THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Office of the General Manager

April 19, 2017

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State Water Resources Control Board
Division of Drinking Water
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Carpinteria, CA 93013

Randy Barnard, P.E.
Recycled Water Unit Chief
State Water Resources Control Board
Division of Drinking Water
1350 Front Street, Room 2050
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Dear Mr. Souza and Mr. Barnard:

<u>Potential Regional Recycled Water Program - Advanced Water Treatment Demonstration Facility and Approach for Alternative Treatment Technology Acceptance</u>

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 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, Calif. It is envisioned that this facility would take secondary effluent from the JWPCP and employ AWT processes to purify the water for recharge of groundwater basins in Los Angeles and Orange counties. 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. Metropolitan recently completed a feasibility study for the Regional Recycled Water Program which concluded that the potential program is technically feasible. Currently, Metropolitan and the Sanitation Districts are in the conceptual planning phase, developing the necessary technical studies and institutional arrangements that would be required to move forward with a potential full-scale program.

Since early 2016, Metropolitan and the Sanitation Districts have been coordinating with the Division of Drinking Water (DDW) and the Regional Water Quality Control Boards (RWQCBs), Los Angeles and Santa Ana Regions, on this potential program. Four in-person meetings have been held to date to present various aspects of the program and gain input from the regulators.

This input has been vital in assessing feasibility and helping to develop this potential regional program. Metropolitan and the Sanitation Districts last met with the regulators on March 10, 2017. A primary focus of that meeting was to present an approach for AWT demonstration testing and Metropolitan's intent to pursue alternative technology acceptance for a membrane bioreactor (MBR) as part of an indirect potable reuse (IPR) treatment train. Meeting presentation material and summary are included with this correspondence (Enclosure 1). In addition, a technical memorandum, *Advanced Water Treatment Demonstration Facility Testing Strategy*, has been prepared and is included as Enclosure 2. This technical memorandum provides details on the general framework for the proposed AWT demonstration testing, with a focus on the approach for alternative technology acceptance testing of the MBR process. The technical memorandum builds upon the information presented and feedback received at the March 10 meeting.

AWT Demonstration Facility

A key component of the potential Regional Recycled Water Program is the establishment of a 0.5-million gallon per day AWT Demonstration Facility. A demonstration project will build upon a successful pilot study conducted by Metropolitan and the Sanitation Districts in 2010-2012 evaluating two AWT process trains. Design of the AWT Demonstration Facility was completed in March 2017 and it is anticipated that construction will begin in June 2017 pending Metropolitan's Board approval. Construction of the facility is expected over a period of 12 to 15 months.

The process train associated with the AWT Demonstration Facility is comprised of a nitrifying-denitrifying MBR, reverse osmosis (RO) membranes, and ultraviolet light/advanced oxidation process (UV/AOP). The facility will treat non-nitrified secondary effluent from the JWPCP to levels that meet relevant regulatory requirements for groundwater replenishment. Product water and all waste streams, including brine concentrate, from the AWT Demonstration Facility will be recycled back to the head of the JWPCP. During demonstration testing, the feed water from the JWPCP will be fully nitrified which will improve downstream membrane processes. The level of denitrification will vary to meet the target effluent water quality goals. As MBR validation testing is a key component of the demonstration project, two different MBR systems will be installed with two full-size membrane cassettes each. The demonstration testing phase is expected to begin fall 2018 and run for approximately one year.

A primary objective of the AWT Demonstration Facility will be to provide the necessary data for DDW's conditional acceptance of the MBR as an alternative treatment technology for the proposed IPR application. The facility will also serve a number of other objectives including demonstrating the ability of the proposed process train to meet groundwater basin water quality objectives, determining optimum design and operating criteria for a full-scale AWT facility, developing data for a Title 22 Engineering Report as part of the water recycling permitting process, and providing an effective platform for public outreach and acceptance.

MBRs and Potable Reuse

MBRs have been widely used in non-potable reuse applications, benefitting from its small footprint and high quality effluent. A primary challenge facing implementation of a MBR in a potable reuse treatment train is the lack of pathogen reduction credits granted to date. Groundwater replenishment regulations in California require full advanced treatment through microfiltration or ultrafiltration, RO, and UV/AOP to achieve 12, 10, and 10 log reduction of virus, *Cryptosporidium*, and *Giardia*, respectively. National and international efforts are ongoing to quantify pathogen log reduction values (LRVs) achieved by the MBR process. MBRs in these research efforts have been applied as a secondary wastewater treatment process (e.g., replacing a conventional activated sludge process) in a potable reuse treatment scheme. Notably, Branch and Le-Clech (2015) demonstrated LRVs for pathogens through MBRs and the Australian Water Recycling Centre of Excellence developed multi-tiered protocols to aid in developing validation guidelines for MBRs used for potable reuse. In addition, Santa Clara Valley Water District (2017) and partners have worked with MBR suppliers to research MBR LRVs, reaffirming many conclusions from Australia. These efforts have been discussed with DDW at our March 10 meeting with positive feedback received in terms of its application to California. Further details on these research efforts are provided in the enclosed technical memorandum.

Alternative Technology Acceptance Testing

As indicated earlier, a primary objective of the demonstration project will be to provide the necessary data to support conditional acceptance of a MBR as an alternative treatment technology for potable reuse. An approach and framework for MBR validation testing is described in the enclosed *Advanced Water Treatment Demonstration Facility Testing Strategy* technical memorandum. Testing will include the demonstration of integrity monitoring of the MBR process to achieve pathogen LRVs for *Cryptosporidium* and *Giardia*. The impact of membrane breach on pathogen rejection, as well as integrity monitoring techniques to detect a breach, will be examined. Further, the enclosed technical memorandum describes a testing framework for the RO system, focusing on approaches for increased LRVs through the RO process and assessing the impact of MBR filtrate on RO performance and fouling potential.

Metropolitan and the Sanitation Districts, supported by its consultant team of MWH (now part of Stantec), Trussell Technologies, and Carollo Engineers, are currently preparing a detailed Testing and Monitoring Plan for the AWT Demonstration Facility. This plan will build upon the framework described in the enclosed technical memorandum and incorporate input from DDW and the RWQCBs. It is anticipated that a workshop will be scheduled in fall 2017 to present a draft Testing and Monitoring Plan to the regulators and gain input. A final Testing and Monitoring Plan is expected to be submitted for approval in spring 2018, prior to the start of demonstration testing anticipated to begin later that year.

In summary, this correspondence outlines the demonstration testing approach and framework that Metropolitan is intending to proceed with to ultimately seek DDW's conditional acceptance of the MBR as an alternative treatment technology for the proposed IPR application. Recognizing the demonstration project is at a preliminary stage, we respectfully request your acknowledgement of our intended approach and appreciate any feedback you may have at this time. Your response is requested by June 1, 2017, prior to Metropolitan's scheduled Board action to award construction of the AWT Demonstration Facility. Any feedback provided on the technology acceptance pathway will be fully addressed as we develop the Testing and Monitoring Plan for the AWT Demonstration Facility.

We truly appreciate the ongoing engagement and input by DDW and the RWQCBs as we proceed with the demonstration phase of the potential Regional Recycled Water Program. We will continue to closely coordinate with the key regulators during its development. Should you or other DDW staff have any questions regarding this correspondence or need further information, please do not hesitate to contact me at (213) 217-7558 or hcollins@mwdh2o.com, or Mickey Chaudhuri at (909) 392-5477 or mchaudhuri@mwdh2o.com.

Sincerely,

Heather L. Collins, P.E.
Water Treatment Section Manager

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Enclosures

cc w/enclosure:

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Enclosure 1

Regulator Meeting 4 – AWT Demonstration Approach
Presentation Material and Summary - March 10, 2017

SANITATION DISTRICTS OF LOS ANGELES COUNTY

Potential Regional Recycled Water Program

AWT Demonstration Testing Approach
Regulator Meeting 4

March 10, 2017

Overview

- Welcome and Introductions
- Meeting Objectives
- Feasibility Study
- AWT Demonstration Testing
  - Overview of Demonstration Process Train
  - Current State of Knowledge of MBRs for IPR
  - Alternative Technology Acceptance Approach
- Upcoming Activities and Regulatory Coordination
- Next Meeting

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Meeting Objectives

Objectives for Today

- Describe and gain feedback on approach to seek alternative treatment technology acceptance for membrane bioreactor (MBR) through demonstration project
- Update on Feasibility Study completion and other program activities
- Identify upcoming program and regulatory coordination activities

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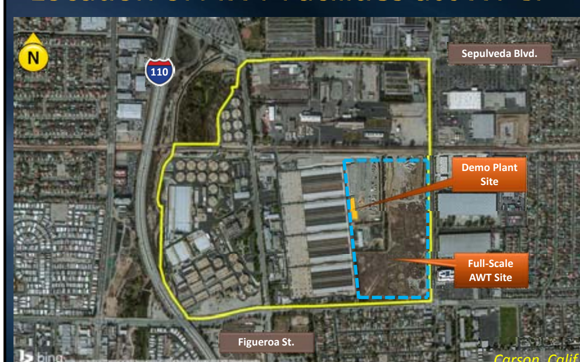
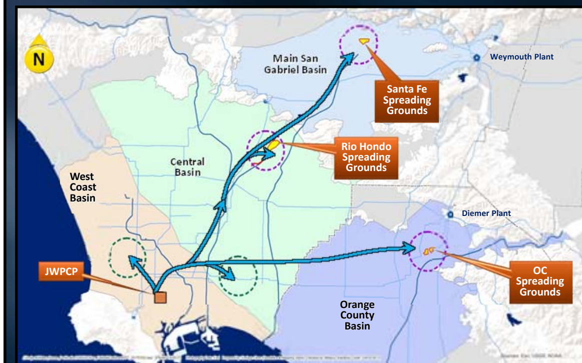
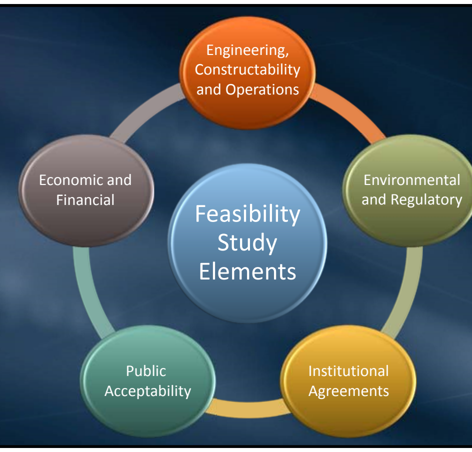
Feasibility Study

Location of AWT Facilities at JWPCP



Potential Full Program (up to 150 MGD)





Feasibility Study - Key Questions

- No Fatal Flaws?
  - Is it technically, institutionally and legally possible to implement a 150 MGD IPR program using effluent from the JWPCP?
- Justified and Cost Effective?
  - Are costs and benefits of the program consistent with the IRP and other approaches for achieving comparable amounts of recycled water?
- Impacts on cost of water to Member Agencies?
  - How would the cost of water be affected if the base case and its assumptions were implemented?

Feasibility Study - Major Findings

- Potential 150-mgd IPR program is feasible
  - Treatment, conveyance and groundwater recharge technically feasible
  - Institutional complexity but no fatal flaws
  - Regulatory approvals and permitting feasible
- Program provides significant regional benefits
- Costs and benefits are consistent with the 2015 IRP Update
- Program could be expanded to consider future DPR opportunities

Program Element Findings

Program Element	Feasibility
Advanced Water Treatment Plant	Feasible
Conveyance System	Likely Feasible
Groundwater Basins, Storage and Extraction	Feasible
Environmental and Regulatory Feasibility	Feasible
Feasibility of Essential Agreements with LACSD	Feasible
Feasibility of Essential Institutional Arrangements	No Fatal Flaws
Regional Benefits and Consistency with IRP	Feasible
Overall Estimated Program Costs	Feasible
Public Acceptability (with robust outreach effort)	Feasible

Feasible: No fatal flaws, limited dependence on other parties, other examples of success, and some unknowns

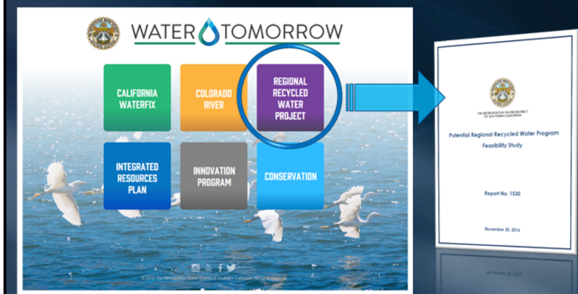
Likely Feasible: No fatal flaws, significant dependence on other parties, limited comparable existing examples, and many unknowns

No Fatal Flaws: No fatal flaws but in need of further investigations and studies

Advisory Panel

- Concluded findings are reasonable
- Do not see any technical fatal flaws
- Emphasized institutional complexity
- Helped identify program risks
- Contributed to and support recommendations

"The Advisory Panel agrees with the findings and recommendations of the Feasibility Study Report and supports moving forward"



http//www.mwdwatertomorrow.com/

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AWT Demonstration Testing

Demonstration Facility Objectives

- Achieve conditional acceptance of MBR as an alternative treatment technology for a Groundwater Replenishment Reuse Project
- Demonstrate ability of MBR-RO-UV/AOP process train to meet basin plan objectives
- Develop data for Title 22 Engineering Report for regulatory approval
- Determine optimum design and operating criteria for full-scale AWT facility and coordinate operations with Sanitation Districts
- Provide vehicle for public outreach and acceptance

AWT Demonstration Facility

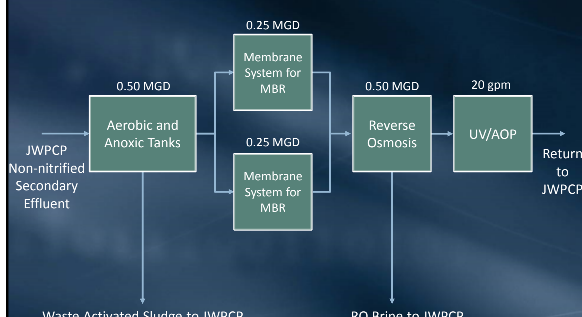
Design includes initial unit processes, and provisions for future unit processes

- Demonstration project to be advertised March 2017
- MWD Board action for construction June 2017

Process Train Update

- Demonstration facility treatment train will be MBR-RO-UV/AOP
- Seek alternative technology acceptance of MBR for a GRRP process train
- Process train to include:
  - Two MBR systems
    - Three vendors pre-qualified: Evoqua, GE, Koch
  - Single 2-stage 0.5-MGD RO system
  - Single 20-gpm UV/AOP system

Alternative Technology Acceptance



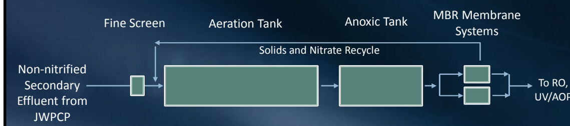
Log Reduction Credits for an Alternative IPR Train

Unit Process	Currently Approved Train MF-RO-AOP	Alternative Train MBR-RO-AOP
MBR	-	0.0 / 2.5 / 2.5
MF/UF	0.0 / 4.0 / 4.0	-
RO	1.5 / 1.5 / 1.5	1.5 / 1.5 / 1.5
AOP	6.0 / 6.0 / 6.0	6.0 / 6.0 / 6.0
Free Cl_2	5.0 / 0.0 / 0.0	5.0 / 0.0 / 0.0
Total	12.5 / 11.5 / 11.5	12.5 / 10.0 / 10.0

Target: Virus/*Giardia*/*Cryptosporidium* = 12/10/10

- Seeking MBR log reduction credits of 2.0-4.0 logs for *Cryptosporidium* and *Giardia*
- Also seeking RO log reduction credits of 2.0-4.0 logs for *Cryptosporidium* and *Giardia*

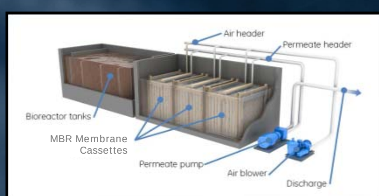
Evaluate MBR Upstream of RO and UV/AOP



- Both MBR membrane systems
  - Will include at least two full-scale membrane cassettes
  - Will be equipped with equipment enabling facility to perform Pressure Decay Test (PDT)
- Common mixed liquor for biological treatment and challenge conditions
- Dedicated filtrate turbidimeters for each membrane system for indirect integrity
- Nalco's TRASAR analyzer installed on the RO skid for additional log credits for RO

Anticipated Challenges with MBR in a FAT Train for GRRP

- Demonstrating necessary LRV with MBR-RO-UV/AOP
- Assessing long-term biological/organic fouling of downstream RO



Process train to include 2 different MBR membrane systems, each with 2 full-scale cassettes

Validation Guidelines for MBR in Australia

- A three-tier concept to grant LRV credits to MBR
- Concluded that indirect monitoring using filtrate turbidity along with information on MBR system could be used to establish LRV

Tier 1 – Adopting Predefined LRVs Based on Statistical Analysis

- If 95th percentile filtrate turbidity is less than 0.4 NTU, then
  - 1.5 log credits for virus
  - 4.0 log credits for bacteria, and
  - 2.0 log credits for protozoa
- If membrane pore size is less than 0.1 um, membrane flux is below 17.6 gfd <u>OR</u> 95th percentile filtrate turbidity is less than 0.3 NTU, then log credit for protozoa can be increased to 4.0 logs

Validation Guidelines for MBR in Australia

Tier 2 – System-specific Challenge Testing under Most Conservative Operating Conditions

- Determine minimum expected LRV specific to the membrane system
- Implement regular testing of target pathogen or surrogates

Tier 3 – Demonstrate Correlation between Online Parameters and Pathogen Removal

- Use challenge testing to demonstrate correlation
- Establish critical limits specific to the LRVs claimed

Alternative Technology Acceptance of MBR National Efforts

- Validate Australia work with sampling conducted by Carollo
- Carollo sampled four full-scale MBR facilities to assess pathogen removal
  - Project Partners: GE and Evoqua
  - Research Team: SCVWD, Carollo, NWRI, BioVir, and SNWA
  - Host Utilities: Ironhouse SD (CA), Hamby (TX), Modesto (CA), Healdsburg (CA), King County (WA)
  - 12 months of full-scale testing, 6 rounds of testing at each site
- Demonstration facility will be used to collect additional microbial data

Tier 2 Approach Taken for GE and Evoqua MBRs

Microbial Log Reduction Value Ranges

Site	Male Specific Phage	Enterococci	Total Culturable Virus	Enterovirus	Norovirus GIA	Norovirus GIB	Norovirus GII	Giardia
Ironhouse	3.9 - 5.3	3.4 - 6.6	3.0 - 3.8	3.9 - 8.7	4.4 - 7.0	2.7 - 7.3	5.1 - 7.7	4.0 - 5.0
Hamby	3.3 - 5.1	4.0 - 6.7	3.0 - 3.7	7.1 - 8.1	4.9 - 7.0	5.7 - 6.8	5.4 - 7.2	2.9 - 5.6
Healdsburg	5.0 - 5.7	6.5 - 6.8	3.7	4.7	6.1	5.5	7.5	3.9 - 5.0
Modesto	2.5 - 3.5	5.7 - 6.0	3.0	7.4	4.6	5.8	6.2	3.3 - 4.1

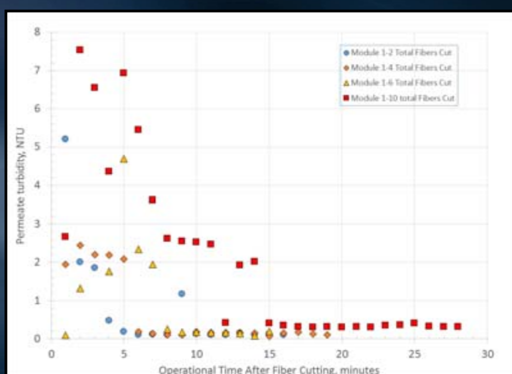
Tier 2 Approach Taken for GE and Evoqua MBRs

Comparison of LRVs During Standard Production and After Cleaning Events

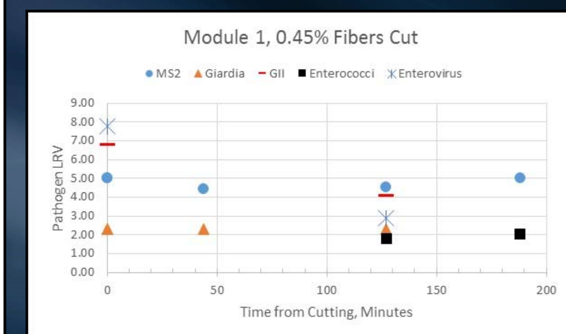
Event	Log Reduction Value							Turbidity
	Male specific Coliphage	Total Culturable Virus	Enterococci	Giardia	Norovirus GIA	Norovirus GIB	Norovirus GII	
Ironhouse WRF								
Standard Production	3.9	3.8	3.4	5.0	4.4	2.7	5.1	0.07
After Cleaning Event	4.8-5.3	3.2-3.3	6.4-6.6	4.0-4.3	5.5-7.0	6.0-7.3	6.4-7.7	0.06-0.09
Hamby WRF								
Standard Production	4.8	3.6	6.7	3.4	7.0	6.8	5.4	0.11
After Cleaning Event	3.3-5.1	3.0-3.7	4.0-6.1	3.0-5.6	5.0-5.3	5.7-5.8	6.9-7.2	0.06-0.13
Healdsburg WRF								
Standard Production	5.4-5.8	3.7	6.5-6.8	3.9-4.0	6.1	5.5	7.5	0.05-0.09
After Cleaning Event	5.0	DTBR	6.8	5.0	DTBR	DTBR	DTBR	0.06-0.28
Modesto WWTP								
Standard Production	3.5	DTBR	5.7	3.3	DTBR	DTBR	DTBR	0.13
After Cleaning Event	2.5	3.0	6.0	4.1	4.6	5.8	6.2	0.05-0.13

Notes: DTBR = Data to be received

Fiber Cutting Documents Impact and Recovery Time



Fiber Cutting Documents Impact and Recovery Time



Note: Most Pathogens Near or Below Detection in MBR Filtrate

MBR Monitoring Recommendations

Full-scale AWT control and monitoring system

- Measure a combination of surrogates such as particle size distribution, adenosine triphosphate (ATP), enterococci, MS coliphage, turbidity
- For a full-scale facility, closely monitor MBR trains and divert flow during turbidity exceedances that may represent damaged conditions

Demonstration of MBR for GRRP

Goal: Validation of MBR for protozoa removal

- Test plan under development and will be presented to regulators in Fall 2017
- Builds on growing knowledge base from recent Australia work and Carollo study on pathogen removal performance in MBR systems
- Project will develop and demonstrate an MBR monitoring strategy using concepts in USEPA (2005) *Membrane Filtration Guidance Manual*
  - Indirect integrity monitoring using turbidity
  - Direct integrity monitoring using a *modified* pressure decay test or possible marker

Demonstration of MBR for GRRP
Strawman of Demonstration Facility Test Plan

- Primary test plan goals
  - Validate other studies → turbidity is an effective indirect integrity monitoring method
  - Demonstrate that for an established direct integrity method, the awarded LRV is always conservative
- Demonstration of LRV will be based on:
  - Routine large volume (>200L) sample analysis for *Cryptosporidium* and *Giardia* to improve detection limits in filtrate
  - Membrane system pressure decay
  - Online turbidity data will be measured for each 0.25-MGD MBR train
  - Multiple compromised system tests will be performed
  - Challenge tests will be performed to increase demonstrable LRV
  - Statistically significant dataset to establish LRV for a given condition

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Feedback/Discussion

Objectives for Today

- **Describe and gain feedback on approach to seek alternative treatment technology acceptance for membrane bioreactor (MBR) through demonstration project**
- Update on Feasibility Study completion and other program activities
- Identify upcoming program and regulatory coordination activities

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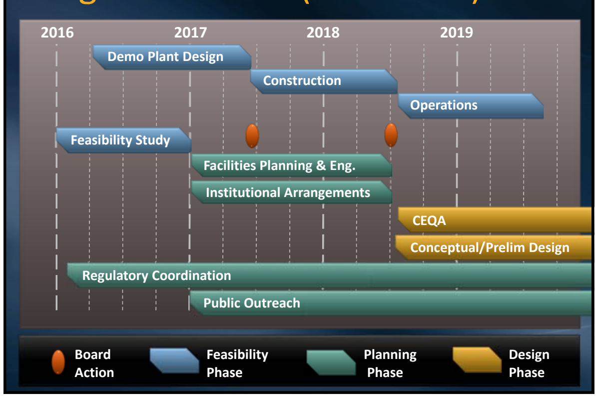
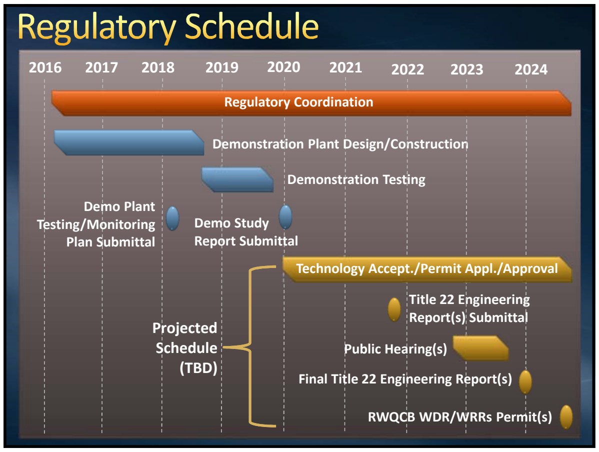
Upcoming Activities and Regulatory Coordination

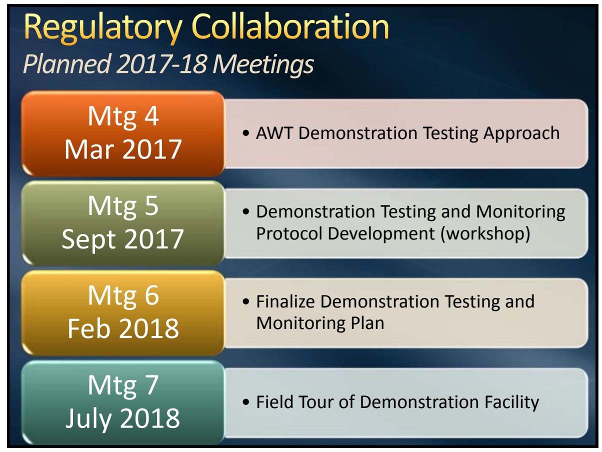
Upcoming Activities

- Complete design, construction, start-up and operation of Demonstration Plant
- Proceed with facility planning and optimization, engineering and additional groundwater modeling
- Finalize agreements between MWD and LACSD
- Develop institutional and financial arrangements needed for implementation
- Initiate public outreach effort focused on Demonstration Plant

Program Timeline (2016-2019)




Regulatory Schedule
2016 2017 2018 2019 2020 2021 2022 2023 2024
Regulatory Coordination
Demonstration Plant Design/Construction
Demonstration Testing
Demo Plant Testing/Monitoring Plan Submittal
Demo Study Report Submittal
Technology Accept./Permit Appl./Approval
Title 22 Engineering Report(s) Submittal
Projected Schedule (TBD)
Public Hearing(s)
Final Title 22 Engineering Report(s)
RWQCB WDR/WRRs Permit(s)


Regulatory Collaboration
Planned 2017-18 Meetings
Mtg 4 Mar 2017
• AWT Demonstration Testing Approach
Mtg 5 Sept 2017
• Demonstration Testing and Monitoring Protocol Development (workshop)
Mtg 6 Feb 2018
• Finalize Demonstration Testing and Monitoring Plan
Mtg 7 July 2018
• Field Tour of Demonstration Facility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Thank you!


Potable Uses
Homes, Businesses, & Industries
Joint Water Pollution Control Plant
Advanced Water Treatment Plant
Conveyance System
Spreading Grounds or Injection Wells
Groundwater Basins
Extraction Wells
Regional Recycled Water Program
Public Acceptance
Source Control
Regulatory Approval
Partnerships

Potential Regional Recycled Water Program
Regulator Meeting 4 – AWT Demonstration Approach
March 10, 2017 – 9:30-11am

Meeting Summary/Discussion

1. Welcome and Introductions – Heather Collins

a. Introduced meeting attendees
b. Previous meetings – overall project, process train, groundwater basin considerations, feasibility study, and Advisory Panel reviews
c. Current status – demonstration plant phase and approach to Title 22 Engineering Report; pathogen credit for MBR is the crux of this meeting

2. Meeting Objectives – Heather Collins

a. Main objective – Describe and gain feedback on our approach for alternative treatment technology acceptance for MBR for IPR; this is a key focus of the demonstration plant process train
b. Provide an update on activities to date and feasibility study
c. Plan for future regulatory coordination

3. Feasibility Study – Paul Brown

a. Major milestone reached in Feasibility Study – "it can be done"
b. Presented program overview, feasibility study criteria, and key questions
c. Major findings:
    i. Program is feasible including all of the major parts, with institutional arrangements possibly complex but not fatally flawed
    ii. Regional benefits would be realized
    iii. Costs are consistent with Metropolitan's 2015 IRP Update
    iv. Future opportunities would exist to build on the program, including possible DPR
d. All program elements graded as "feasible" except:
    i. Conveyance system – "likely feasible" given complexity and length, and likely sits on the critical path for the program
    ii. Institutional arrangements – "no fatal flaws" but additional work is needed
e. Advisory Panel supported the conclusions, while emphasizing the importance of overcoming institutional challenges; making clear assumptions; and identifying risks
f. MWD estimated program cost is $1600/AF, with detailed cost estimates provided in the feasibility report appendices
g. <u>RWQCB question:</u> example of "institutional complexity" box?
    i. Answer: figuring out how to price this water if Metropolitan were to provide it, e.g. melding it into rate structure vs. pricing it separately
    ii. Groundwater basins would need to commit to taking water on a daily basis, which is a change from how they currently buy water

4. **AWT Demonstration Testing** – Mickey Chaudhuri, Jim Borchardt, Shane Trussell, Andy Salveson

   a. Current status:
      i. Completing demonstration plant design with a goal of advertising bids later this month
      ii. Construction will focus on the preferred alternative of MBR-RO-AOP
   b. Demonstration plant objectives
      i. Key focus of demonstration testing will be to demonstrate log removal of MBR to seek *Cryptosporidium*/*Giardia* log credits
      ii. Demonstrate ability of the process train to meet basin plan objectives
      iii. Support Title 22 Engineering Report in a few years
      iv. Provide data to support the full-scale design; gain operational experience with AWT technology for MWD staff, and work on coordination with LACSD
      v. Emphasize public outreach, with material under development
   c. Timeline: bid advertisement in March 2017, with MWD board action in June 2017
   d. Process train approach and schematic:
      i. Two different vendors will be used for MBR, out of a prequalified list of three
      ii. Allow testing of the full process train with focus on MBR
   e. <u>DDW question:</u> how will the MBR be configured? Did the vendors design the biological process? Will this be a full MBR system?
      i. Answer: there will be a single biological process tank configuration (aerobic and anoxic tanks) with flexibility for varying levels of nitrification/denitrification, feeding two parallel membrane tanks
      ii. The consultant team designed the biological process tank, and the MBR vendors are providing membrane tanks/cassettes and associated process equipment
   f. MBR concept approach:
      i. Table of log removal credits for traditional FAT vs. proposed demonstration process train
      ii. Configuration of MBR system in the Demo Plant with common mixed liquor
      iii. Systems will have the ability to do pressure decay test and measure filtrate turbidity; Nalco TRASAR will also be included to increase log credit for RO
   g. <u>DDW comment:</u> DDW had a meeting yesterday with Nalco and provided verbal approval for 3 log credit of RO based on San Diego data. This approval will come in writing upon project proposals. No other fluorescent dye or monitoring system of this type has been evaluated for RO LRVs.
   h. <u>DDW question:</u> did MWD specify an upper limit on pressure decay test?
      i. Answer: It's unclear how high of a feed pressure the MBR suppliers will commit to applying during the pressure decay test (PDT). The feed pressure will not be high enough to obtain a 3 µm resolution required for *Cryptosporidium*/*Giardia* credit, but it will be high enough to check if fibers are broken. Research to date on MBR suggests that there is not a need for the 3 µm resolution to prove LRVs.
      ii. Operationally, turbidity monitoring will be a way to check for broken fibers in the full scale system
      iii. MWD conveyed message to vendors to make the feed pressure for the PDT as high as tolerable by their MBR membrane product, and two of the three prequalified vendors can go over 12 psi
   i. Validation guidelines from Australia:
      i. Their work found that turbidity could be used to establish LRVs

ii. Three-tier approach proposed: Tier 1 uses statistical analysis of indirect integrity monitoring via turbidity; Tier 2 establishes system-specific minimum LRVs under conservative conditions through challenge testing; and Tier 3 proposes direct correlation between LRV and monitored parameters

j. DDW question: DDW reviewed the protocol for this work and it mentioned an upper limit of 0.2 NTU, whereas the results are discussing 0.4 NTU
   i. Answer: MWD will look into this issue
k. DDW question: what is the proposed size rating and flux for the Demo Plant?
   i. Answer: the prequalified vendors have pore sizes less than 0.1 µm, in the UF range. The design flux is 14 gfd
l. DDW comment: Tier 3 is the best approach if one can get there
   i. Answer: MWD and consultant team agrees – if it's possible; these correlations are hard to develop even in drinking water
   ii. MWD and consultant team think it's realistic to say "under these conditions, we know we are in a safe region achieving minimum LRVs." Direct correlations between LRVs and monitored parameters are difficult to find.
   iii. If the demonstration plant study collects the data for Tier 3 and does not find the right correlation, the approach can fall back to Tier 2
m. The state of the knowledge on MBR:
   i. Discussed Carollo's work with four full-scale MBR facilities to measure LRVs
   ii. Presented data for LRVs of various native and spiked pathogens at each plant under various operating conditions, along with turbidity data. LRVs were robust and sometimes increased after cleaning, with turbidity generally <0.2 NTU.
   iii. Presented results from pilot-scale fiber cutting tests at King County, showing turbidimeter sensitivity, recovery time, and associated pathogen removal. Fiber cutting was not shown to affect LRVs for viruses or protozoa. This pilot scale work did find holding pressure was difficult even when LRVs were being achieved.
   iv. Report will be submitted soon to DDW
   v. Recommendation for the MWD-LACSD project: measure a number of surrogates at the demonstration plant such as particles, biological parameters, and microbial surrogates. At full scale, use a sensitive turbidimeter with diversion based on turbidity spikes.
n. MWD question: was there any difference in performance between GE and Evoqua?
   i. Answer: there was a slight difference although it would be hard to correlate
   ii. Slightly reduced performance was observed for Evoqua membranes – these were the only ones for which pathogens were ever found on the filtrate side. Slightly higher passage of particles was also noted after a chemical clean.
   iii. Observed log removal by MBR is much greater and more robust than can be explained by simple size exclusion, especially for virus. The biofilm and mixed liquor surrounding the membrane surface contribute to removal and self-healing properties.
   iv. Future testing could include *Clostridium* as recommended by Australian study
o. Validation approach for Demo Plant:
   i. Test plan will be presented to regulators in Fall 2017
   ii. Goals: validate other studies and demonstrate that for an established integrity testing method, awarded LRV is always conservative
   iii. Approach: large volume sampling for low level detection of pathogens (as developed at San Diego); pressure decay testing at MBR; turbidity monitoring; fiber cutting to run compromised system testing; and other challenge testing
p. DDW question: was PDT used in the Carollo study?

i. Answer: Full-scale systems were not designed for PDT. One was rigged onto the Ironhouse plant and it did not work well. PDT was included and worked better at the King County pilot.
ii. There are only a few MBRs in the world with PDT, mainly in Australia

q. DDW question: good point on self-healing properties of MBR. Would pressure decay testing make performance worse by pushing solids off of membrane surfaces? Filter-to-waste may be needed for the first couple minutes after PDT.
i. Answer: PDT would likely have a temporary negative impact on filtrate water quality, particularly in a compromised system
ii. For this reason, a filter-to-waste for first couple minutes after PDT may be advisable
iii. Beyond the importance for LRVs, low MBR filtrate turbidity and good membrane integrity are desirable for RO feed to mitigate biological and organic fouling

5. Feedback / Discussion

a. Trussell question: DDW comments on the Australian work that may impact this project?
i. Answer: DDW reviewed the Australian study protocol but has not yet looked at the longer comprehensive report because of current review workload
ii. Tier 1 – conservative LRVs would be based on never exceeding 0.2 NTU, which meant 0.2 NTU was a hard figure. Diversion at 0.2 NTU is seen as a strict limit.
iii. DDW believes that the default approach is probably to awarding conservative LRVs without other testing, based on filtrate turbidity monitoring
iv. Inclusion of Nalco TRASAR does give possibility of higher LRVs for RO
v. Filter-to-waste capability is included at the Demo Plant

b. RWQCB comment: RWQCB staff have had limited input during this meeting as topics have mostly concerned DDW, but will stay involved for an efficient sequential approach

c. DDW comment: in the Australian approach, Tier 1 included flat plate MBR systems. In their data, the 5th percentile was better than LRV = 2, probably closer to 2.5. With flat plate systems excluded, LRVs greater than 2 can probably be shown.

d. Carollo comment: Tier 1 is a statistical dataset, and Tier 2 is a system-specific validation window. Proper monitoring and diversion should increase credits for Tier 2 standard.

e. DDW comment: Is *Clostridium* a better surrogate, since *Cryptosporidium* is hard to find?
i. Answer: Australian report suggests that it would be. MWD should be looking at all of these things during Demo Plant testing.
ii. Recovery of spiked *Cryptosporidium* can be low even in drinking water testing and this encourages the pursuit and development of meaningful surrogates

f. MWD question: A formal communication from MWD indicating intent to proceed on pathway for alternative technology acceptance of MBR is coming by the end of March/early April, and a response from DDW is requested by June 1
i. Answer: DDW says that a simple letter of response should be doable
ii. RWQCB would like be copied on this correspondence
iii. For MWD, this creates confidence in proposed Demo Plant process train prior to Board action for construction award planned for June

g. DDW question: what is the Demo Plant approach doing about UV-AOP?
i. Answer: no particular special testing, except for nitrosamines and H_2O_2 vs. Cl_2 oxidant
ii. NDEA was observed in the previous MWD/LACSD pilot work and will need to be addressed

6. Upcoming Activities and Regulatory Coordination – Mickey Chaudhuri

a. Summary of ongoing and upcoming project work:
    i. Final demonstration plant checkset to be submitted next week for advertising in March. Construction period would be about a year, coming online in late summer 2018.
    ii. Conceptual planning of the full-scale system will happen in parallel. This includes engineering on treatment/conveyance and groundwater modeling.
    iii. MWD and LACSD are establishing additional agreements to move forward with demonstration plant testing and full-scale planning
    iv. Work will be continued with member agencies and groundwater agencies to build the institutional arrangements
    v. Public outreach efforts are starting, with forthcoming update on communication plan at future meetings

b. Key upcoming MWD Board Actions include Demo Plant construction (June 2017) and to potentially launch full-scale program (mid-2018)

c. Regulatory schedule:
    i. Continue roughly quarterly communication with regulators (via meetings or electronic communication/updates)
    ii. Submittal of demonstration testing/monitoring plan is scheduled for early 2018, with final demonstration study report in early 2020
    iii. Upcoming planned meetings – Sept 2017 (workshop for draft testing and monitoring protocols), Feb 2018 (final testing and monitoring protocols), July 2018 (field tour of demonstration plant site)

d. <u>RWQCB comment:</u> can slides and meeting materials be shared?
    i. Answer: slides, attendees list, and meeting summary will be shared
    ii. Some preliminary scope or outline will be shared in advance of fall workshop
    iii. Agencies would like 1 month lead time, preferably

Enclosure 2

Advanced Water Treatment Demonstration Facility Testing Strategy Technical Memorandum

Potential Regional Recycled Water Program

Task Order 28 – AWT Demonstration Facility – Testing Strategy

Agreement No. 140025

Advanced Water Treatment Demonstration Facility

Testing Strategy

Final Technical Memorandum | April 18, 2017

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1 Introduction

Metropolitan Water District of Southern California (Metropolitan) and Sanitation Districts of Los Angeles County (Sanitation Districts) are in the conceptual planning phase for a large-scale Advanced Water Treatment (AWT) Facility at the Joint Water Pollution Control Plant (JWPCP) in Carson, Calif. The full-scale AWT Facility would augment existing potable water supplies by means of groundwater recharge using basins located across Los Angeles and Orange Counties. Metropolitan and Sanitation Districts conducted a two-year pilot study to assess the feasibility of the potential process trains in achieving the desired effluent water quality goals and determining the viability of the JWPCP as a source of reuse water. Based on the successful results from the pilot study, the agencies are now planning to evaluate the process train at a demonstration-scale of 0.5 million gallons per day (MGD). The primary objectives of the AWT Demonstration Facility are to (1) achieve conditional acceptance for a membrane bioreactor (MBR) as an alternative treatment technology within an indirect potable reuse (IPR) process train, and (2) acquire the necessary monitoring data to evaluate compliance of the preferred process train with regulatory requirements, including groundwater basins objectives and concentrate discharge requirements. A secondary objective is to determine optimum process design and operational parameters for the full-scale AWT Facility. It is anticipated that the preferred process train will achieve the regulatory requirements for IPR via groundwater recharge, including removal of pathogens as well as inorganic and organic compounds. Sanitation Districts are investigating the possibility that some of the target constituents may either be reduced or removed from the source water via source control modifications, while the remaining constituents will be removed to target levels via treatment at the AWT Facility. Additionally, the AWT facility will be utilized as a vehicle for public outreach and acceptance.

In order to achieve the AWT Demonstration Facility objectives, a process train consisting of MBR, Reverse Osmosis (RO) and Ultraviolet/Advanced Oxidation Process (UV/AOP) will be evaluated at the demonstration-scale for a period of 12 months or more. This process train is shown in **Figure 1**. The demonstration testing strategy along with the objectives and desired outcomes, focused on achieving alternative technology acceptance of the MBR process, are summarized in this Technical Memorandum (TM). In addition, the AWT Demonstration Facility could be utilized in the future to evaluate alternative process trains for IPR and DPR. This TM summarizes the overall approach for demonstration testing.

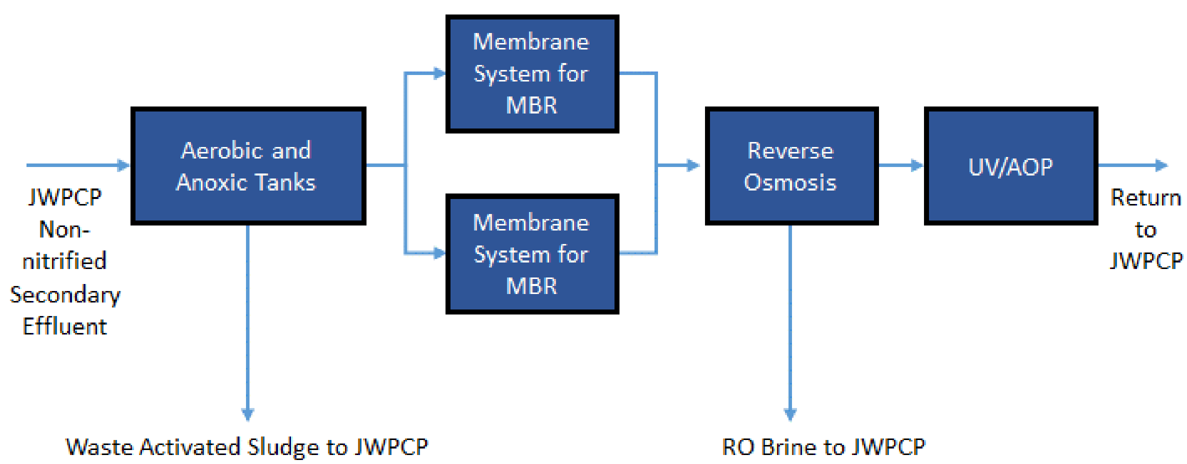

Figure 1 - Process Schematic of the AWT Demonstration Facility's Process Train.

2 Background

Metropolitan and Sanitation Districts conducted a two-year pilot study from June 2010 to June 2012 to evaluate two different process trains – membrane filtration (MF)-RO-UV/AOP and MBR-RO-UV/AOP on non-nitrified secondary effluent from the JWPCP. Based on the success of this pilot phase, Metropolitan and Sanitation Districts decided to proceed with a demonstration-scale project. The MWH team (MWH, Carollo Engineers and Trussell Technologies) was hired to design the AWT Demonstration Facility and operate it for the first year.

Metropolitan's AWT Demonstration Facility is designed to achieve the primary objective of obtaining regulatory acceptance of the MBR-RO-UV/AOP process train for a full-scale AWT Facility. Additionally, the AWT Demonstration Facility will be used to determine the optimum full-scale process design and operational parameters for the individual unit processes. Following the initial testing period, Metropolitan may use the facility in the future to satisfy long-term objectives of evaluating alternative process trains for indirect potable reuse (IPR) and direct potable reuse (DPR).

The AWT Demonstration Facility will treat non-nitrified secondary effluent from the JWPCP that has COD, ammonia (as nitrogen) and TDS median concentrations of 54, 42, and 1,400 mg/L, respectively. The IPR train using MBR offers several advantages to Metropolitan and Sanitation Districts from operational and water quality standpoints. Since the AWT Demonstration Facility will treat non-nitrified secondary effluent, a nitrification/denitrification process step will immediately precede the MBR membranes. It is anticipated that nitrified secondary effluent will improve membrane performance at the AWT Demonstration Facility, because operation at higher SRT (>10 days) required for complete nitrification also ensures complete degradation of slowly biodegradable organic matter that tends to foul the membranes. MBR membranes have been shown to successfully perform in such an environment. Partial denitrification is anticipated to be necessary to meet nitrate objectives for certain groundwater basins.

One challenge facing implementation of IPR using MBR is the lack of pathogen removal credits granted to the process by the State of California Division of Drinking Water (DDW). Current regulations require the full advanced treatment (FAT) train (MF-RO-AOP) to achieve 12, 10 and 10 log removal of virus, *Cryptosporidium* and *Giardia*, respectively. The MF, RO and UV/AOP processes are granted a maximum of 4, 2 and 6-log credits for both *Cryptosporidium* and *Giardia*, exceeding the 10-log requirement. Even though the MBR process uses membranes for solids separation which provides excellent pathogen removal, the process is not granted any pathogen removal credit at this time. As such, replacing the MF process with MBR would make achieving the necessary pathogen removal credits more challenging, as additional treatment would need to be installed. One approach to deal with this challenge is by obtaining conservative log removal credits for MBR. The remaining credits, if necessary, can be achieved by receiving higher log removal values (LRVs) for the RO process (3+ log) using Nalco's 3D TRASAR. The fluorescence dye used in TRASAR is rejected effectively by the RO membranes and therefore a higher LRV (3+ logs) can be demonstrated when using TRASAR.

Other challenges to the successful implementation of this project include meeting regulatory levels for certain target constituents, including boron, 1,4-dioxane, and nitrosamines. For example, the median boron concentration in secondary effluent during the pilot study was 0.88 mg/L and has remained relatively constant to date. With a combination of source control and treatment, the boron concentration will need to be reduced to less than 0.5 mg/L to meet the water quality objectives for the

Main San Gabriel Basin - one of the four basins that will be recharged using product water from a full-scale AWT Facility. Source control could be a key component to address these challenges. Sanitation Districts will continue to take proactive approaches for source control, monitoring for possible sources of boron in the JWPCP service area and identifying potential strategies and means for boron reduction. The AWT Facility will also need to meet the limits for other key parameters such as chloride, sulfate, TDS, coliform bacteria, nitrate, nitrosamines and 1,4-dioxane.

3 Current State of Knowledge on MBRs for Indirect Potable Reuse

MBRs are widely used in non-potable recycled water applications because they use a small footprint and produce high quality water, which is potentially suitable for subsequent advanced treatment for potable reuse. Yet, real and perceived hurdles remain, resulting in only one United States facility that uses MBR as part of a treatment train for IPR (Abilene, Tex.), which has been in operation since January 2015. The primary issue that impedes the use of MBR technology for potable reuse is the lack of pathogen credits, which ideally is based upon an integrity/monitoring technique, such as a pressure decay test (PDT), with sufficient sensitivity to detect a membrane breach. However, there is limited data available on application of PDT for MBRs.

Although PDT is widely used for low-pressure membranes in low solids application (e.g., tertiary filtration), it has not been employed for membranes used in MBRs due to absence of need to demonstrate pathogen removal in the past, and technical challenges associated with implementing PDT in MBR. One of the challenges associated with the use of PDT for MBRs includes a much higher volumetric concentration factor (VCF) in MBRs compared to low solids membrane applications. A high VCF requires a much higher feed pressure to demonstrate the breach resolution of 3 microns needed to obtain *Cryptosporidium*/*Giardia* log-removal credit. Another challenge is the maintenance of the membrane integrity, as it is exposed to harsher environments (e.g., much higher solids concentrations) than tertiary membranes.

Unlike low-pressure membranes used for tertiary filtration, additional pathogen removal mechanisms exist in the MBR process that are not considered in LRV calculations based on PDT. These removal mechanisms include predation in the bioreactor, adsorption to the biomass, as well as pathogen removal by biofilm formed on the membrane surface and membrane pore constriction by foulants. Removal of pathogens by these mechanisms results in much higher LRVs for pathogens by MBRs than those calculated based on PDT results. Therefore, there is a need to rigorously document alternative ways of monitoring membrane integrity in MBRs. An alternative approach is the use of extensive pathogen removal databases, statistically conservative values (e.g., 5th percentile) coupled with surrogate monitoring such as particle size distribution (bench scale), adenosine triphosphate, enterococci, MS-2 coliphage and online and rapid response (e.g., seconds) turbidity (Santa Clara Valley Water District, 2017).

Several studies have quantified the LRVs achieved by the MBR process for virus, bacteria and protozoa.

- Hirani et al (2012) evaluated nine different MBR systems with varying process configurations, membrane geometries, membrane pore sizes and membrane materials and showed 50th percentile LRVs of 6.6, 5.9 and 4.5 for total and fecal coliform bacteria and indigenous MS-2 coliphage, respectively.

- Branch and Le-Clech (2015) showed that 1.5, 4.0 and 2.0 LRVs can be granted for virus, bacteria and protozoa, respectively if 95th percentile MBR filtrate turbidity does not exceed 0.4 NTU. Additionally, if both the membrane pore size is less than 0.1 µm and membrane flux is kept below 30 L/m^2/h, **OR** 95th percentile filtrate turbidity is less than 0.3 NTU, then the LRV for protozoa can be increased further to 4.0 logs. The Australian guideline for MBR validation developed based on this work took a conservative approach by limiting the maximum filtrate turbidity to 0.2 NTU.

- Santa Clara Valley Water District (2017) investigated pathogen removal at four full-scale MBR facilities and one pilot-scale facility under a broad range of cleaning procedures and membrane conditions over 12 months and found that each of these facilities achieved greater than 3-log removal of virus and protozoa, including a facility that was operating with 8-year-old membranes.

3.1 Australian Validation Guidelines for MBR

Pathogen removal and the determination of pathogen log removal credits by MBR has been extensively studied in Australia (Branch and Le-Clech, 2015). The Division of Drinking Water (DDW) has noted this work and indicated its value to California as it considers approaches for granting pathogen credit through an MBR process, hence the keen focus and inclusion of Australia's work within this TM. Significant findings from the work conducted by the Australian Water Recycling Centre of Excellence (AWRCE) on developing the national validation guidelines for MBR for water recycling is summarized below.

- Sampling campaign included 180 visits at 11 different full-scale MBRs to create the pathogen log removal value (LRV) database;

- Membrane pore size has little to no impact on pathogen removal, due to the particle-association of pathogens in MBR mixed liquor;

- Pathogen accumulation in the MBR is "not typical" due to predation and sludge wasting;

- Turbidity can be used to measure loss of membrane integrity due to resulting spikes in mixed liquor suspended solids (MLSS) that would occur from membrane breakage;

- Diversion of MBR filtrate could be used to protect against a loss of containment of pathogens;

- Direct membrane integrity testing techniques, such as PDT, are not favored in MBR due to the difficulty in maintaining control PDT with the harsh operating environment, the limitation to specific membrane configurations (certain hollow fiber and tubular, not flat sheet), and the lack of correlation between PDT and LRV in MBR due to the action of mechanisms other than pure size exclusion;

- No adequate data set was available to correlate influencing factors on LRV through MBR. MBR removal mechanisms are complex and synergistic, leading to difficulties when applying simplistic modelling approaches;

- Likelihood that poor LRV correlates with low hydraulic residence time (HRT), high flux, high permeability, low transmembrane pressure (TMP), high turbidity, low MLSS and high dissolved oxygen (DO), resulting in an “operational envelope”;

- Intensive clean in place (CIP) and regular chemically enhanced backwash did not reduce LRV below typically observed process variability (5^{th} percentile) for a 0.04-µm hollow fiber membrane. However, significant reduction in LRV observed with a 0.4-µm flat sheet membrane operating at high flux (30 $L/m^2/h$) after intensive CIP with sodium hypochlorite and oxalic acid was attributed to a substantial increase in permeability (5-fold) after cleaning;

- 10-year-old membranes performed similarly well compared to 5-year-old membranes, with greater than 3.5 LRV for all indicators;

- Proposed default LRVs, based upon the lower 95^{th} percentile of data, was 1.5 for virus and 2.0 for protozoa, based upon a turbidity of less than 0.4 NTU. These values would apply for the membranes cited within the study as long as they are operated within the range of conditions documented within the report;

- For a membrane with a pore size of less than 0.1 µm, flux less than 30 $L/m^2/h$ **OR** 95^{th} percentile filtrate turbidity of 0.3 NTU or less, the default LRVs are 1.5 for virus (no change) and 4.0 for protozoa. Again, these values would be acceptable for the membranes tested within the report and operating within the ranges specified in the report.

Australia’s Membrane Bioreactor Validation Protocol (AWRCE 2016) presents a tiered approach to allowing pathogen LRV credit in an MBR.

- "**Tier 1** - adopting predefined, conservative LRVs based on the statistical analysis of historical MBR performance data and associated operating conditions." Under Tier 1, a "wide-ranging review of MBR industry data and specific investigations of full-scale facilities (Branch & Le-Clech 2015) led to the establishment of default LRVs for viruses, protozoa and bacteria of 1.5, 2 and 4, respectively. These default values can only be applied to submerged MBR systems that have nominal pore sizes of 0.04–0.1 µm, are operated in accordance with design specifications, and under the conservative operating conditions…". Those operating conditions are described in **Table 1**. A detailed read of (Branch & Le-Clech 2015) will see that the LRV values are highly conservative, representing the lower 95^{th} percentile values, rounded down to the nearest 0.5-log value and often using surrogate organisms that are more conservative (e.g., *Clostridium Perfringens* (smaller organism, lower LRV) compared to *Cryptosporidium* (larger organism, higher LRV);

- "**Tier 2** - conducting challenge testing under the most conservative operating conditions expected for the specific system being validated to determine the minimum expected LRV, and implementing regular testing of target pathogens or surrogates." The document goes on to state "Tier 2 is designed to validate a specific MBR installation when a proponent considers that LRVs above default values (presented in Tier 1) can be demonstrated within a specific operating envelope….The system is to be operated within the validated envelope at all times for the validated LRVs to remain applicable.";

- "**Tier 3** - under this approach an investigation is undertaken incorporating challenge testing to demonstrate the correlation between online parameter(s) and the pathogen removal performance of the MBR. This allows critical limits to be established that are specific to the LRVs claimed. Until it can be further tested, this new method remains hypothetical and does not form part of the validation protocol."

Table 1 - MBR Operating Envelope for Adoption of Tier 1 Conservative LRVs.

Parameter	Operating Envelope	
	Minimum	Maximum
Bioreactor pH	6	8
Bioreactor Dissolved Oxygen, mg/L	1	7
Bioreactor Temperature, °C	16	30
Solids Retention Time, days	11	-
Hydraulic Retention Time[1], hours	6	-
Mixed Liquor Suspended Solids, g/L	3	-
Transmembrane Pressure, kPa	3	-
Flux, $L/m^2/h$	-	30
Turbidity, NTU	-	0.2

Source: AWRCE, 2016.
- = no limit specified under the protocol
1. Hydraulic retention time is to be calculated based on total influent volume from the last 24 hours of operation.

Within AWRCE (2016), the authors detail how the MBR testing program meets the goals of the protocol for validating pathogen LRV. The focus is on nine steps to proper validation:

- Identification of the mechanisms of pathogen removal by the treatment process unit;
- Identification of target pathogens and/or surrogates that are the subject of the validation study;
- Identification of factors that affect the efficacy of the treatment process unit in reducing the target pathogen;
- Identification of operational monitoring parameters that can be measured continually and are related to the reduction of the target pathogen;

- Identification of the validation method to demonstrate the capability of the treatment process unit;
- Description of a method to collect and analyze data to formulate evidence-based conclusions;
- Description of a method to determine the critical limits, as well as an operational monitoring and control strategy;
- Description of a method to determine the LRV for each pathogen group in each specific treatment process unit performing within defined critical limits; and
- Provision of a means for revalidation or additional onsite validation where proposed modifications are inconsistent with the previous validation test conditions.

3.2 National Efforts for MBR Technology Acceptance

The latest work on MBR validation for potable water reuse is the Santa Clara Valley Water District (2017) project, led by Carollo Engineers, which began in 2014 as part of the Santa Clara Valley Water District's (SCVWD's) broad potable water reuse program. SCVWD and Carollo developed an extensive MBR validation program and invited all major MBR suppliers to participate. Both GE and Evoqua joined the program, bringing along utilities that had MBR installations: GE - Ironhouse Sanitary District (Calif.), Abilene (Tex.), and King County (Wash.); Evoqua - Modesto (Calif.) and Healdsburg (Calif.).

Sampling was done at four full-scale operating MBR facilities and one pilot-scale MBR facility through the 2016 calendar year. The sampling coincided with different fouled membrane conditions (prior to backwash, after backwash, prior to chemical cleaning, after chemical cleaning). **Table 2** contains the sampling periods at each facility. Note that during some months, pending operational conditions, multiple samples were collected at a facility. It should also be noted that no upgrades or replacements were made to any facility at any time for this work (i.e., the facilities were not optimized for this new research).

Table 2 - Sampling Frequency at the MBR Facilities.

Facility	Sampling Period	N(1)
Ironhouse WRF	December, January, March, August	4
Hamby WRF	March, April, May, June, September	6
Healdsburg WRF	April, May, June, July, August, September, October, November	14
Modesto WWTP	April, May, June, July, August, September, October	10
King County	Pilot system, sampled over one-week period	NA
Notes: (1) Total number of sample events.		

The microbiological and chemical parameters evaluated during this project are provided in **Table 3**. The work is documented in Santa Clara Valley Water District (2017), which is in its final draft stage and will be complete and submitted to DDW in May 2017. This work consistently and repeatedly demonstrates 3+ log removal of all target pathogens, the use of a broad range of chemical and microbiological surrogates, the impact (or lack thereof) of fiber damage, and the use of accurate and rapid response low level turbidity monitoring for diversion of "off-spec" water. It is important to note that this new research by SCVWD and project partners reaffirms many of the conclusions from the Australian efforts. In summary, this new work follows the "Tier 2" approach detailed in ACWRE (2016) and the project team fully expects a minimum of 3 log removal virus and protozoa credit for the two tested MBR systems (GE ZW500D and Evoqua MemPulse), as long as the systems are operated within the documented operational range.

Table 3 - Parameters Sampled at MBR Facilities.

Parameter	Raw Wastewater (Primary Influent)	MBR Filtrate
Male Specific & Somatic Coliphage	X	X
Enterococci	X	X
Enterovirus and Norovirus	X	X
Giardia/Cryptosporidium	X	X
BOD	X	X
COD	X	X
Temperature, pH, DO	X	
TDS		X
Ammonia, Nitrate, Nitrite	X	X
TOC	X	X
Turbidity, EC		X
Particle Counts		X
Ultraviolet Absorbance	X	X
Fluorescence	X	X
Adenosine Triphosphate	X	X

4 Technology Acceptance Testing – MBR-RO-UV/AOP Train

The first twelve months of testing at the AWT Demonstration Facility will largely focus on technology acceptance for the MBR. During this testing, the AWT Demonstration Facility will be treating non-nitrified secondary effluent from the JWPCP. As indicated earlier, Metropolitan and Sanitation Districts will evaluate the MBR process as part of an alternative treatment train for IPR consisting of MBR-RO-UV/AOP (**Figure 1**). Two 0.25-MGD MBR systems will be followed by a single 0.5-MGD 2-stage RO system. A single 20 gallons per minute (gpm) UV/AOP system will treat the RO permeate and is designed to achieve the necessary removal of nitrosamines and 1,4-dioxane. Product water from the demonstration facility will be routed to the head of the JWPCP.

A nitrifying-denitrifying MBR has been selected for the preferred process train as an effective technology, to treat non-nitrified secondary effluent from the JWPCP ahead of the RO and UV/AOP processes. During demonstration testing, the feed water will be fully nitrified which will improve membrane performance. The level of denitrification will be varied depending on the target effluent water quality goals. The primary objectives of the AWT Demonstration Facility will be to achieve conditional acceptance of MBR as an alternative treatment technology for IPR, and obtain the necessary data to further evaluate compliance of the MBR-RO-UV/AOP process train with all relevant regulatory requirements.

The MBR process for the AWT Demonstration Facility is designed with a common bioreactor system followed by two parallel and different MBR membrane systems to ensure both membrane systems are fed with mixed liquor of same characteristics. The MBR systems used in the demonstration testing will include the equipment necessary to perform a PDT as well as spare sampling ports that can be used to deploy additional online monitoring equipment in the future. Filtrate sampling ports provided for both MBR systems will allow collection of necessary samples for monitoring of surrogates.

Draft testing and monitoring protocols for the demonstration testing are being developed and will be reviewed with the regulators once complete. These protocols will focus on the ability of the MBR-RO-UV/AOP process train to meet required LRVs and water quality goals and establish necessary process monitoring protocols. A detailed Testing and Monitoring Plan for the AWT Demonstration Facility will be submitted to regulators for approval prior to start of the testing period.

Test Objectives

- Demonstrate integrity monitoring of MBR process to achieve pathogen LRVs for *Cryptosporidium* and *Giardia.* Such integrity demonstration can be based on PDT or surrogate monitoring or a combination of both.
- Monitor performance of the RO membranes, especially fouling, downstream of MBR process
- Collect sufficient data to claim additional pathogen LRVs for virus, *Cryptosporidium* and *Giardia* for RO using TRASAR and other surrogates
- Determine the impact of membrane breach on pathogen rejection and RO membrane performance, as well as the ability of the integrity monitoring techniques to detect the breach
- Compare UV/AOP removal of 1,4-dioxane and N-nitrosodimethylamine (NDMA) using different oxidants (e.g., hydrogen peroxide and sodium hypochlorite) and UV doses
- Determine the ability of the process train to meet the water quality objectives for the groundwater basins
- Assess the ability to meet ocean plan water quality objectives for the concentrate discharge, the impact on the JWPCP, and the appropriate manner for permitting the concentrate discharge

Desired Outcome

- Obtain alternative technology acceptance for MBR log removal credits for *Cryptosporidium* and *Giardia,* and meet water quality objectives for regulatory approval of the full process train.

4.1 MBR Testing Approach and Framework

The project team will work closely with the regulators to develop an integrity monitoring protocol for MBRs based on the principles outlined in the 2005 USEPA Membrane Filtration Guidance Manual (MFGM). The integrity monitoring techniques required in the MFGM are classified as indirect (turbidity monitoring) and direct (pressure decay test). Considering the limitations of relying solely on PDT to calculate LRV, the project team will work with the regulators to evaluate a modified pressure hold test in combination with surrogate monitoring to verify membrane integrity in MBR.

Phase 1 – MBR Process Acclimation and Methods Development

Testing of the MBR will be conducted in four phases with a duration of three months each. Phase 1 will begin once startup and commissioning of the AWT Demonstration Facility is complete. This phase of testing will be used for process acclimation and to develop the analytical methods that will be used during subsequent testing. The biological process will be monitored to evaluate its stability and to assess the achievement of water quality goals. If necessary, adjustments to the operation of the biological process will be made to optimize performance. Weekly sampling of *Giardia*, *Cryptosporidium* and cultured enteric virus will be collected to determine the concentrations of these pathogens in the source water and the MBR filtrate. *Clostridium perfringens*, fecal coliform and *E. coli* will also be measured weekly to evaluate their relationship to pathogen concentrations and to determine their usefulness as pathogen surrogates.

The project team will determine the optimal sample volume to detect pathogens in the secondary effluent and MBR filtrate. For example, sample volumes of 100 L and 300 L have been collected from the secondary effluent and tertiary effluent at the City of San Diego's North City Water Reclamation Plant (NCWRP) for *Cryptosporidium* measurements. The volume of water collected from the MBR filtrate at the AWT Demonstration Facility is expected to be larger than the 300 L collected after the granular media tertiary filters at NCWRP because membranes are a better barrier to *Cryptosporidium* than granular media filters. Matrix effects in the secondary effluent will be evaluated using ColorSeed (BTF Precise Microbiology, Pittsburgh, Penn.), which is a product containing *Cryptosporidium* and *Giardia* that have been permanently labeled with red fluorescent dye. This method will allow the recovery of these pathogens to be evaluated while still permitting the enumeration of naturally occurring *Cryptosporidium* and *Giardia*.

With the assistance of the MBR system suppliers, the project team will develop the parameters of the PDT to evaluate MBR system integrity. Important parameters will include the initial test pressure, the duration of the test, and its frequency. These tests will be performed on the entire MBR system and on individual cassettes to develop pressure decay curves for the new membranes. Since the parallel MBR systems will be provided by different suppliers, the specifics of the pressure hold test are likely to vary between these systems. MBR suppliers will also be consulted to optimize membrane cleaning protocols.

Phase 2 – Baseline Testing

During the fourth to sixth months of operation, data will be collected to establish the baseline performance of the MBR systems. The operation of the biological process and the MBR equipment will be stable to provide a reference point for future testing while also satisfying water quality goals for nitrification and denitrification. The microbiological methods developed during the first three months of operation will be applied to calculate the log removals of pathogens and surrogates. PDTs performed under the criteria established during Phase 1 will provide pressure decay curves that will be compared with future tests with intentional integrity breaches.

Phase 3 – Compromised MBR System Challenge Tests

After baseline testing is complete, there will be three months of testing the MBR systems with increasing numbers of intentionally breached fibers. Each MBR system will include two membrane cassettes. During Level 1 testing, fibers will be cut in one cassette of each MBR provider, and the effect of these breaches on routine pathogen sampling, surrogate measurements, MBR filtrate turbidity, and PDTs will be evaluated for one month. During Level 2 testing, fibers in the second cassette of each MBR provider will be cut, and the effects of this compromise on the routine performance metrics will be evaluated for one month. Level 3 testing during the final month of Phase 3 will involve cutting enough fibers to increase the turbidity of the MBR filtrate to an average of approximately 0.2 NTU. As with Levels 1 and 2, the routine performance metrics will be evaluated for one month to determine the effect of this membrane damage.

Phase 4 – Effect of MLSS on Performance Metrics

The last phase of testing will involve evaluating the effect of different MLSS concentrations on MBR performance metrics for log removal. At the start of Phase 4, the cassettes will be repaired so the breaches created during Phase 3 no longer impact MBR filtrate water quality. During the first month of this phase, the MBR system will be operated at an MLSS concentration lower than the first nine months of operation. During the next month, the MLSS concentration will be increased above what was tested during the first nine months of operation. For the final month of testing, the MBR system shall be returned to the operating conditions of the baseline testing from Phase 2 to compare its current performance to earlier test conditions.

Table 4 summarizes the MBR testing phases, estimated duration and milestones for each phase.

Table 4 - MBR Testing Phases.

Phase	Duration	Milestone
1 – Process Acclimation	3 months	Achieve steady-state MBR operation, develop PDT parameters, establish sampling volumes
2 – Baseline Testing	3 months	Determine baseline LRVs for target pathogens and develop system-specific pressure decay curves
3 – Challenge Testing	3 months	Determine the effect of membrane fiber breakage on LRVs and assess sensitivity of PDT
4 – Effect of MLSS on Performance	3 months	Determine the LRVs for a range of MLSS concentrations

4.2 RO Testing Approach and Framework

RO system testing will focus on options for gaining DDW approval for enhanced log-removal credits through that unit process and assessing the impact of MBR filtrate on RO performance. This study will expand upon the work performed for other projects to achieve higher log-removal credits. The project team will work with DDW to develop a test plan for multiple methods that Metropolitan could choose to employ in the RO system of the full-scale AWT Facility. The investigation of RO fouling will determine the suitability of operating an RO system downstream of an MBR process treating this source water.

Phase 1 – RO Baseline Testing and Performance Evaluation

During the first three months of testing, the RO system will produce baseline water quality and performance data. Water quality samples will be collected weekly, and the control system for the AWT Demonstration Facility will monitor performance continuously. Sulfuric acid and antiscalant chemical dosages will be optimized. Any methods development required for the evaluation of options for enhanced log-removal testing will be conducted during this phase.

Phase 2 – Evaluation of Enhanced Log-Removal Methods

The next three months of testing will evaluate the methods selected to demonstrate higher log removal through the RO system. Possible surrogates for this approach include additives, such as TRASAR (Nalco, Naperville, Ill.) and Rhodamine WT, and naturally-occurring constituents, such as strontium and total organic carbon (TOC). Testing will include spiking MS-2 into the RO feed to compare the log removal of MS-2 with the log removal of potential surrogates. Intentional integrity breaches, such as O-ring cutting/removal, will be created to evaluate the sensitivity of the surrogates with detecting potential failures in the RO elements. Log-removal testing of oxidized modules will be performed to evaluate the impact of degraded RO elements on MS-2 and surrogate rejection. Sample collection during different test conditions will be performed at least daily to develop a database for evaluating statistical variance and to establish control limits for detecting breaches.

Phase 3 – Evaluation of RO Fouling Downstream of Breached MBR Membranes

Phase 3 of RO testing will occur during the three months of intentional breaching of MBR membrane fibers, providing an opportunity to evaluate the effect these breaches have on RO fouling. Compromised MBR membranes could allow more organic matter and microorganisms to reach the RO system, which could increase the rate of fouling. During this phase of testing, the project team will evaluate RO performance to determine if fouling becomes a problem as the compromised MBR challenge testing progresses.

Phase 4 – Monitor Fouling Rate after MBR Resumes Normal Operation

The last phase of testing for the RO system will evaluate the continuing effect of treating MBR effluent on RO performance after the breaches in MBR membranes have been repaired. Operations data from these final three months of testing will be compared to operations data from the first three months of testing to determine how rapidly RO performance has changed during the testing period. RO elements will be removed from the lead position of the first and second stage and the tail position of the second stage and sent for analysis to identify the foulants that have collected on those membranes.

Table 5 summarizes the RO testing phases, estimated duration and milestones for each phase.

Table 5 - RO Testing Phases

Phase	Duration	Milestone
1 – Baseline Testing	3 months	Establish baseline water quality and performance data, optimize chemical dosages, develop testing methods
2 – Log-Removal Evaluation	3 months	Demonstrate log-removals using surrogates, assess effects of intentional integrity breaches and degraded elements, establish control limits
3 – Fouling Potential	3 months	Assess RO fouling with breached MBR membrane fibers and evaluate performance
4 – Performance Assessment	3 months	Evaluate RO performance after MBR repairs, compare with baseline performance, identify foulants

4.3 UV/AOP Testing Approach

A 20-gpm UV reactor will be placed after the RO system for disinfection and advanced oxidation. Constituents of concern in the secondary effluent include nitrosamines [specifically N-nitrosodimethylamine (NDMA) and N-nitrosodiethylamine (NDEA)] and 1,4-dioxane. Advanced oxidation will be tested in the AWT treatment train through the use of a UV process in combination with free chlorine and with hydrogen peroxide to meet target effluent concentrations and regulatory requirements (e.g., 10 ng/L notification level for NDMA and NDEA, 0.5-log reduction of 1,4-dioxane). As UV/AOP technology has been successfully applied in numerous IPR applications as part of a FAT train, no special testing conditions associated with this process is anticipated.

5 Flexibility and Future Opportunities

Flexibility has been incorporated into the AWT Demonstration Facility design and site layout to support additional unit processes that may potentially be added in the future, as needed, to allow evaluation of alternative process trains. Following completion of MBR technology acceptance testing as part of the MBR-RO-UV/AOP process train, consideration may be given for future evaluation of alternative process trains as follows:

- **MBR-MF-RO-AOP**
  MF systems could potentially be added between the MBR and RO processes, establishing an approved full advanced treatment (FAT) train preceded by MBR providing the necessary pretreatment. The MBR process could be initially operated as a tertiary MBR during this evaluation and later be operated as a secondary MBR. When primary effluent is fed to the bioreactor basins for organics, ammonia and/or nitrate removal, the process is considered a secondary MBR. Alternatively, when non-nitrified secondary effluent is fed to the bioreactor basins for ammonia and/or nitrate removal, the process is referred to as tertiary MBR. Typically, a tertiary MBR will involve operation at lower mixed liquor suspended solids (MLSS) concentration (3,000-4,000 mg/L) compared to secondary MBR because most of the biodegradable organics are already removed from the wastewater before secondary effluent is fed to the bioreactor basins. If an external carbon source is added to the tertiary MBR for denitrification, then the MLSS concentration in the bioreactor basins would be comparable to secondary MBR and can range from 5,000-9,000 mg/L.

- **Non-MBR Biological Process-MF-RO-UV/AOP**
  Additional testing opportunities could include evaluating the MF-RO-UV/AOP process train, an approved FAT train, preceded by an alternative (non-MBR) biological treatment process. Alternative biological processes could include Granular Activated Sludge (GAS) or Anammox systems.

- **MBR-UV-RO-UV/AOP**
  A UV system could potentially be used in lieu of the MF process in a FAT train to achieve the required *Cryptosporidium*/*Giardia* log credits. However, a breach in the MBR system may result in fouling of the RO membranes. Further data is needed on RO systems operating downstream of the MBR and/or UV process when treating municipal wastewater.

- **Potential DPR Process Train**
  A future phase of testing may include evaluation of a treatment train for DPR that consists of ozone and biologically activated carbon, or other unit processes, upstream of an FAT train. Alternative treatment trains for DPR are still being developed within the industry as the water quality goals for DPR have not yet been established by the regulators.

6 Next Steps

The design of the AWT Demonstration Facility has been completed and a contract will be awarded for the construction of the facility in summer 2017. The construction is expected to last at least one year. During this period, the testing and monitoring protocols for the MBR-RO-UV/AOP process train will be developed and reviewed with the regulators, while initiating a process to ultimately seek conditional acceptance for the MBR as an alternative treatment technology for IPR. The AWT Demonstration Facility is expected to be operational in mid-2018.

7 References

AWRCE (2016) Membrane bio-reactor, WaterVal validation protocol, *Australian Water Recycled Centre of Excellence (AWRCE), Brisbane*.

Branch, A. and Le-Clech, P. (2015) National Validation Guidelines for Water Recycling: Membrane Bioreactors. *Australian Water Recycled Centre of Excellence*, Brisbane.

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

Salveson, A., Fontaine, N. (2016) Resolving the final hurdles to MBRs for potable reuse. Presentation at the Annual Water Reuse Symposium, Tampa, FL.

Santa Clara Valley Water District. (2017) Membrane bioreactor demonstration for potable reuse. Draft Report by Carollo Engineers, Inc. with support from Evoqua, GE, Ironhouse Sanitary District (CA), King County (WA), City of Modesto (CA), City of Healdsburg (CA) and Abilene (TX).

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