ACHIEVING ZERO EFFLUENT PHOSPHORUS – THE MEMBRANE TREATMENT SOLUTION

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ABSTRACT

Googong Township is a new residential property development located near Queanbeyan, which is south east of Canberra, Australia. The Township has adopted an Integrated Water Cycle (IWC), with the primary objective being to ensure sustainable use of water. At the heart of the IWC strategy is the state-of-the-art Googong Water Recycling Plant (WRP).

The WRP has a relatively tight effluent phosphorus limit of 0.5 mg-P/L and also has a restriction on total dissolved solids (TDS) in the effluent of 700 mg/L. The semi-closed loop water cycle in the township leads to accumulation of non-biodegradable dissolved solid compounds which pose a challenge in achieving the licence limits, with traditional mechanisms for achieving very low phosphorus limits being reliant on chemical dosing which is inherently a source of additional TDS.

In order to meet this challenge a new approach was taken comprising 3 point dosing with sequential membrane separation processes in order to achieve low phosphorus, with minimal chemical addition. The plant has now been operational for over 1 year and operational data to date has demonstrated exceptionally low phosphorus limits may be achieved with average effluent concentrations less than 0.05 mg/L. In fact, the effluent quality is so low that one of the on-going tasks has been to optimise the plant to further reduce chemical consumption.

This technical paper outlines the design approach to achieving a low phosphorus effluent from the WRP which included network TDS modelling to optimise the usage of recycled water and the WRP plant design. The paper presents operational data from the first year of operation which demonstrated exceptionally low phosphorus levels without compromising the TDS quality and also explores the mechanisms for optimising chemical use whilst achieving 'Zero Effluent Phosphorus'.

KEYWORDS

Membrane Bioreactor, MBR, Water Recycling Plant, TDS, Phosphorus

PRESENTER PROFILE

John is a chartered chemical engineer with over 13 years' experience. He is currently Stantec's Asia Pacific Process Discipline Leader and his key areas of professional interest are wastewater treatment and odour management. He has worked on a broad range of projects from strategy development to detail design and commissioning. John and his family recently relocated to sunny Dunedin, after 8 years with MWH/Stantec in Sydney, Australia.

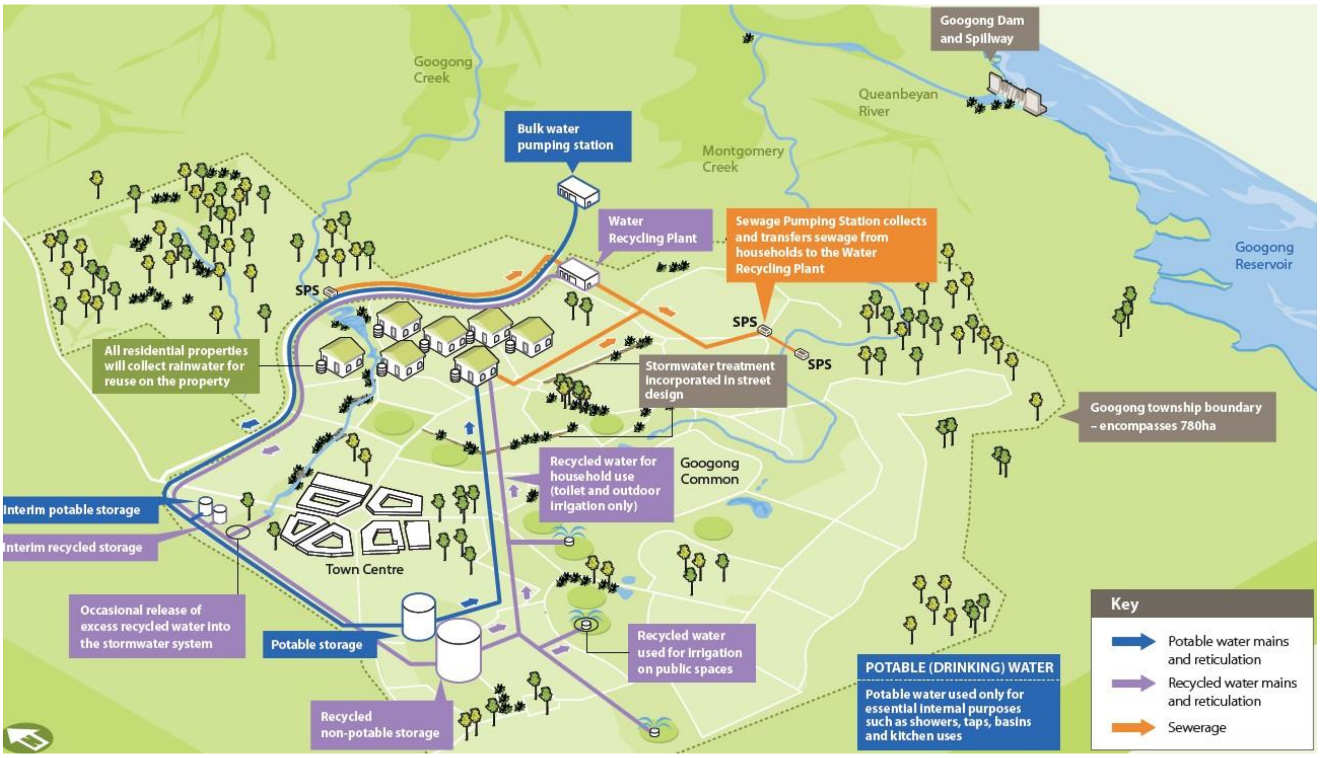
1 INTRODUCTION

Phosphorus is ubiquitous in wastewater. When harnessed appropriately, it can be reclaimed as a major resource, particularly for the agricultural industry. Uncontrolled release of phosphorus into waterways, however, could lead to a stressed ecosystem and potential eutrophication which may be fatal to the local aquatic life.

Achieving lower phosphorus level in wastewater effluent is an increasingly important issue for inland townships, particularly those which discharge to sensitive river ways. Tighter limits for phosphorus (e.g. 0.1-0.5 mg-P/L) are becoming a norm for more wastewater treatment projects across the world. For example for new discharges to the Hawkesbury-Nepean Rivers in metropolitan Sydney, environmental regulators are starting to impose conditions such as “no additional phosphorous load”, because the river system is known to be sensitive to phosphorous-induced algal blooms.

The new township of Googong is located approximately 25 km south-east of Canberra, Australia, within the Queanbeyan region. The township will ultimately be home to 18,000 people and has been designed with a dedicated recycled water supply from the new Water Recycling Plant (WRP) for outdoor irrigation and toilet flushing. This reduces the average water consumption to approximately 40-45% of a typical Australian township. A schematic of the Googong Integrated Water Cycle is presented in Figure 1.

Figure 1: The Googong Integrated Water Cycle



The new Googong WRP is owned and operated by Queanbeyan-Palerang Regional Council (QPRC). The WRP utlises a Membrane Bioreactor (MBR) technology combined with tertiary membranes, UV disinfection and chlorination to produce recycled water for non-potable reuse in the township (see Photograph 1). The dedicated recycled water use results in a semi-closed water cycle and recycled water produced by the WRP is returned to the facility as a portion of the influent. Consequently, non-biodegradable compounds such as most dissolved solid will accumulate. It is therefore important to consider phosphorus and Total Dissolved Solids (TDS) together to ensure compliance with the effluent licence limits.

Photograph 1: Membrane bioreactor at the Googong Water Recycling Plant

2 DESIGNS TO MINIMISE EFFLUENT PHOSPHORUS AND TDS

Conventional methods are currently available to achieve the effluent phosphorus limit of 0.5 mg-P/L. The main approach includes chemical precipitation and enhanced biological phosphorus removal. In both cases, phosphorus is removed from the system as bound particulate compounds.

The initial method proposed at Googong WRP was based on multi point chemical dosing. Iron salt is dosed to the bioreactor followed by alum dosing prior to the tertiary ultra-filtration (UF) membranes. The first dosing points aim to achieve a target of 1 to 2 mg-P/L while the subsequent polishing step reduces effluent phosphorus to less than 0.5 mg-P/L. This is a proven approach employed at most of Sydney Water's inland wastewater treatment plants. The addition of iron salt and alum, however, introduce chloride and/or sulphate compounds which elevate TDS in the recycled water.

In order to meet the effluent TDS limit, a number of additional measures to the conventional approach was undertaken at Googong WRP. These include the following measures:

- Establishment of a water balance based TDS model to elucidate the amount of chemicals that could be added without breaching the TDS limit in a semi-closed water cycle.

- The use of membrane technologies to further remove phosphorous in the colloidal forms.

- Incorporation of enhanced biological phosphorus removal (EBPR) mode in the design of the bioreactor to minimise the addition of chemicals for the precipitation of phosphorous.

- A multi-point dosing approach to improve efficiency in chemical use for phosphorous removal.

At the time of writing, the WRP is operating under a 4-stage Bardenpho configuration and the results of this paper reflect this operation.

3 TDS MODELLING

A TDS model was created to simulate the dynamics of non-biodegradable compounds in the Googong water cycle. The model marries a traditional water balance model with an iterative, semi-closed loop salt balance model, thus enabling various scenarios to be explored in terms of the extent of recycled water supply to the township.

An overview of the TDS model is presented in Figure 2. The background water balance model was based on 40 years of climatic data for the Canberra region and water demand prediction for the proposed development mix of the Googong Township. The key outcomes of the TDS modelling include:

- Elimination of machine washing as one of the end uses for recycled water.

- Direct plumbing of recycled water to household backyards for garden irrigation. This maximises the use of recycled water (and thus the associated TDS) onto land.

- Determination that phosphorus precipitating chemicals (alum and/or iron salts) are one of the major contributor to TDS in the effluent and its management is key to achieving the effluent TDS limit.

- Process decisions on the chemical dosing design at the WRP, with dosing of ferric and alum at three locations to maximise efficiency and minimise excess dose:

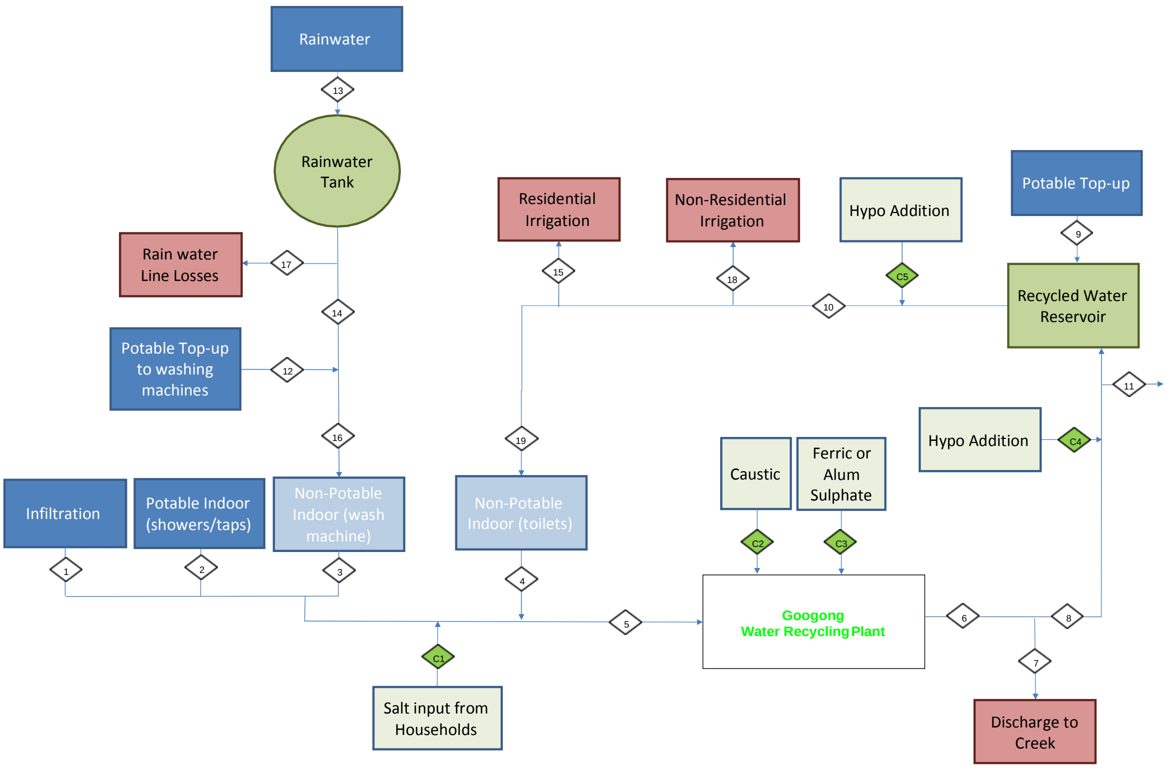
    - Dosage of ferric sulphate at the sewer main, prior to the inlet works

    - Dosage of ferric sulphate in the membrane bioreactor (MBR)

    - Dosage of alum prior to a set of ultrafiltration membrane trains

The TDS model was a critical tool used to inform the development of Googong’s integrated water cycle. By incorporating live operational data, the model can also be verified and used as assistance in operational decision-making.

Figure 2: Schematic Diagram of Googong Township's water and TDS balance models



4 OPERATIONAL OUTCOMES

4.1 PHOSPHORUS REMOVAL EFFICIENCY

In early 2016, the Googong WRP was successfully commissioned and underwent 90-day performance verification testing. At the time of writing, the plant has been in operation for over a year following handover to QPRC. Daily grab samples are collected by the plant operators from the MBR filtrate and effluent streams while influent samples are collected monthly as 24-hour composite samples. The phosphorous levels in the wastewater feed, MBR filtrate and final effluent over the commissioning and operating periods are shown in Figure 3 and 4, respectively.

Feed phosphorus has increased from around 10 mg-P/L during commissioning up to 14 mg-P/L in December 2016. Outcomes from the project to date demonstrated that median phosphorus level as low as 0.01 mg- P/L was achieved during commissioning, with longer term operating median of 0.03 mg-P/L being observed. This corresponds to 99.9% removal of phosphorus and the effluent quality is well within the licence limit of 0.5 mg-P/L on a 90th percentile basis.

In terms of chemical consumption, the total molar doses of ferric and alum is estimated to be around 2.3:1 when compared to the moles of phosphorous removed from the wastewater. The calculated molar dose is checked against measurement of sulphate increase across the WRP. This is significantly better than the molar ratios quoted in the literature (Metcalf & Eddy, 2003) for attainment of the very low phosphorus levels, where molar ratios up to 4.5:1 is quoted. Examination of the data suggests that the following are key contributing factors for the high chemical efficiency:

- Multi point dosing of chemical prior to a solid separation step, which facilitates different ways to optimise chemical dosage

• Tight pore sizes of the filtration membranes remove colloidal phosphorous compounds and allows for very low filtrate phosphorus levels.

• Recycling of alum precipitates back to the bioreactor to facilitate a "secondary" precipitation of phosphorus with alum in the bioreactor

• Managing sludge return liquor rate to prevent shock loading of high phosphorus centrate on treatment processes

In addition to the above factors, the Googong WRP has the option to utilise EBPR in the future to further reduce chemical use.

Figure 3: Phosphorous levels at different parts of Googong WRP (commissioning)

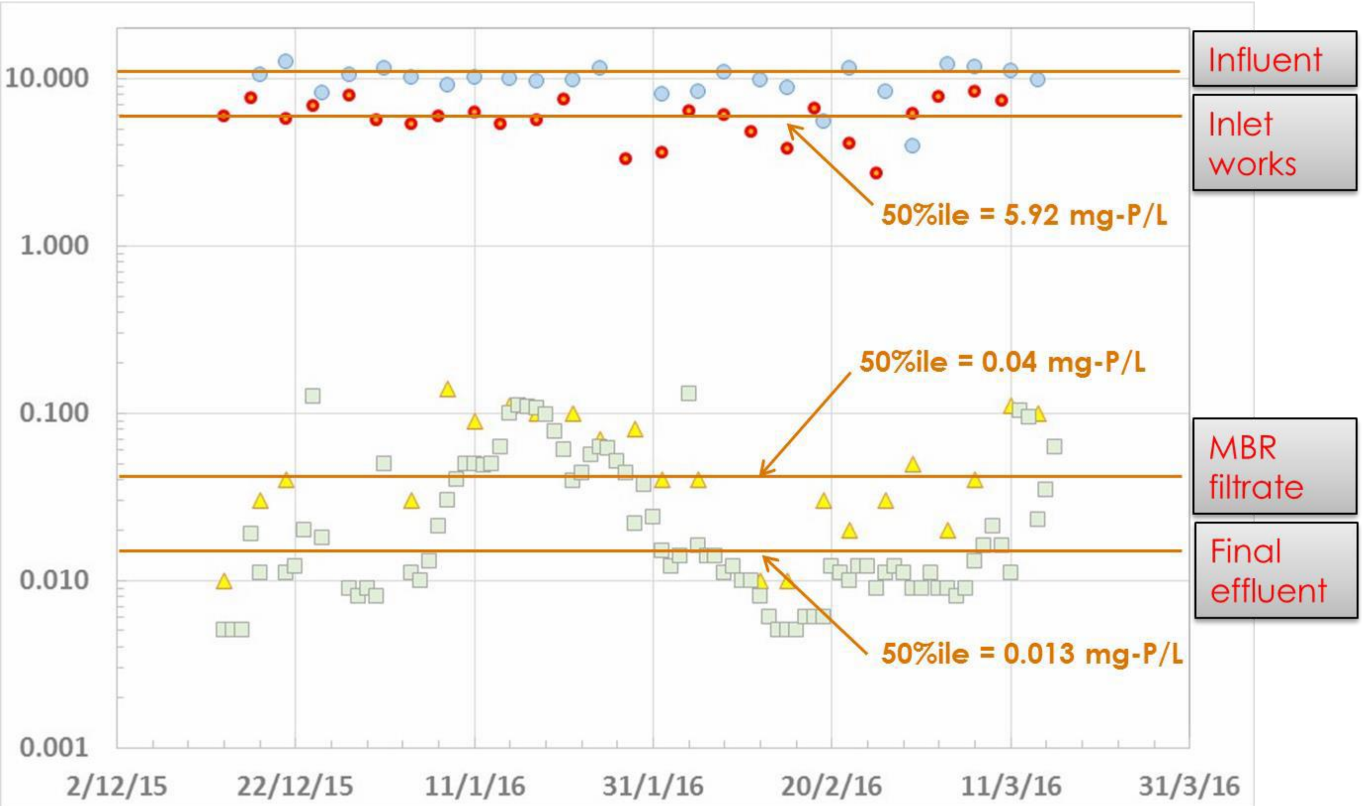
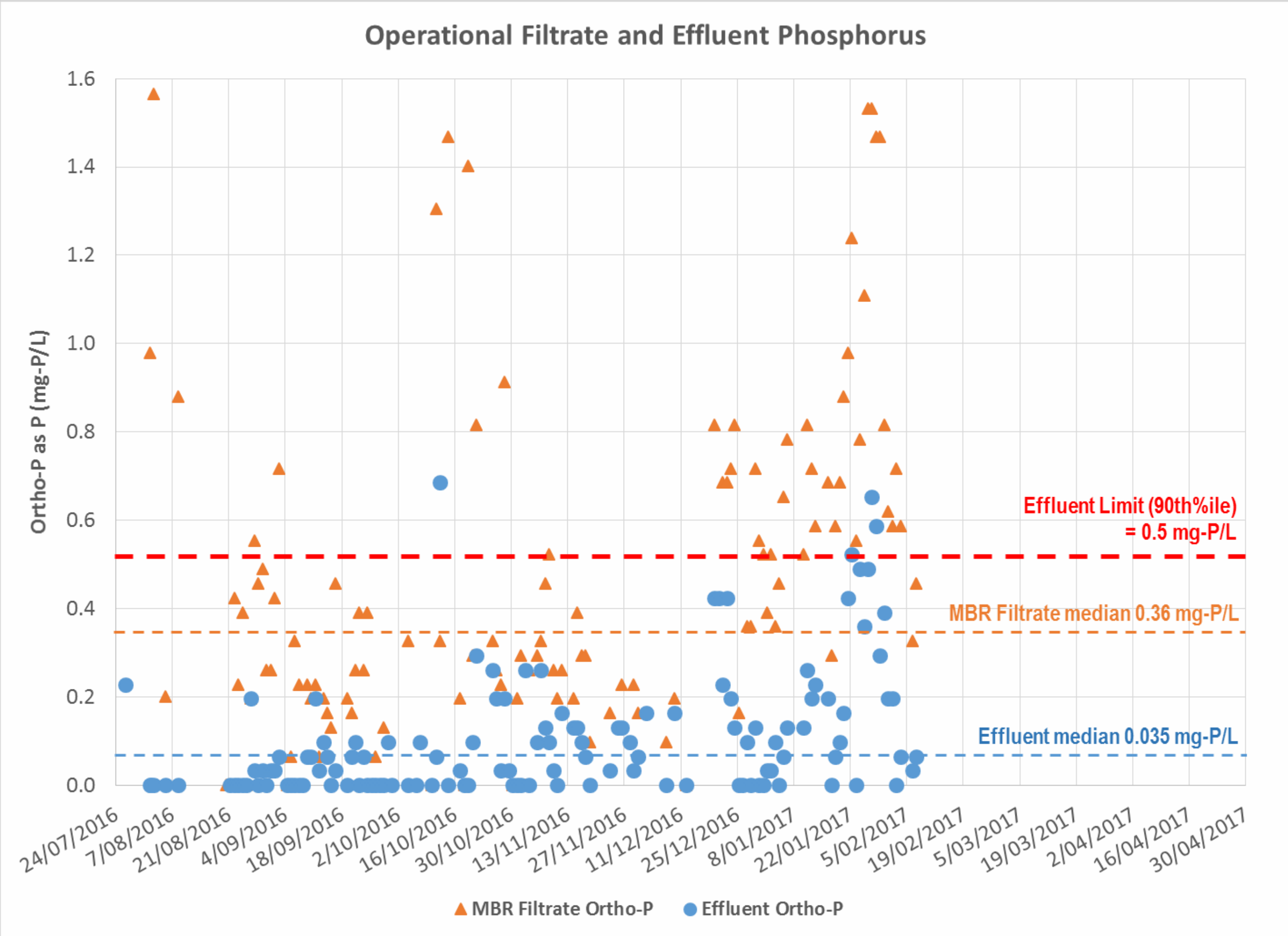


Figure 4: Operational phosphorus level in MBR filtrate and effluent streams (Aug'16 to Feb'17)



4.2 TDS Management

A summary of the Googong WRP operational TDS balance is shown in Table 1. Chemicals used in phosphorus removal stands out as the biggest contributor of TDS in the effluent, adding on average 75 mg/L of dissolved solids in the form of sulphate (SO4) to the treated wastewater stream.

Table 1: TDS balance across Googong WRP

Process	Influent (mg/L)	Effluent (mg/L)	Difference (mg/L)
P removal	31 (PO4)	106 (SO4)	+75
N removal	64 (NH3)	4 (NO3)	-60
Disinfection & membrane cleaning	-	17 (Na) 12 (Cl)	+29
Bicarbonate	311 (alkalinity)	63 (alkalinity)	-151
Others (Mg, Ca)	26	28	+2
Total TDS impact:			**-105**

The high efficiency in chemical use has been key to the achievement of low TDS in the effluent, which was measured to be less than 400 mg/L. This is well within the 700 mg/L limit imposed on effluent TDS. Other initiatives that assisted with TDS management at the WRP include:

- Avoiding conservatively high dose rates during initial commissioning. This also led to fewer iterations when optimising the chemical doses.

- Daily monitoring of key nutrients from the MBR filtrate and final effluent streams via on-site lab which allowed for faster response to variations (e.g. seasonal).

5 CONCLUSIONS

Overall the Googong project points to a new way to achieve lower effluent phosphorus while managing TDS increase through minimising the use of chemicals. The new Googong WRP is capable of achieving very low phosphorus (<0.1 mg-P/L) limit with TDS constraints (<700 mg/L) through a combination of conventional and new approaches.

Lessons learnt from this project, specifically the development of a TDS model, multi-point dosing and utilising recycle streams to maximise chemical efficiency, could be beneficial for other projects that face similar challenges to meet near-zero phosphorus limits and TDS constraints in the wastewater effluent.

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