water e-journal
Online Journal of the Australian Water Association
ISSN 2206-1991
Volume 2 No 2 2017
https://doi.org/10.21139/wej.2017.010

THE NEXT STEP: UPGRADE OF THE MEMBRANE BIOREACTOR AT NORTH HEAD RECYCLED WATER PLANT

After nine years of operation, SWC considered options to cater for the increased demand for recycled water at North Head WWTP

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INTRODUCTION

The Recycled Water Plant (RWP) at Sydney Water Corporation's (SWC) North Head Wastewater Treatment Plant (WWTP) was commissioned in August 2005. The RWP consists of a Membrane Bioreactor (MBR) and chlorine disinfection to provide high-quality process water for several processes at the WWTP. The RWP was designed to provide 2.0 ML/d recycled water and as such contributes to the reduction in potable water usage by the WWTP – a key target for SWC's wastewater operations.

It was determined in 2013 that the WWTP's demand for recycled water may increase to 2.6 ML/d following the installation of new odour control equipment. Due to control system issues, the RWP's chemical cleaning could not commence as scheduled. To still satisfy increased demand, potable water had to be used as additional supplement to meet overall supply of recycled water. The membrane modules of the RWP were also approaching the end of their service life.

SWC engaged with the original supplier of the membrane modules and associated hardware, Evoqua Water Technologies (EWT), to jointly optimise control system performance and obtain a comprehensive performance audit of the RWP plant and process. SWC's controls engineers and operators collaborated with Evoqua process experts to re-commence chemical cleaning of the membrane modules.

The audit made recommendations on improvements to operation of the current plant and provided two upgrade options to increase the average recycled water production capacity to 2.25 ML/d and up to 2.8 ML/d respectively within the existing civil structure. Both options proposed to replace the existing MEMCOR® B10R membrane modules with EWT's new generation MEMCOR® B40N modules including MemPulse® aeration technology. SWC decided to adopt the 2.25 ML/d option with a membrane inventory for the 2.8 ML/d option. The physical upgrade works were scheduled to take place in September 2014. This provided an opportunity to examine the operation of the RWP through it first nine years of operation with a focus on the performance of the membranes. The RWP became the subject of a detailed study of pathogen removal comparing aging and replacement membranes (Branch et al. 2016) following on from a study by Pettigrew *(Pettigrew 2010)*.

The upgrade and membrane replacement was completed 'on line', with at least one of the two membrane trains producing filtrate at any time and the biomass remaining within the system.

Once the upgrade was complete, data from the re-commissioned plant provided an opportunity to compare filtrate quantity and quality, chemical cleaning, power and operator labour data from the initial membranes in their new condition, after nine years of operation and the new replacement membranes.

YEAR CASE STUDY WAS IMPLEMENTED 2005 to 2016

PROCESS AUDIT AND IDENTIFICATION OF UPGRADE OPTIONS

The audit was carried out by process engineers from EWT in mid- 2013. Its main purpose was to examine the existing mechanical and electrical equipment with the view of potentially increasing future capacity within the existing civil structure.

The audit's output was a series of recommendations on improvements to operation of the current plant and also presented two upgrade options to increase the RWP's recycled water production capacity. For each option, requirements and recommendations for all existing pieces of key ancillary equipment were given. Depending on the option, some pieces of equipment could be used without upgrade, other equipment would require a retrofit and other equipment again would require replacement.

Proposed Option 1 involved minor changes to the control system, replacement of the RWP feed pumps, changes to the membrane scour air blower drive (change of pulley or VSD), replacement of the transfer pumps for CIP chemicals as well as inspection and refurbishment of valves.

Option 2 involved the changes for option 1 plus additional membranes and replacement of the filtrate pumps. Re-modelling of the bioprocess was also recommended.

In parallel to the audit, EWT carried out preliminary mechanical design work to detail how to install new generation MBR rack assemblies into the existing concrete tanks.

The options are summarised in Table 1.

It was a design objective to retain the method of lifting rack assemblies out of tanks and also to keep existing manifolds for air, filtrate and mixed liquor recirculation.

Table 1 – Options for RWP upgrade

Option No.	Description	MOS size	Membrane Area per Tank (m2)	Average Flow (MLD)	Peak Instantaneous Flow (MLD)	Scour Air Requirement (m3/h)	
						average	peak
N/A	Existing plant	2x4x-40B10R	1600	2.00	2.30	887	
1	Replace both tanks with B40N modules (4 racks per membrane tank)	2x4x-14B40N	2059	2.25	2.60	448	672
2	Completely fill both tanks with B40N modules (5 racks per membrane tank)	2x5x-14B40N	2632	up to 2.8	Up to 3.1	560	840

THE UPGRADE PROJECT

SWC's choice was option 1 excluding replacement of the RWP feed pumps as a first upgrade phase in September 2014. Following the on-time and under-budget completion of phase one, the membrane portion from option 2 was installed in December 2014.

SWC's scope in the upgrade project included PLC work, installation of a VSD on the membrane scour air blower and replacement of chemical transfer pumps.

EWT's scope included detail process and mechanical design, supply of membrane modules and rack hardware, removal and disposal of old membrane hardware, installation of new module hardware and plant re-commissioning.

Early engagement between key EWT and SWC personnel identified the expectations, risks and concerns of SWC. The most significant risk being loss of production.

On project completion the following successes were acknowledged:

- Zero safety incidents.
- Continuity of Recycled Water Supply throughout the upgrade works.
- Expedited delivery and installation of fifth MBR rack assembly upon SWC decision to upgrade scope of supply.

PLANT OPERATION PRIOR AND AFTER MEMBRANE REPLACEMENT

Once the upgrade was complete, data from the re-commissioned plant provided an opportunity to compare filtrate quantity and quality, chemical cleaning and power as well as operator labour data from three different points in time:

- The initial 2005 membranes in their new condition.
- Old membranes after nine years of operation.
- The new replacement membranes.

Plant Capacity

Filtrate production for the RWP is demand-based, controlled by the level of the on-site 2 ML industrial water tank. If filtrate production is less than the requirements for process water in the STP, the shortfall is made up by potable water. An example of this is the lower average daily filtrate production from the RWP in the months prior to the upgrade, which was low due to missed chemical cleans in the previous months.

Figure 2 presents production data averaged over a month. Each month includes a mixture of high-demand and low-demand days.

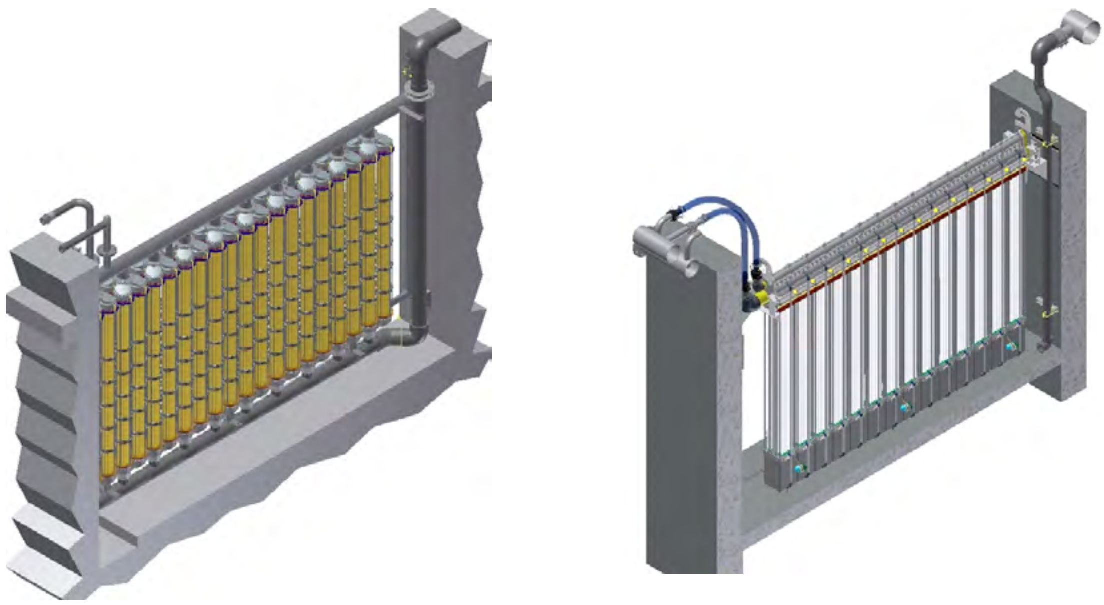

Figure 1 – An old MEMCOR® B10R MBR rack assembly (left) and a new B40N MBR rack assembly with MemPulse® technology (right) inside the existing concrete tank.

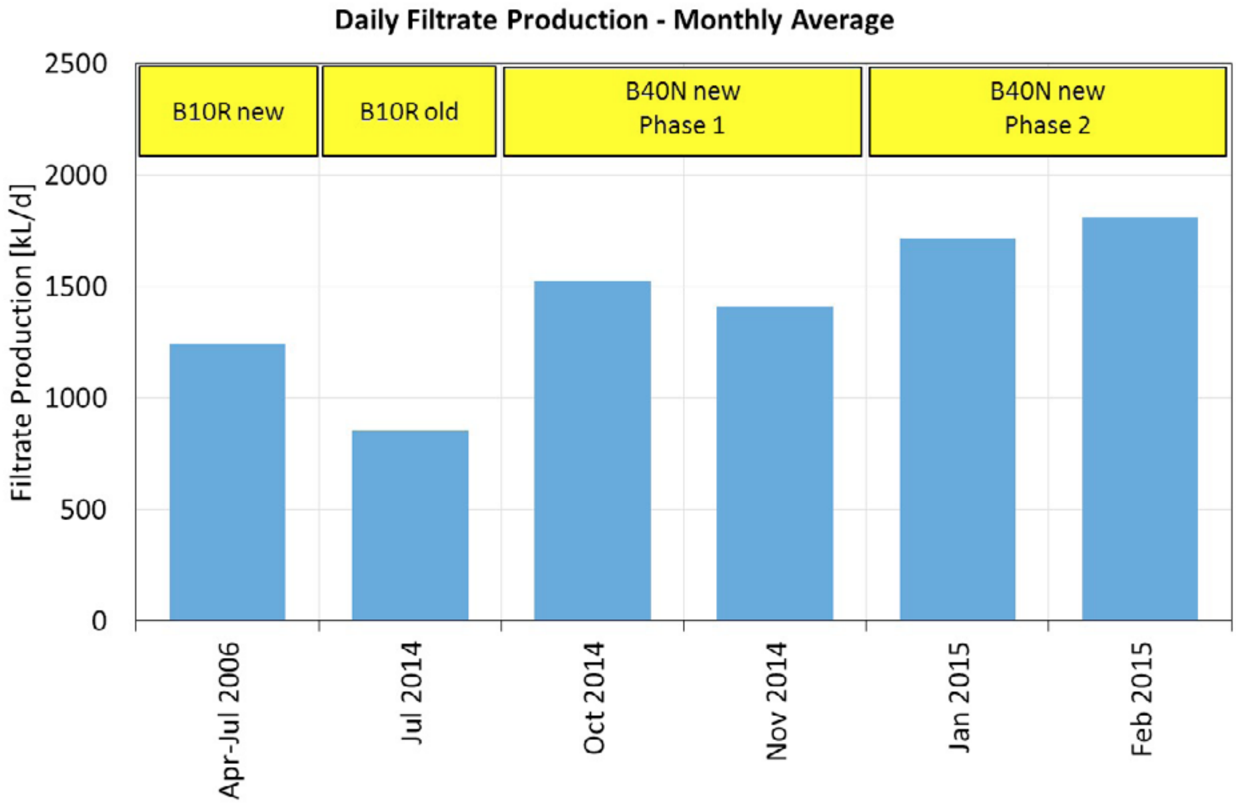

Figure 2 – Daily Filtrate Production – Monthly Average

There is now a sufficient membrane inventory in place to allow a higher production rate of up to 2.8 ML/d. This represents 40% higher production than the original plant was specified to achieve. The hydraulic bottlenecks for achieving this 2.8 ML/d are simply the capacity of the feed pumps and the filtrate pumps, both of which could be easily upgraded should demand increase further.

Filtrate Quality

Filtrate quality was assessed via the RWP's online filtrate turbidity meter and results from filtrate grab samples analysed in the plant lab. In addition, references are made to a study of Log removal values (LRV) of four indicator microorganisms: *clostridium perfringens, E. coli, FRNA bacteriophage and somatic coliphage* (Branch et al, 2016).

Filtrate Turbidity

The RWP does not rely on filtrate turbidity as a critical control point to demonstrate disinfection, however filtrate turbidity has always been typically below < 0.05 NTU, comfortably meeting the plant filtrate specifications of ≤ 2 NTU (24 hr mean 100th%ile) and < 5 NTU max instantaneous.

Averaged filtrate turbidity for periods with initial MEMCOR® B10R membranes when they were new (June – July 2006), after approximately nine years of operation (August – September 2014) and with new MEMCOR® B40N membranes (October 2015 to March 2016) are all below 0.05 NTU. Minimum, maximum, Average and 99 percentile values are summarised in Table 2. A long-term turbidity trend for the period October 2015 to March 2016 is shown in Figure 3. Note that the data in this trend are unfiltered and showing high turbidity spikes created by events such as no filtrate flow.

Table 2 – Filtrate Turbidity at key points in time

	7/6/06 to 7/7/06	26/8/14 to 24/9/14	19/10/15 to 5/3/16
n	342	20	196,039
Average	0.05	0.03	0.01
99%ile	1.08	0.07	0.02

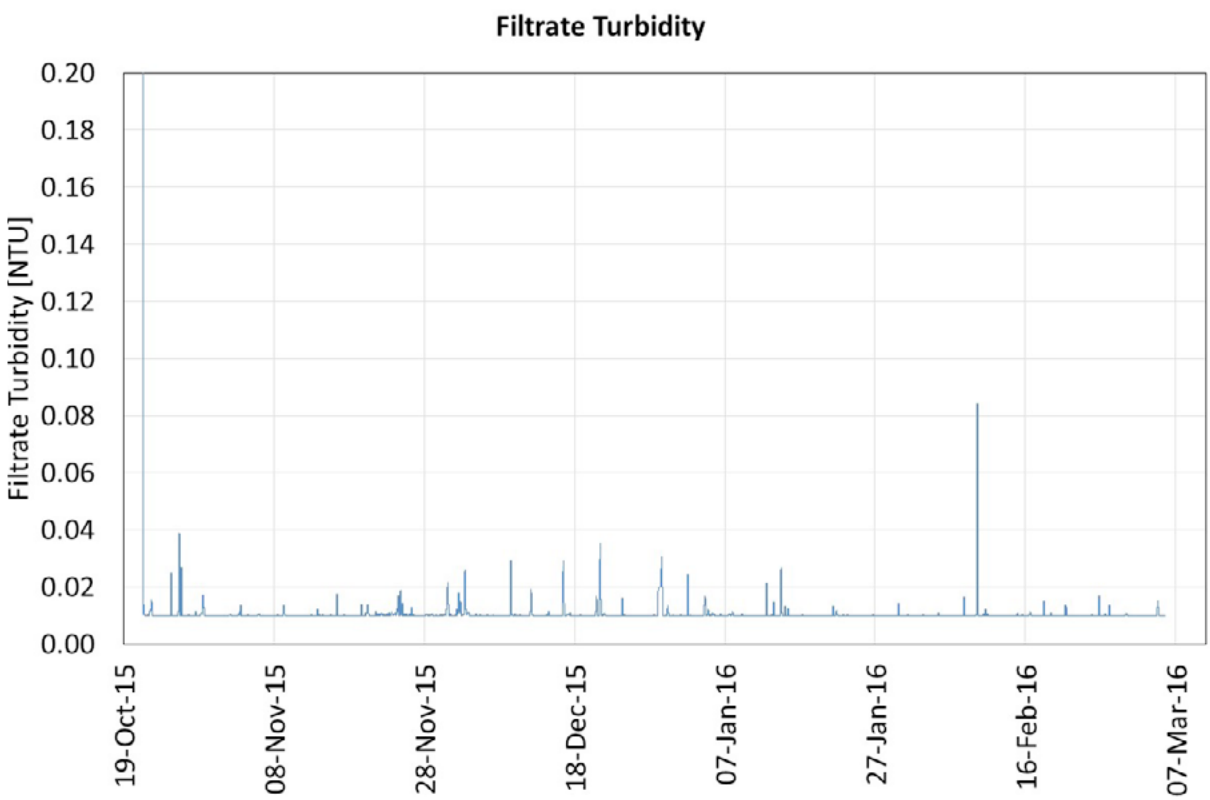

Figure 3 – Filtrate turbidity October 2015 to March 2016 – moving average (255 data points)

Filtrate Characteristics

Typical filtrate characteristics from 2006 (initial new MEMCOR® B10R membranes) and 2016 (new MEMCOR® B40N membranes) are presented in Table 3. Filtrate specifications were reported by Chapman (*Chapman et al. 2006*) and typical values in 2006 were reported by Landers (*Landers et al. 2006*).

Log Removal Values of four Indicator Microorganisms

The upgrade of the North Head MBR plant and the associated membrane replacement provided an opportunity for researchers to study the impact of membrane age on pathogen log removal. In additional to the study conducted in 2010 (Pettigrew et al) a study carried out by Branch examined temporal changes in LRV for a suite of microorganisms (Branch et al. 2016), Table 4. Sample sets of influent wastewater, activated sludge and filtrate were analysed before and after total membrane replacement. Four indicator microorganisms were analysed to quantify removal of viruses, bacteria and protozoa. The results of this study suggest that within 10 years, no significant decline in LRV is expected. Unless gross, easily detectable, membrane integrity failure occurs, a MBR will continue to produce high quality water.

Table 3 – Filtrate characteristics

Parameter	Specification	Typical Values 2006*	Typical Values 2016†
Thermotolerant Coliforms (cfu/ 100mL)	< 10 (median)	<1	<1‡
Total Chlorine (mg/L)	1 after 30 min	1 – 2	no data
Turbidity (NTU)	≤ 2 (24 hr mean 100th%ile) and < 5 max instantaneous	≤ 0.1	0.01
NH3-N (mg/L)	≤ 1 (Mean)	0.03	<0.5
NO3-N (mg/L)	No limit	12.2	11.3
Alkalinity (mg/L)	> 40 (Mean)	67.0	54
Total Iron (mg/L)	< 0.5 (Mean)	0.16	no data
pH (pH units)	6.5- 8.5 (90th percentile)	7.2	8.0
CBOD5 (mg/L)	None – monitoring requirement only (median)	4.0	no data
COD (mg/L)	Not specified	28.7	no data
PO4 – P (mg/L)	Not specified	4.6	no data
Total P (mg/L)	Not specified	5.0	no data
TDS (mg/L)	Not specified	786	no data
Conductivity (μS/cm)	Not specified	1322	no data

* Landers et al. 2006
† From grab sampling in Feb 2016
‡ E. Coli

Table 4: Comparison with available 5-year performance data, n is the number of sampling events (from Branch et al, 2016)

Indicator	5-year performance (Pettigrew et al. 2010), n = 6			Before replacement (S1, n = 22)			After replacement (S2 and S3, n = 37)		
	min	median	max	5th	median	95th	5th	median	95th
FRNA									
LRV_{MBR}	>3.8	>4.5	>4.9	3.7	5.1	6.4	3.4	4.5	5.6
LRV_{Bio}	-0.5	0.0	0.6	0.1	0.7	1.3	-0.7	0.7	2.1
SC									
LRV_{MBR}	3.7	4.6	>4.7	3.6	4.4	5.3	2.8	3.5	4.2
LRV_{Bio}	-1.0	-0.7	-0.5	-0.4	0.1	0.6	-0.9	-0.5	-0.1
EC									
LRV_{MBR}	5.4	5.7	6.7	5.1	5.8	6.5	6.4	7.1	7.8
LRV_{Bio}	0.0	0.6	0.7	0.5	1.1	1.7	0.1	0.6	1.0

Membrane Cleaning prior and after Membrane Replacement

Chemical cleans as per EWT's design are as following:

- One Maintenance Clean (MC) per membrane train once a week. A MC uses a low concentration chlorine solution to backwash membranes and disinfect pipework. The duration of the cleaning sequence is approximately 45 minutes and Mixed Liquor does not have to be drained from the membrane tank.
- One Chlorine CIP (C-CIP) per membrane train every three months. A C-CIP uses a high concentration chlorine solution to recirculate through and soak membranes. The duration of the cleaning sequence is approximately 3 hours and Mixed Liquor is drained from the membrane tank.
- One Acid CIP (A-CIP) per membrane train every six months. An A-CIP uses a low concertation Citric acid solution to recirculate through and soak membranes. The duration of the cleaning sequence is approximately 3 hours and Mixed Liquor is drained from the membrane tank.

In the examination of actual usage of membrane cleaning chemicals prior and after membrane replacement, data for the various periods were either established from chlorine tank levels, chemical flow rate records or the number of cleans performed multiplied and typical chemical usage per clean.

As membranes age, the interval of CIP typically has to be reduced to counteract increased fouling. Analysis of Sodium Hypochlorite usage data from the North Head RWP confirmed this behaviour. For the period April to July 2006, when the initial membranes were new, Landers reported a use of 3.45 L of 12.5 % Sodium Hypochlorite per ML filtrate produced. In the period July 2013 to June 2014, shortly before the initial membrane inventory was replaced, the usage had increased to 19.7 L/ML. After replacement of the membranes, usage went down to 2.7 L/ML in the period February 2015 to February 2016.

Usage of Citric Acid showed a similar behaviour. In April to July 2006, as reported by Landers, it was 4.57 L 50 % Citric Acid per ML filtrate produced. Shortly before membrane replacement, between July 2013 and June 2014, it was 14.4 L/ML. The replacement membranes between February 2015 and February 2016 used 0.4 L/ML.

It has to be noted that in 2012/2013 the ability to perform chemical cleans was impacted by problems with the CIP control system. These problems were rectified by SWC in early 2013 and the recommended schedule of chemical cleans re-commenced.

The lower than expected usage of Citric Acid on replacement membranes is due to upgrades of the CIP control system that delayed scheduled cleans. At the time of writing, SWC is in the process of rectifying these problems. Usage of membrane cleaning chemicals is summarised in Table 5.

Table 5 – Use of membrane cleaning chemicals

Period	Comment	Chemical use (L/ML filtrate)	
		12.5 % Sodiu Hypochlorite	50 % Citric Acid
April to July 2006	Initial membranes (B10R) new	3.5	4.6
July 2013 to June 2014	Initial membranes towards the end of their service life	19.7	14.4
February 2015 to February 2016	Replacement membranes (B40N)	2.7	0.4

Table 6 – Power consumption

Period	Comment	Specific power consumption (kWh/ML)
April to July 2006	Initial membranes (B10R) new	837
July 2013 to June 2014	Initial membranes (B10R) towards the end of their service life	1,185
February 2015 to February 2016	Replacement membranes (B40N)	613

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Power Consumption prior and after Membrane Replacement

Power consumption was evaluated using instantaneous power meter numbers (in kW) at 1-minute resolution for all power consumers of the plant. The main power consumers are the blowers with the biological air blower being the largest one followed by the Membrane scour air blower. Smaller power consumers are the mixed liquor recirculation pumps, filtrate pumps drive, biological mixer, air dryer, chemical dosing and transfer pumps, local controls and lighting and other minor ancillary equipment. Devices not included in this power consumption figures are the feedwater pump drives and air compressors. These devices are located in plant areas away from the RWP and were also excluded from the numbers reported previously for 2006. It can be assumed that their power consumption has remained the same between 2006 and the plant upgrade. For the period April to July 2006, when the initial membranes were new, Landers reported a specific power consumption of 837 kWh per ML filtrate produced. In the period March 2014 to September 2014, shortly before the initial membrane inventory was replaced, the power consumption had increased to 1,185 kWh/ML. After replacement of the membranes, power consumption went down to 613 kWh/ML in the period September 2015 to February 2016.

A certain reduction can be expected with new membranes based on the fact that the filtrate pumps have to overcome a lower transmembrane pressure (TMP). An additional TMP reduction can be assumed from the increased membrane surface area due to the current 5-rack assembly configuration compared with the original 4-rack assembly configuration. On the other hand, the increased demand for recycled water after the plant upgrade requires the biological process to operate at higher MLSS. Aeration efficiency reduces as MLSS increases hence the higher demand for recycled water should trigger higher power consumption. A significant reduction in power consumption after the plant upgrade can be attributed to a reduction in membrane scour air flow rate made possible by EWT's new aeration technology. The MemPulse® system deployed with the new generation MEMCOR® B40N MBR membrane modules used on the plant upgrade, generates random rapid pulses at each MBR module using a continuous air flow without the use of valves or other moving parts. Scouring effectiveness is increased and power consumption is reduced. The previous generation MEMCOR® B10 R MBR modules required an air scour flow rate of 443 m3/h per membrane tank. This compares to 224 m3/h and 280 m3/h per membrane tank for the 4-rack and 5-rack assembly configuration respectively for the current-generation B40N MBR modules. The result is a reduced overall specific power consumption per ML treated.

Table 7 – Operator labour hours

	2006		2016	
	Daily	**Weekly**	**Daily**	**Weekly**
SCADA monitoring by shift coordinator	0.5	3.5	0.5	3.5
Plant and condition monitoring by area operator	0.5	3.5	0.5	3.5
Daily sampling and laboratory analysis	1.5	7.5	0.5	3.5
Weekly sampling and calibration	n/a	2.5	n/a	n/a
Calibrations (6-monthly, scaled to weekly)	n/a	n/a	n/a	0.07
Total		17		10.6

Operator Labour Hours

The plant is highly automated. Both the bioreactor and the Membrane Operating Systems typically only require operator intervention for process adjustments once a day, during equipment isolation for planned and breakdown maintenance and during CIP. Controls are in place for bioreactor level and DO control, automatic ramp up and down of filtrate production based on the level in the on-site 2 ML industrial water tank, scour air flow, relaxation cycles and Maintenance Cleans. Operator labour requirements were estimated for a typical day. Usual tasks performed by operators include monitoring the process on SCADA, physical inspection of plant components, sampling and lab work. In addition to the daily effort, operators spend some time every six month on instrument calibrations. Not included in these numbers are hours operators spend carrying out CIPs. MCs typically run automatically and do not require operator intervention.

The current estimates are compared to the finding of Landers in 2006 and summarised in Table 7.

CONCLUSIONS

After nine years of operation, SWC considered options to cater for the increased demand for recycled water at North Head WWTP. An audit performed by the supplier of the original membrane equipment informed SWC's choice of upgrade option. The selected option included the replacement and upgrade of MEMCOR® membrane modules with a new generation product by the original supplier. The upgrade that was done 'on line' while the plant was producing recycled water, resulted in a plant that now produces more recycled water without compromising filtrate quality at lower dollar per ML energy costs compared with the original design. Examining pre and post upgrade plant operating data allowed findings to be made on the performance of nine-year-old membranes compared with new membranes. The upgrade was also an opportunity to upgrade controls incorporating operating experience from previous years.

ACKNOWLEDGEMENTS

The authors thank Tom Watson from Sydney Water Corporation for his valuable support.

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Gerin has over 10 years' experience in water and wastewater field in Australia, Asia and North America. During this time he has worked in variety of roles encompassing: R&D, design, supply, commissioning and technical sales. His work has focused on projects involving membranes, biological wastewater treatment and solids reduction technologies.

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