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ASSESSMENT OF THE FIRST YEAR OF OPERATION OF THE UF/NF WHITEMARK WTP

Evaluation of the performance of the new Whitemark WTP including chemical-free organics removal and assessment of the performance of the UF and NF membrane systems

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ABSTRACT

While low pressure membrane treatment processes are increasingly being used in water treatment for both particulate and pathogen removal, the task of removing dissolved contaminants such as NOM, iron and manganese is commonly addressed with physiochemical processes including coagulation and oxidation. For applications where chemical dosing and sludge production is undesirable however, nanofiltration (NF) can prove a viable alternative.

NF membranes are capable of selectively removing problem compounds or ions, while retaining some hardness and most monovalent ions. In particular large molecular weight organic compounds that compromise dissolved colour are readily rejected by NF membranes. Low fouling NF membranes have beneficial properties for such an application including a smooth surface with more neutral surface charge which helps minimise organic fouling. Additionally, lower rejection of monovalent ions allows moderate TDS levels in permeate and provides more modest concentrate salinity levels for environmental discharge.

At Whitemark on Flinders Island, Tasmania, a new water treatment plant (WTP) combines low pressure ultrafiltration (UF) with spiral wound NF membranes to achieve these treatment objectives without the need for chemical pre-treatment or oxidative processes. The UF not only achieves the required levels of particulate and pathogen rejection but provides a low silt density index (SDI) feed for the NF membranes. The NF system in turn eliminates the need for upstream coagulation or oxidation pre-treatment processes and provides near-total removal of colour and natural organic matter (NOM). Furthermore the NF eliminates lead from the treated water, where levels previously exceeding Australian Drinking Water Guidelines (ADWG) health limits led to a Public Health Alert - Do Not Consume.

INTRODUCTION

The Whitemark Water Treatment Plant provides water to the township of Whitemark on Flinders Island, a remote location north-east of mainland Tasmania. Whitemark is the most populous town on the island, with the island itself being estimated to have a population of 783 as of 2015[1]. The 0.45ML/d capacity WTP was delivered under a Design and Construct contract for TasWater by Laurie Curran Water Pty Ltd, with the plant entering service in September 2016.

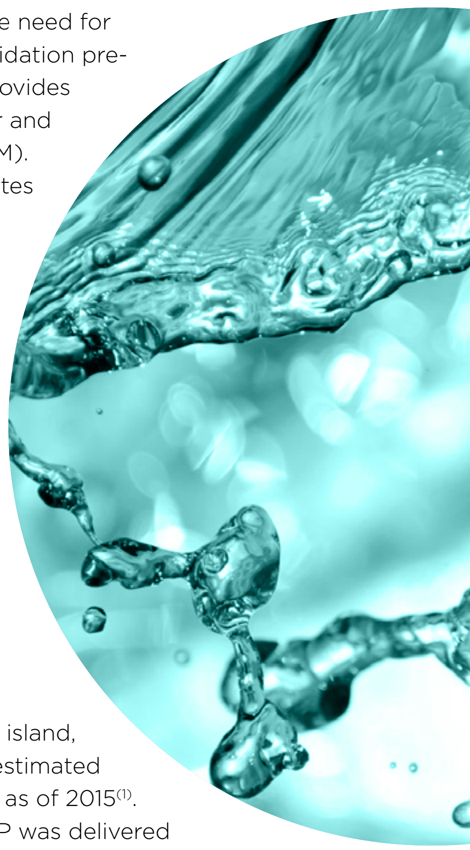


Table 1. Whitemark Raw Water Quality Data (2)

Characteristic	Units	Maximum	Minimum	Median
pH	pH units	7.7	6.3	7.0
Conductivity	µS/cm	902	476	631
Total Dissolved Solids (TDS)	mg/L	520	304	399
Colour Apparent	CU	331	102	190
Turbidity	NTU	16	0.6	2.75
Alkalinity Total	mg/L $CaCO_3$	34	16	26
Hardness (Total Cations)	mg/L $CaCO_3$	90.4	46.2	68.4
Total Iron	µg/L	1840	588	918
Total Manganese	µg/L	6.0	13.1	9.5

The WTP is fed from water in Pats Creek which is collected at a series of weirs then pumped into a 27ML storage basin at the WTP. The weirs and 27ML basin provide storage capacity for prolonged dry periods, typically over summer, where the limited catchment receives little rainfall or other inflow.

The principal objective of the new Whitemark WTP was to produce drinking water satisfying ADWG quality requirements and allowing the removal the Public Health Alert – Do Not Consume to residents.

Additional key treatment objectives included removal of the high level of dissolved organics to prevent DBP formation, and minimisation of the quantity and environmental impact of any wastes produced by the WTP. The WTP waste streams are returned to environment immediately downstream of the raw water intake weir. Consequently the minimisation of any chemical residue in this stream was a primary design requirement.

Nanofiltration was the preferred process nominated for the project with the final WTP process comprising raw water straining, UF, NF, pH/alkalinity adjustment via calcite filters, granular activated carbon (GAC) adsorption, ultraviolet (UV) disinfection and chlorination. A modest NF recovery rate of 70% combined with no requirement for pre-treatment chemicals results in a chemical-free return waste stream which discharges into Pats Creek.

The remote nature of the location and lack of a permanent WTP operator presence necessitated a high level of automation and reliability of operation in the design. Accordingly, all processes including membrane clean-in-place (CIP) are automated and can be performed remotely if required.

PROCESS DESIGN

Raw Water Quality and Challenges

Raw water for the plant is sourced from South Pats River, from which it is pumped to raw water storage basins adjacent to the plant. Identified water quality concerns at Whitemark prior to WTP design were lead, colour, aluminium, iron, manganese, dissolved organic carbon (DOC) and microbiological pathogens. Table 1 displays raw water quality results compiled from quarterly chemical testing data taken from the Whitemark Council Depot across 2010 to 2014.

WTP Design

The preferred process for the plant was stated to be nanofiltration and throughout the design process a number of other requirements were identified including:

- A preference for no antiscalant dosing due to the eventual discharge of WTP waste to the environment, which was in turn a driver for the reduction of the nanofiltration design recovery rate from 80% to 70%;
- A preference for easily neutralised or environmentally safe and biodegradable CIP chemical solutions;
- Preference for re-treatment of neutralised waste where possible.

Taking into account TasWater's preferences and requirements, a WTP process design of raw water straining, dual train UF membranes, dual train NF membranes, pH/alkalinity adjustment via dual train calcite filters, dual train GAC adsorption, UV disinfection and chlorination was adopted.

A neutralisation system was designed to automatically neutralise CIP waste from both UF and NF processes and discharge this to the plant raw water basin for dilution with incoming raw water for re-treatment. In the case of specialist NF cleaning chemicals, CIP waste can also be discharged to a chemical waste tank for offsite disposal, or, where appropriate, to provide sufficient residence time for chemical degradation before environment disposal.

Ultrafiltration

UF membrane selection was made to provide a minimum 2.5 log reduction value (LRV) of cryptosporidium and to minimise CIP waste volumes via a conservative flux rate. The Whitemark WTP is provided with 2 x 50% Evoqua XP-E18L20N low pressure ultrafiltration membrane units arranged in duty/duty configuration. The L20N PVDF membranes operate outside-in and utilise an air-driven backwash with air scour to minimise waste production volumes. The 0.04mm pores provide 4LRV cryptosporidium and 2LRV virus reduction. Each train provides 630m^2 membrane area and operates at a typical flux rate of 28-30LMH. Fully automatic filtration, backwash, integrity testing and CIP sequences allow stable long-term operation without the need for operator intervention.

Evoqua L20N membranes employ two primary chemical agents for cleaning: sodium hypochlorite for chlorine cleans and citric acid for low pH cleans. CIP setpoints are 400ppm free chlorine and citric acid concentrations of 1.5% – 2.5% to achieve a cleaning pH of 2.0-2.2. Typically, a CIP Cycle consists of either a chlorine CIP only or consecutive citric acid / chlorine CIP combinations.

Nanofiltration

Dual NF trains are arranged in 2 x 50% configuration containing Hydranautics ESNA1-LF2-LD membranes. A 2:1 array with six NF membranes per tube produces the required 11.5m^3/hr (3.2L/s) permeate flow per train at a flux rate of 17.3LMH. Projections indicated that the initial design recovery rate of 80% required antiscalant dosing so, to avoid environmental discharge of chemicals, a final recovery of 70% was selected.

These low fouling NF membranes were selected on the basis of providing near-total colour and organics removal while minimising TDS and, in particular, hardness rejection. Standard NF membranes were considered to reject too much TDS whereas these LF2 membranes, the 'loosest' commercially available membranes, allow significantly more TDS passage and minimise the requirement for downstream remineralisation and stability control.

Hydranautics ESNA1-LF2-LD membranes employ a range of chemical agents for cleaning. These include high pH cleans with caustic soda and low pH cleans with citric acid while the addition of specialist chemicals for scaling and fouling issues is facilitated through a powder eduction system. Due to the small three-tube system design both stages are cleaned concurrently in series. To facilitate this, the flow through Stage 1 is kept at the low end of its acceptable range while Stage 2 flow is at the upper end.

Pathogen LRV

The WTP was required to achieve the following minimum log reduction values (LRV) of pathogens:

A contact time of several days in the 1ML Clearwater Tank, combined with a chlorine top-up and a tank mixing recirculation system that maintains the residual in the 0.8-1.0mg/L range, ensures a CT in the hundreds, eclipsing the 18.7mg.min/L required for the 3LRV virus inactivation.

The final design provided far in excess of the target LRV values and, while UV disinfection was not required from an LRV perspective, TasWater elected to include a validated system for additional safety and as a best-practice measure.

Table 2. Treatment System LRV Values

Parameter	Cryptosporidium Log Removal	Virus Log Removal	Bacteria Log Removal	Critical Limit
MINIMUM LRV	2.5	3.0	5.0	
Ultrafiltration	4.0	2.0	4.0	
UV Disinfection	3.0*	0	4.0	UV Dose: 40mJ/cm^2
Chlorination	0	3.0	3.0	CT ≥18.7mg.min/L
TOTAL	7.0	5.0	11.0	

*4-log ONorm validated UV granted 3-log cryptosporidium inactivation in accordance with USEPA guidelines

WTP Wastewater

The concentrate stream from the nanofiltration membrane trains is the main contributor of WTP wastewater. Other contributing streams are raw water strainer flush water, UF backwash washwater, filter backwash washwater, and WTP sample water. WTP wastewater is discharged downstream of the raw water source at South Pats River.

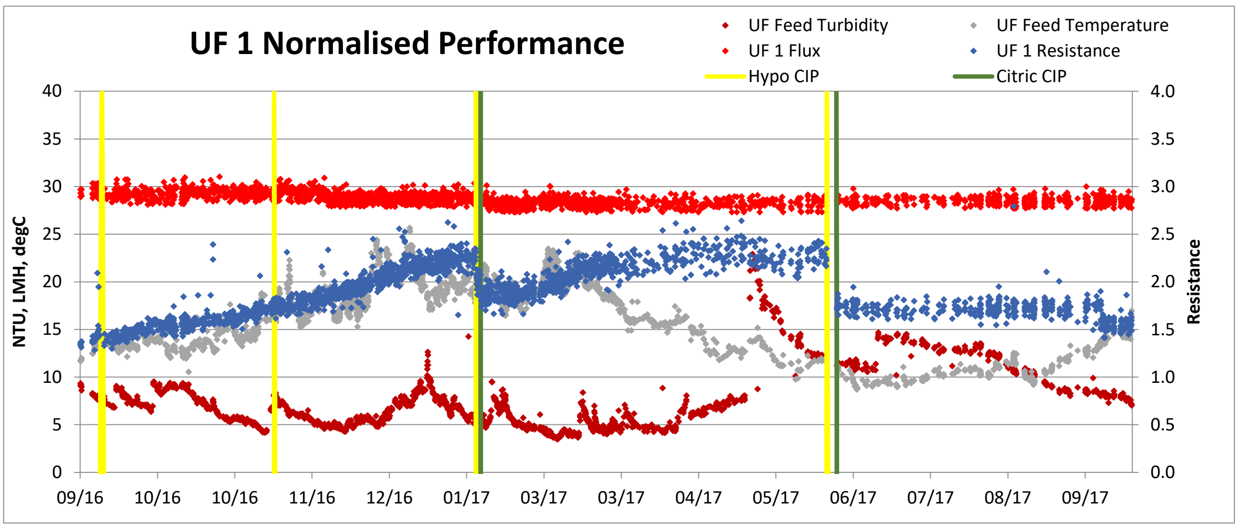
Plant Performance

The WTP commenced network supply in September 2016 and recently completed its first year of operation. In this period the plant operated stably with the need for little operator intervention. Moderate raw water quality conditions provided for stable initial performance.

Over the summer/autumn period in early 2017 a prolonged period of no rainfall, combined with unknown network leaks, resulted in a water shortage crisis at Whitemark and projected demand indicated that all available feed water would be consumed before the seasonal rainfall period returned.

To counter this situation, concentrate discharge was redirected to Pats Weir for blending and pumping to the 27ML raw water basin for retreatment. Additionally, water cartage commenced from the Lady Barron WTP (the only other WTP facility on Flinders Island). This water was added to the raw water supply to buffer the TDS increase from the concentrate recycling. Nonetheless the feed TDS increased from around 700mS/cm to over 1400mS/cm over a 2-3 month period.

A focused leak identification and repair program over this period decreased network consumption by over 50%, helping to cease water cartage and alleviate the crisis prior to any supply interruption to consumers.



Ultrafiltration Membrane Performance

Over the first 12 months of operation the UF trains initially experienced a steady increase in resistance but, after backwashing and cleaning optimisation, have operated stably since the end of the concentrate recycling period when raw water TDS and organics have steadily decreased. A cleaning cycle in May 2017 reduced resistance back to near-new membranes levels and operation since that period has been extremely stable.

The expected CIP interval of one month has not been required. While frequent chlorine CIPs were initially performed, this was part of the commissioning and performance testing period and once this period concluded CIPs have been performed at far greater intervals. Current indications are that two to three CIP cycles will be required per year although this is likely to increase as network demand rises over time.

While chlorine CIPs were expected to form the majority of cleans, low pH CIPs have proven extremely effective. Given the stable performance of the UF without the need for frequent cleans the results of recent cleaning cycles suggest chlorine/low pH CIPs be performed as a combination when cleaning is required.

Only one single membrane fibre breakage has occurred in the first year of operation. This was detected by the automated daily pressure decay test and the fibre was quickly and easily pinned.

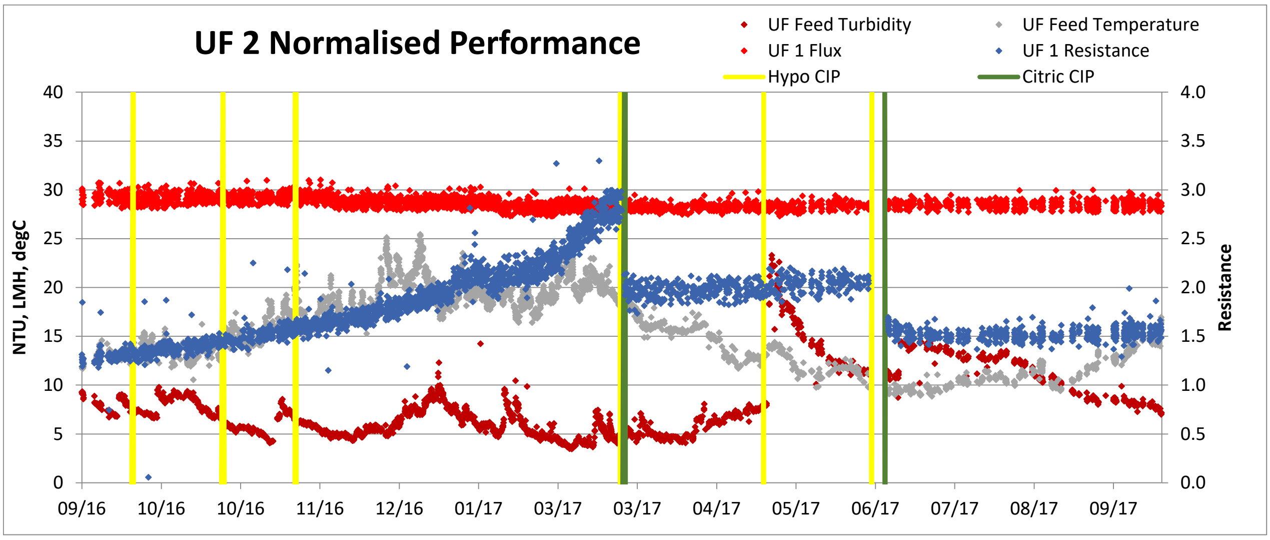
Nanofiltration Membrane Performance

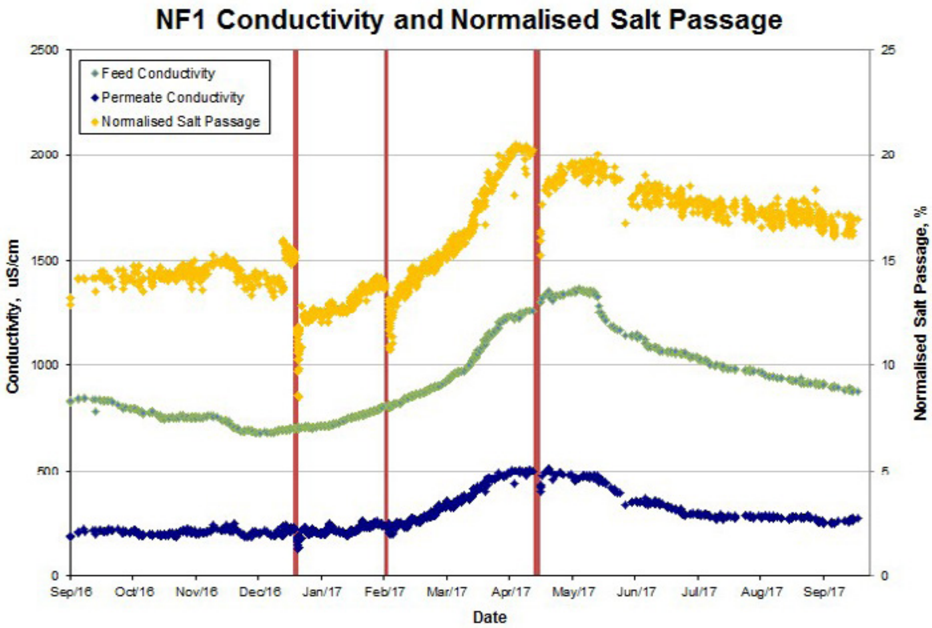
From startup of NF operation, normalised DP rose slowly but steadily, in line with expectations. NF Train 1 was loaded and commissioned prior to Train 2 and since the early phase of production the NF1 normalised DP was approximately 0.1 bar higher than that for NF2, remaining slightly elevated since then. CIP cycles have not eliminated this gap, possibly indicating that some start-up exposure to residual particles has occurred. The initial CIP cycle on NF1 also operated at a flow rate greater than used in subsequent cleans, possibly leading to some foulants being stripped and plugged within Stage 2.

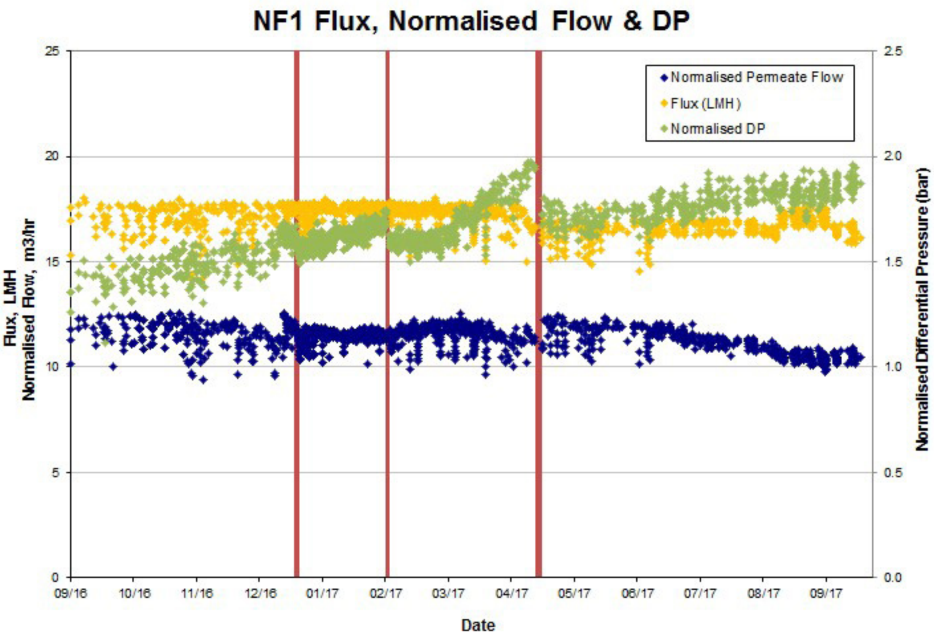
From March to May 2017 the impact of concentrate recycling became noticeable both in terms of EC and normalised DP. A feed water analysis during this period indicated that the $BaSO_4$ scaling threshold was being exceeded and the recovery rate was decreased to 67% to prevent ongoing scaling. Nonetheless the raw water quality continued to deteriorate, as did NF performance, until rainfall resumed in May 2017.

The impact of this period of concentration recycling is stark in the long term trends for both trains (Figure 3 & 4). NF performance was carefully monitored across this period to limit any deleterious impact of the feed quality. When rainfall occurred and Pats Weir quality improved markedly, the buffering in the 27ML raw water basin limited the rate at which feed quality to the WTP actually improved.

Nonetheless, when the peak passed and EC began decreasing, an intensive cleaning cycle was performed in May 2017. While this did not return both trains to start-up levels, the decrease was in the order of 0.15 bar on each train. In the four months of operation since that period,





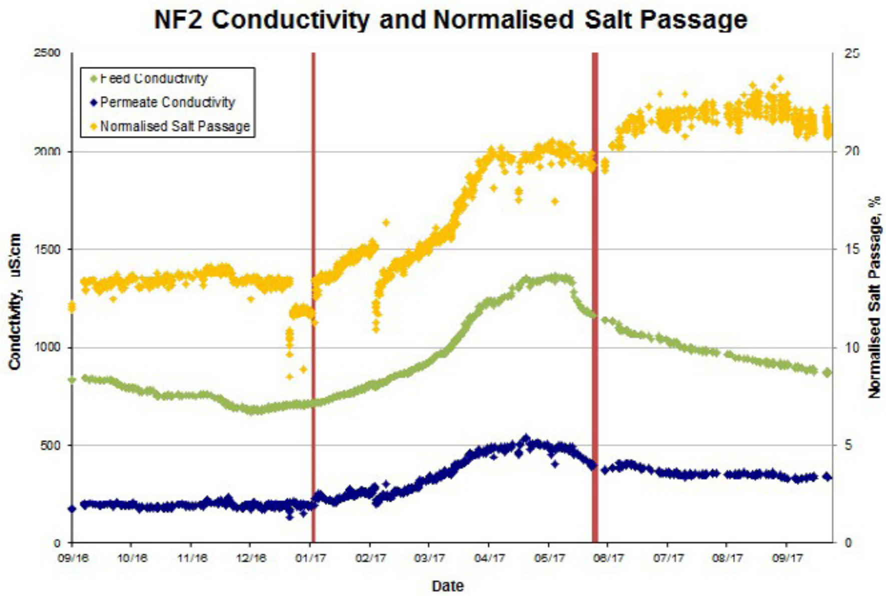


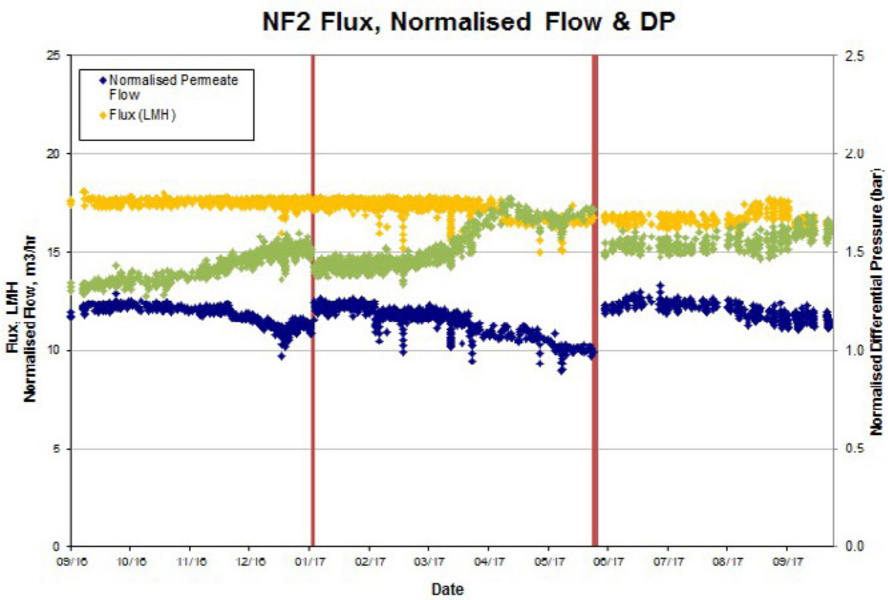
normalised DP has again risen at a slow rate and remains below the levels prior to the last CIP. On current trends each train should operate greater than 6 months before the next CIP is required.

Salt passage has increased to around 17% on NF1 and 22% on NF2 since startup however this is not considered undesirable, with treated water EC in the order of 200-400mS/cm providing acceptable TDS levels.

Treated Water Quality

Monthly water analyses performed over the operating year of the WTP are presented below. While true colour and DOC are slightly reduced through ultrafiltration the NF membranes provide complete removal to below detection levels. This achieves a major treatment objective without the need for the downstream GAC filters.





As a result it is anticipated that the GAC media will only encounter trace levels of residual organics over time, significantly prolonging the life expectancy of the media. Furthermore, total elimination of colour and TOC compounds prevents the formation of trihalomethanes (THMs) or other disinfection byproducts (DBPs).

The dissolved metals are similarly eliminated through the UF/NF process. Ultrafiltration provides moderate reduction in these parameters however nanofiltration then reduces all levels to near or below the limits of detection. No oxidation or chemical-driven processes are required to achieve this reduction and the only waste streams returned to the environment are UF backwash water, NF concentrate and minor strainer flush and sample water flows.

All water parameters met ADWG requirements and the plant-specific performance targets. A prolonged network cleaning and testing regime, commenced during WTP commissioning, found no pathogens in the network following commencement of supply from the new WTP. As a result the Public Health Alert – Do Not Consume notice was lifted in November 2016, marking the first time the water was deemed suitable for consumption in Whitemark.

True Colour (PtCo)	95%ile limit: ≤ 5		
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	199	180	<5
9/11/2016	166	160	<5
7/12/2016	225	188	<1
11/01/2017	296	222	<1
8/02/2017	259	189	<1
8/03/2017	238		<1
5/04/2017	208	138	<1
3/05/2017	177		<1
7/06/2017	167	131	<1
5/07/2017	174		<1
2/08/2017	165		<1
13/09/2017	161		<1
4/10/2017	164		<1

DOC (mg/L)		100%ile limit: ≤ 4	
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	24.0	24.0	<0.3
9/11/2016	23.0	22.0	<0.3
7/12/2016	23.6	23.8	<0.3
11/01/2017	29.1	27.2	<0.3
8/02/2017	27.6	25.1	<0.3
8/03/2017	26.8		<0.3
5/04/2017	27.6	25.8	0.3
3/05/2017	27.3		<0.3
7/06/2017	26.5	25.6	<0.3
5/07/2017	24.7		<0.3
2/08/2017	25.7		<0.3
13/09/2017	26.2		<0.3
4/10/2017	23.5		<0.3

Total (Dissolved) Iron (mg/L)	95%ile limit: ≤ 0.1		
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	0.83 (0.39)	0.17 (0.17)	<0.02
9/11/2016	0.64 (0.38)	0.14 (0.14)	<0.02
7/12/2016	0.85 (0.65)	0.22 (0.21)	<0.0005
11/01/2017	2.10 (1.74)	0.54 (0.54)	<0.0005
8/02/2017	2.54 (1.46)	0.27 (-)	<0.0005
8/03/2017	2.52 (2.25)		<0.0005
5/04/2017	2.36 (2.11)	0.40 (0.38)	<0.0005
3/05/2017	1.26 (-)		0.0005
7/06/2017	1.61 (1.18)	0.20 (0.19)	<0.0005
5/07/2017	1.23 (0.14)		0.0007
2/08/2017	0.83 (0.70)		<0.0005
13/09/2017	0.94 (0.68)		<0.0005
4/10/2017	0.92 (0.69)		<0.0005

Total (Dissolved) Aluminium		(mg/L) 95%ile limit: ≤ 0.1	
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	0.97 (0.33)	0.25 (0.24)	<0.008
9/11/2016	0.56 (0.28)	0.20 (0.20)	<0.008
7/12/2016	0.69 (0.47)	0.31 (0.30)	0.002
11/01/2017	0.68 (0.52)	0.24 (0.24)	<0.001
8/02/2017	0.69 (0.36)	0.07 (0.06)	<0.001
8/03/2017	0.44 (0.32)		0.001
5/04/2017	0.34 (0.22)	0.06 (0.06)	<0.001
3/05/2017	0.32 (0.18)		<0.001
7/06/2017	0.93 (0.17)	0.08 (0.08)	<0.001
5/07/2017	0.55 (0.14)		0.001
2/08/2017	0.88 (0.24)		<0.001
13/09/2017	1.13 (0.25)		<0.001
4/10/2017	0.89 (0.29)		0.003

Total Manganese (mg/L)	95%ile limit: ≤ 20		
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	17 (4)	1 (1)	<1
9/11/2016	16 (5)	<1 (<1)	<1
7/12/2016	18 (9)	4 (3)	<1c
11/01/2017	22 (14)	16 (16)	1
8/02/2017	32 (8)	5 (4)	1
8/03/2017	27 (13)		<1
5/04/2017	21 (10)	1 (<1)	<1
3/05/2017	20 (9)		<1
7/06/2017	9 (5)	2 (2)	<1
5/07/2017	11 (2)		<1
2/08/2017	11 (6)		<1
13/09/2017	11 (5)		<1
4/10/2017	12 (4)		<1

Total Lead (mg/L)		95%ile limit: ≤ 1.0	
Date	**Raw Water**	**UF Filtrate**	**NF Permeate**
19/10/2016	<0.5 (<0.5)	<0.5 (<0.5)	<0.5
9/11/2016	<0.5 (<0.5)	<0.5 (<0.5)	<0.5
7/12/2016	0.4 (0.5)	0.1 (<0.1)	<0.1
11/01/2017	0.6 (0.3)	<0.1 (<0.1)	<0.1
8/02/2017	0.6 (0.2)	0.2 (<0.1)	<0.1
8/03/2017	0.4 (0.3)		<0.1
5/04/2017	0.5 (0.4)	<0.1 (<0.1)	<0.1
3/05/2017	0.5 (-)		<0.1
7/06/2017	0.4 (0.2)	<0.1 (<0.1)	<0.1
5/07/2017	0.4 (<0.1)		<0.1
2/08/2017	0.4 (0.2)		<0.1
13/09/2017	0.5 (0.2)		<0.1
4/10/2017	0.4 (0.2)		<0.1

Chemical and Power Usage

Over the operational year, the Whitemark WTP produced an average of 198kL/d of treated water at an overall WTP recovery of 63.8%. The UF system recovery was 92.4% while the NF operated at 69.2% recovery, reflecting the temporary 67% recovery setpoint during the concentrate recycling period.

The specific energy consumption was 1.24kWhr/kL and chemical consumption was far below the process guarantees, reflecting the far longer intervals between CIPs for both membrane systems.

CONCLUSION

The Whitemark WTP has supplied safe, reliable water to consumers for the past year. All water quality parameters have remained well within the target limits throughout the operating life of the plant. Membrane performance has been extremely stable and trouble-free, with only one broken UF fibre and far less frequent UF and NF CIPs than the design forecast.

The plant has been exposed to major water temperature and quality variations without the need for significant operational adjustments. As raw water quality deteriorated due to concentrate recycling over the severe water shortage event the NF system maintained acceptable permeate quality without needing additional CIPs, allowing the WTP to maintain supply of fully-compliant treated water.

Environmental discharge of WTP waste includes minimal residual chemicals due to the chemical-free process stream and infrequent CIPs. Most CIP waste is neutralised and returned for dilution in the raw water basins for eventual retreatment, while specialty biodegradable NF CIP chemicals are stored for a minimum of 28 days to allow for full degradation to occur before being discharged to environment.

The low rejection NF membranes allowed a moderate and desirable passage of EC whilst achieving colour and DOC removal to below detectable levels, resulting in minimal load on the GAC media and eliminating DBP precursor compounds from the permeate. Target dissolved metals have also been reduced to trace levels without the need for pre-treatment chemicals or oxidative processes.

The low fouling NF membranes have proven beneficial in minimising organic fouling. The two NF trains underwent three and two CIPs respectively, and current operation indicates 6-monthly CIP intervals will be sufficient under normal conditions. While monthly UF CIPs were projected, intervals of three-six months are now occurring.

THE AUTHORS

Richard Tarr is a senior process engineer specialising in low and high-pressure membrane treatment processes. Richard has over 20 years of professional experience in water and wastewater engineering, having been involved in design, delivery, commissioning and operation of numerous municipal and industrial water, wastewater and Class A plants. Richard holds a Master of Engineering Science (Research) and a Bachelor of Engineering (Mech) from Melbourne University and was awarded a Churchill Fellowship in 2003 to investigate new developments in desalination and wastewater recovery membrane treatment techniques.

Peter Kafieris is a Process engineer with Laurie Curran Water with 5 years' experience in the water industry which included design, project engineering and commissioning roles on a number of water and wastewater projects. Peter holds a Bachelor of Engineering (Chem) from RMIT.

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WHITEMARK WTP CLIENT SPECIFICATION VOLUME 2