

The Advanced Treatment Center process train will treat un-nitrified secondary effluent from the JWPCP through MBR, RO, and UV/AOP. The process flow diagrams are shown in Figures 1 and 2. The MBR system will include two biological tanks (aerobic and anoxic) that can operate in series, followed by two parallel MBR tanks from different manufacturers. Since it is treating un-nitrified secondary effluent, the MBR system will operate as a tertiary MBR in nitrification/denitrification (NdN) mode. The microbiology in the nitrification process will further oxidize the remaining organic species, which should reduce downstream RO membrane fouling. By incorporating a denitrification zone, nitrate will be removed to allow the effluent water quality to meet groundwater basin objectives after subsequent RO treatment. The combined MBR filtrate will feed the RO system, and 75.7 L/min (20 gpm) of the RO permeate will be directed to the UV/AOP system for further treatment; the remaining flow will be returned to the JWPCP. The Advanced Treatment Center design and site layout are flexible enough to support additional/alternative unit processes, if needed and/or for evaluation.

Testing phases

Demonstration testing will be divided into three phases – Table 4 – in each of which all treatment processes will be evaluated to maximize both the time available for testing and the amount of useful data produced.

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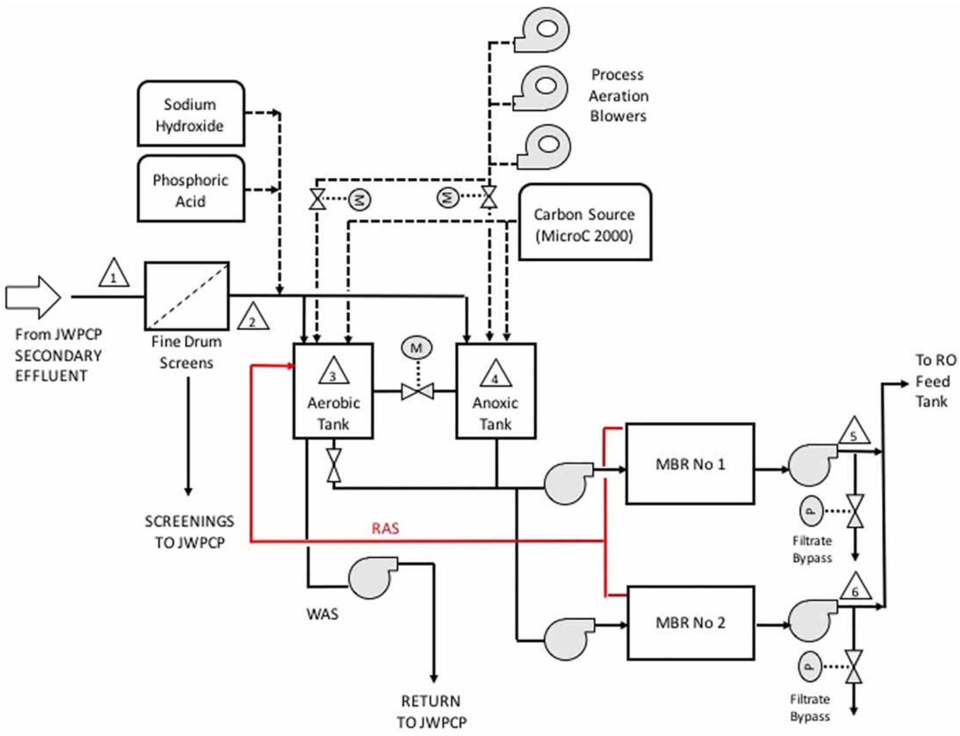

Figure 1 | Process schematic of the MBR system at the Advanced Treatment Center.

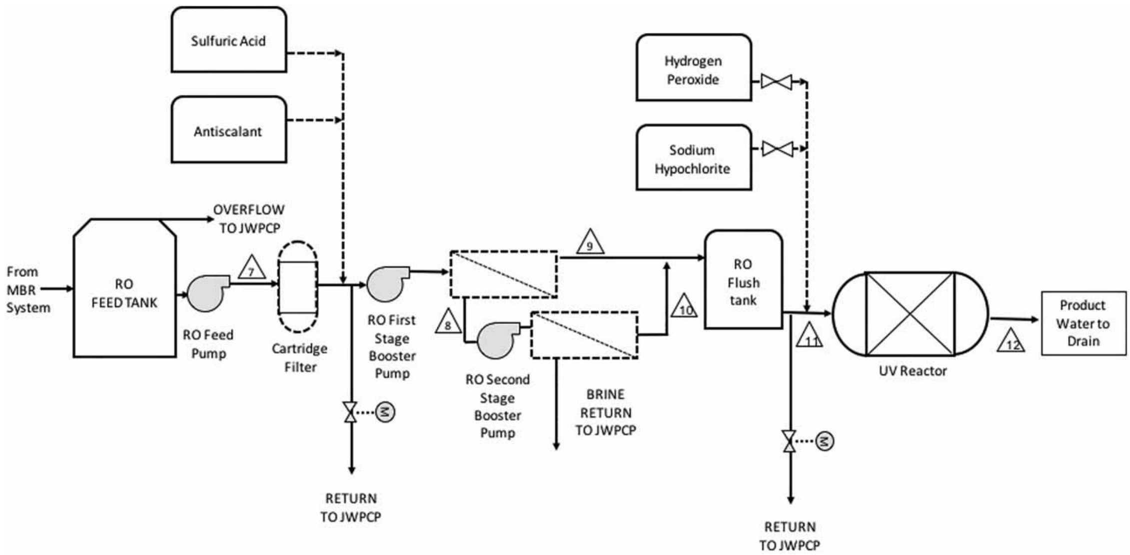

Figure 2 | Process schematic of the RO and UV/AOP systems at the Advanced Treatment Center.

MBR testing approach

The primary goal of MBR testing will be to demonstrate a minimum LRV of 3.0 for *Cryptosporidium* and *Giardia*, and a minimum LRV of 1.5 for viruses. It is important to note that the MBR system will be commissioned outside some Tier 1 operating envelope limits due to the RRWAPC's design criteria. Compliance with Tier 1 operating criteria and LRVs will be established during baseline testing (phase 2). The MBR will operate in NdN mode throughout the study (all phases) to achieve nitrogen management goals. Numerical modeling indicates that the effluent ammonia concentration should be below the method reporting limit (0.2 mg-N/L) and the nitrate concentration less than 12.5 mg-N/L.

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Table 4 | Proposed demonstration test phases

	Study Focus		
Phase	MBR	RO	UV/AOP
1	• Equipment testing • Process acclimation • Method development	• Equipment testing • Process acclimation	• Equipment testing • Collimated beam testing • UV/AOP dose Calibration
2	• Baseline performance testing	• Baseline performance testing	
3	• Compromised system challenge testing	• Evaluation of fouling during compromised MBR system testing	• Testing of UV/H_2O_2 • Testing of UV/Cl_2

Phase 1 (Process acclimation): The MBR system will be operated to (a) establish steady-state operating conditions, (b) refine manufacturer PDT protocols, and (c) refine large volume sample processing to enhance the minimum detection limits for the microbial analyses.

Phase 2 (Baseline testing): This phase will be used to demonstrate the ability of a well-operated MBR system to meet the water quality goals, and to establish the baseline LRVs. Data collected during this phase will be the reference point for evaluating the MBR during challenge testing.

Phase 3 (Challenge testing): In this period the MBR membrane fibers will be compromised intentionally, to investigate how membrane breaches affect LRVs and water quality (e.g., turbidity). An important factor in demonstrating the true LRVs of MBR product water will be the work in Phases 1 and 2 to reduce the method detection limit for protozoa. The most common issue with crediting MBRs historically has been non-detect protozoa – i.e., below the limit of detection – in the MBR filtrate. It is anticipated, however, that work in the first two phases of this study will lead to the ability to quantify the protozoa using enhanced analytical techniques.

RO testing approach

As for the MBR, the RO testing will be divided into three phases. After start-up and commissioning (phase 1), baseline testing (phase 2) will provide RO membrane performance data when fouling is minimal and membrane age low. The impact of damaged MBR fibers on RO fouling will be evaluated in phase 3. Samples for analysis will be collected from the RO feed, concentrate, and permeate.

UV/AOP testing approach

Testing of the UV/AOP system will focus on determining the design criteria required to meet a minimum 0.5-log concentration reduction for 1,4-dioxane and less than the notification limit of 10 ng/L for NDMA. In fact, the RO permeate is anticipated to contain other nitrosamines, such as nitrosodiethylamine (NDEA), and treatment goals have been established to remove the entire suite of nitrosamine compounds to less than 10 ng/L. NDMA was chosen as the chemical indicator for this because it is susceptible to photolysis, is targeted for removal, and is expected to be present in the RO permeate. Removal of NDEA and other nitrosamines will also be measured as previous pilot testing (SDLAC & MWDSC, 2012) demonstrated that NDEA is equally or more challenging to remove than NDMA when complying with the 10 ng/L limit for nitrosamines.

Bench-scale collimated beam testing will be performed (phase 1) to determine the UV dose (mJ/cm^2) delivered by the system, and calibrate it to the system's electrical energy dose (EED), or the total UV lamp power divided by the water flow rate as $kWh/m^3/h$. Once established, this relationship will be used to define the UV dose applied at the Advanced Treatment Center. The UV dose vs.

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NDMA/NDEA removal curve from collimated beam testing will be combined with the EED vs. NDMA/NDEA removal curve from the process train to define the relationship between UV dose and EED for the UV/AOP system. This type of dose-response curve is analogous to the biodosimetry approach in UV disinfection of water used in the UV Disinfection Guidelines for Drinking Water and Water Reuse (National Water Research Institute 2012) and in the USEPA's UV Disinfection Guidance Manual (USEPA 2006). After processing samples and analyzing data from Phase 1, the baseline performance of the UV/AOP system will be tested with hydrogen peroxide and sodium hypochlorite as oxidants, to enhance hydroxyl radical formation to promote advanced oxidation (phases 2 and 3).

CONCLUSION

Data collected during demonstration testing at the Advanced Treatment Center will be used to investigate the potential of an MBR system within an IPR treatment train. The ultimate goal is to maximize the pathogen LRV credits awarded to the MBR process by California regulators and achieve water quality objectives associated with groundwater recharge. The study results will be used to develop the data and information necessary to seek a permit for a full-scale, regional, recycled water program that could beneficially reuse up to 568 MLD (150 MGD) of water currently discharged to the Pacific Ocean. This could be used to replenish aquifers in several Southern California counties. Southern California continues to face challenges of drought, climate change uncertainties, and hydrologic variability of imported water supplies. The RRWP presents a significant opportunity to develop a new, local, drought-proof source of regional supply.

REFERENCES

Bagheri, M. & Mirbagheri, S. A. 2018 Critical review of fouling mitigation strategies in membrane bioreactors treating water and wastewater. *Bioresource Technology* **258**, 318–334.

Bouhabila, E., Ben Aim, R. & Buisson, H. 2001 Fouling characterisation in membrane bioreactors. *Separation and Purification Technology* **22–3**(1–3), 123–132.

Branch, A. & Le-Clech, P. 2015 *National Validation Guidelines for Water Recycling: Membrane Bioreactors*. Australian Water Recycling Centre of Excellence, Brisbane, Queensland, Australia.

CDPH 2014 *Regulations Related to Recycled Water*. California Code of Regulations, Titles 22 and 17, Titles 22 and 17.

Çiçek, N., Winnen, H., Suidan, M. T., Wrenn, B. E., Urbain, V. & Manem, J. 1998 Effectiveness of the membrane bioreactor in the biodegradation of high molecular weight compounds. *Water Research* **32**(5), 1553–1563.

Hirani, Z., DeCarolis, J., Lehman, G., Adham, S. & Jacangelo, J. 2012 Occurrence and removal of microbial indicators from municipal wastewaters by nine different MBR systems. *Water Science and Technology* **66**(4), 865–871.

Hirani, Z. M., Bukhari, Z., Oppenheimer, J., Jjemba, P., LeChevallier, M. W. & Jacangelo, J. G. 2013 Characterization of effluent water qualities from satellite membrane bioreactor facilities. *Water Research* **47**(14), 5065–5075.

Le-Clech, P., Chen, V. & Fane, T. A. G. 2006 Fouling in membrane bioreactors used in wastewater treatment. *Journal of Membrane Science* **284**(1), 17–53.

Melin, T., Jefferson, B., Bixio, D., Thoeye, C., De Wilde, W., De Koning, J., van der Graaf, J. & Wintgens, T. 2006 Membrane bioreactor technology for wastewater treatment and reuse. *Desalination* **187**(1–3), 271–282.

Metropolitan Water District of Southern California 2016 *Potential Regional Recycled Water Program Feasibility Study*. Final Report No. 1530, Los Angeles, California, USA.

Na, J.-H., Nam, D.-H., Ko, B.-G., Lee, C.-Y. & Kang, K.-H. 2017 Reduced sludge production in a membrane bioreactor by uncoupling metabolism and its effect on phosphorus accumulation in the biomass. *Environmental Technology* **38**(23), 3007–3015.

National Water Research Institute & Foundation, W. R. 2012 *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*, 3rd edn. NWRI, Los Angeles, California, USA.

Salveson, A. & Fontaine, N. 2016 Resolving the final hurdles to MBRs for potable reuse. In: *Proceedings of the 2016 Annual Water Reuse Symposium, WateReuse Association*, Richmond, VA.

SDLAC 2014 *Industrial Waste Pretreatment Program Annual Report*. Los Angeles, California, USA.

SDLAC & MWDSC 2012 *Pilot Study of Advanced Treatment Processes to Recycle JWPCP Secondary Effluent*. Final Report. Los Angeles, California, USA.

doi: 10.2166/wpt.2019.042

Sipma, J., Osuna, B., Collado, N., Monclús, H., Ferrero, G., Comas, J. & Rodriguez-Roda, I. 2010 Comparison of removal of pharmaceuticals in MBR and activated sludge systems. *Desalination* **250**(2), 653–659.

USEPA 2006 *UV Disinfection Guidance Manual (EPA 815-R-06-007)*. Cincinnati, OH, USA.

WaterSecure 2017 *Membrane Bio-Reactor WaterVal Validation Protocol*. Australian WaterSecure Innovations Ltd, Brisbane, Australia.