Managing the reverse osmosis concentrate from the Western Corridor Recycled Water Scheme

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Abstract: The Western Corridor Recycled Water Scheme consists of three advanced water treatment plants (AWTPs), with the combined capacity to recycle 232 ML/d. Each AWTP process consists of pre-treatment, microfiltration (MF), reverse osmosis (RO), UV/peroxide advanced oxidation and chlorination. A key objective of the project is to improve the environmental health of regional waterways, particularly in relation to nutrient discharges. Reverse osmosis processes produce a concentrate stream (ROC), which is the main reject stream of the AWTPs. Options for management of ROC were assessed, and ultimate disposal to nearby waterways was the only feasible option identified. ROC flows for the scheme total 41 ML/d at full capacity, divided between the three AWTPs. The contaminants in this stream are generally 6 to 7 times more concentrated than in the feed water. Environmental risks were identified due to potential increased toxicity associated with these higher concentrations, which were exacerbated due to chlorine and ammonia dosed in the AWTP process. Target ROC contaminants have been identified as nitrogen, phosphorus, ammonia, metals and chlorine. The paper presents the selected toxicity management and nutrient reduction strategies for each AWTP, and the results of full-scale operation to date are also summarised.

Keywords: Membrane, nutrient reduction, recycling, reuse, reverse osmosis concentrate, toxicity

INTRODUCTION

The Western Corridor Recycled Water Scheme, located in South East Queensland, is one of the world's largest advanced water treatment projects, with the capacity to recycle 232 ML/d of water for industrial use, indirect potable use, and possibly irrigation (Traves *et.al.* 2008). The scheme is owned by WaterSecure, a Queensland state government statutory authority. Three advanced water treatment plants (AWTPs) contribute to the scheme, each consisting of pre-treatment, microfiltration (MF), reverse osmosis (RO), UV/peroxide advanced oxidation and chlorination processes (Poussade et.al. 2009). In addition to providing recycled water, another key objective of the scheme is to assist in improving the environmental health of regional waterways, particularly in relation to nutrient discharges.

Recycling of treated wastewater is often considered an option for reducing or eliminating the release of nutrients and other contaminants that would otherwise be discharged to waterways. While this may be the case with land irrigation of treated wastewater, the Western Corridor AWTPs (and most industrial and potable reuse water recycling applications) produce a major waste stream that still contains many of the original treated wastewater contaminants, as well as additional contaminants added in the recycling treatment process itself. This waste stream is the reverse osmosis concentrate (ROC). Currently, the release of ROC to nearby waterways is the only feasible disposal option identified and adopted, due to the high cost and the scale of alternatives (such as evaporation solutions).

As named, the waste from reverse osmosis (RO) membrane processes is also concentrated, and this concentration of contaminants may also lead to increased toxicity effects in the receiving environment. The contaminants in the ROC stream are generally 6 to 7 times more concentrated than in the RO feed, due to the high RO recovery rate of 85% adopted by the Western Corridor Scheme. ROC flows for the scheme total 41.5 ML/d at full capacity, divided between the three AWTPs; 11.6, 12.3 and 17.6 ML/d from Bundamba, Luggage Point (Luggage Point) and Gibson Island (Gibson Island) AWTPs respectively. The contaminated and concentrated nature of ROC presents challenges for developing and implementing adequate and sustainable recycling options. Nevertheless, while “zero discharge” options for ROC may be limited, potential impacts associated with the somewhat inevitable discharge of ROC can be minimised; both in the short and long-term.

This paper summarises the drivers for contaminant reduction, outlines the target contaminants identified, and presents the strategies developed for management of the target contaminants.

DRIVERS FOR CONTAMINANT REDUCTION

WaterSecure, through the Western Corridor Scheme, is committed and obligated to contribute to the minimisation of contaminants released through ROC discharges to receiving waterways and ultimately, Moreton Bay. The following strategic objectives have been adopted:-

- Reduce ROC contaminant concentrations and loads in general.
- Prioritise actions for contaminant reduction in accordance with the South East Queensland Healthy Waterways Strategy and Queensland Water Quality Strategy.
- Minimise acute or chronic toxicological effects at zero dilutions in the ROC discharge.

However, these commitments are tempered with the realisation that:-

- The main function of the Western Corridor Scheme is to produce recycled water and not provide further wastewater treatment.
- The AWTPs are the last step in a broader wastewater treatment process, but are dependant on the performance of other entities embedded within the treated wastewater "supply chain".
- The contaminant reduction achieved by the AWTPs only impacts the treated wastewater used for recycling, with any remainder continuing to discharge via the wastewater treatment plant (WWTP) releases.

Described below are the policy and regulatory drivers currently supporting and impacting upon the Western Corridor Scheme's commitment to reducing the impacts of ROC discharge.

South East Queensland Healthy Waterways Strategy

WaterSecure is a partner of the regional Healthy Waterways Strategy, which has identified nutrient reduction as the priority for the ecosystem health of the regions waterways. The strategy has set targets for nutrient reduction for point source discharges; the most relevant of these targets being:-

- 100% reduction of nutrient loads originating from point sources by 2026.
- Until the 2026 target is achieved, WWTP discharges limited to 50th percentile concentrations of 3 mgN/L total nitrogen and 1 mgP/L total phosphorus (and due to the concentrating effect, this equates to about 18 mg/L total N and about 7 mg/L total P in the ROC).
- At least 25% of nutrient loads from WWTPs to be removed by recycling or other means by 2012 (Healthy Waterways Strategy 2007-2012).

The actions in the Healthy Waterways Strategy place heavy reliance on recycling of wastewater to achieve the nutrient load reduction objectives, with an underlying assumption that recycling would lead to ultimate disposal of contaminants to land. Accordingly, the strategy appears to underemphasise issues associated with the disposal of concentrate waste streams where recycled water is purified for higher uses. However, Bundamba AWTP has shown that it is possible to achieve significant nutrient reductions, albeit at substantial capital and operating cost.

Development Approvals

The AWTPs all operate under discharge limits given in development approvals (DAs) negotiated with the Department of Environment and Resource Management (DERM). These limits reflect the Healthy Waterways Strategy nutrient targets, in addition to specific contaminant limits related to acute toxicity and identified through DTA testing (such as chlorine and ammonia concentration limits). The DAs also include requirements for monitoring of receiving environment impacts and ongoing continuous improvement in relation to reduction of contaminants in ROC.

Recognising that the Western Corridor Scheme has little control over incoming metal concentrations, strict compliance limits for metals have not been imposed through the DAs, with metal "trigger" levels set to implement an "event based" direct toxicity assessment (DTA) of a sample of the ROC with the elevated metal level. For example, metal trigger levels for lead, cadmium, inorganic mercury and zinc are set at 17.6, 2.8, 0.4 and 310 µg/L respectively. Routine DTAs are also undertaken to monitor ROC toxicity. DTA testing includes a 1-hour urchin fertilisation test, a 72-hour sea urchin larval development test, a 92-hour amphipod acute toxicity test, a 48-hour rock oyster larval development test and a 72-hour chronic algal growth toxicity test. Tests are performed on a 2-hour composite of 15-minute interval ROC samples.

State Water Quality Objectives

Water quality objectives for the AWTPs discharge waterway are set in the Environment Protection (Water) Policy 2008 and the Queensland Water Quality Guidelines 2006. These objectives apply to the water quality achieved in the receiving environment. They do not set Water Quality Objectives for metals for most locations in the waterway and reference is made to ANZECC 2000.

IDENTIFICATION OF TARGET CONTAMINANTS

Target ROC contaminants were selected with reference to the above drivers and the following:-

- Feed water quality data for each of the AWTPs, including assessment of chemical addition and process effects within the AWTPs.
- ROC monitoring data from pilot plants during the project delivery phase, and from each of the three full-scale AWTPs since commissioning.
- Results of direct toxicity assessment for ROC from pilot plants and the full-scale AWTPs.
- Receiving environment monitoring data.

Nutrients

Phosphorus. Figures 1 to 3 show that the phosphorus concentration of the treated wastewater feed to all AWTPs exceeds the current Healthy Waterways Strategy target of 1 mgP/L. As a consequence, without further reduction of phosphorus in the AWTPs, the discharge phosphorus load would exceed target levels. However, in addition to meeting ROC discharge requirements, phosphorus removal is also undertaken at the AWTPs to reduce the incidence of scaling on RO membranes and to achieve product water quality requirements. The optimal level of phosphorus in feedwater to avoid unacceptable levels of scaling depends on a number of factors including pH, the antiscalant being used, RO recovery rate and calcium concentrations in the feedwater. Targets of 1 to 2 mgP/L in the RO feed (resulting in about 7 to 14 mgP/L in the ROC) have generally been adopted by the Western Corridor Scheme in design, but the potential for higher levels of phosphorus to have adverse effects has not been tested.

Nitrogen. The following observations can be drawn from the nitrogen data given in Figures 1 to 3:

- The total nitrogen concentration in the Luggage Point ROC stream is relatively high compared to that of Gibson Island (28 mgN/L compared to 12 mgN/L), with about 63% of the Luggage Point ROC nitrogen existing as nitrate (13 mgN/L) and ammonia (5 mgN/L). This is due to substantially lower nitrogen in the feedwater from Gibson Island WWTP, which easily meets the Healthy Waterways target of 3 mgN/L (averaging 1.8 mgN/L); whereas the Luggage Point and Bundamba levels exceed the target (averaging 4.5 and 3.4 mgN/L respectively).

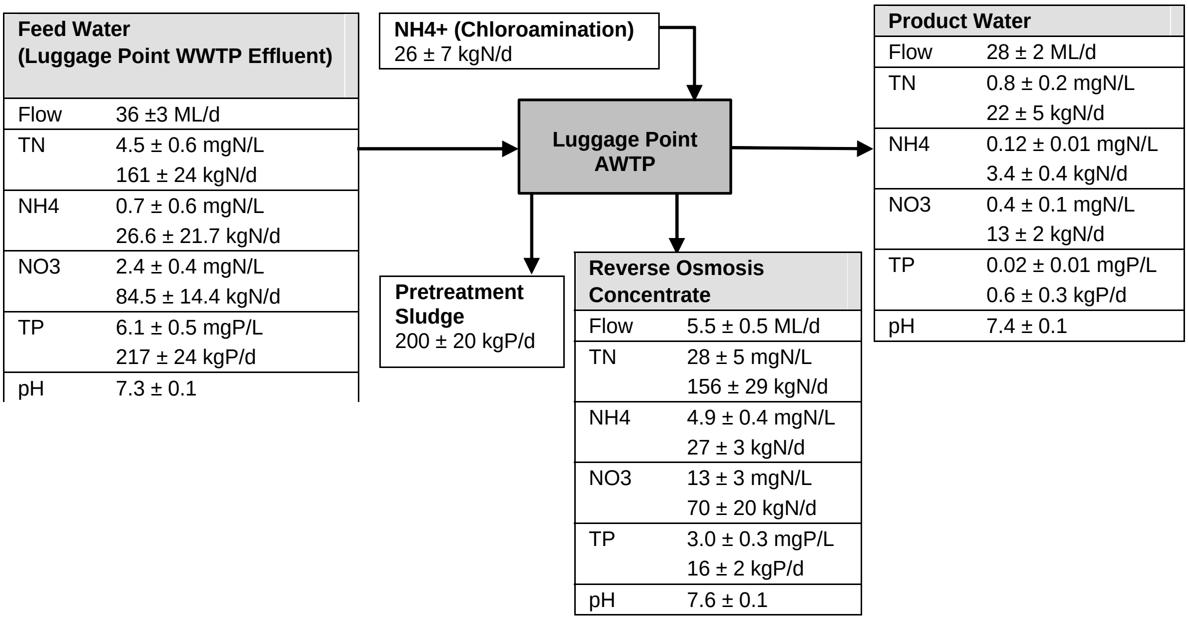

Figure 1: Nutrient mass balance for Luggage Point AWTP – August 2008 to February 2009.

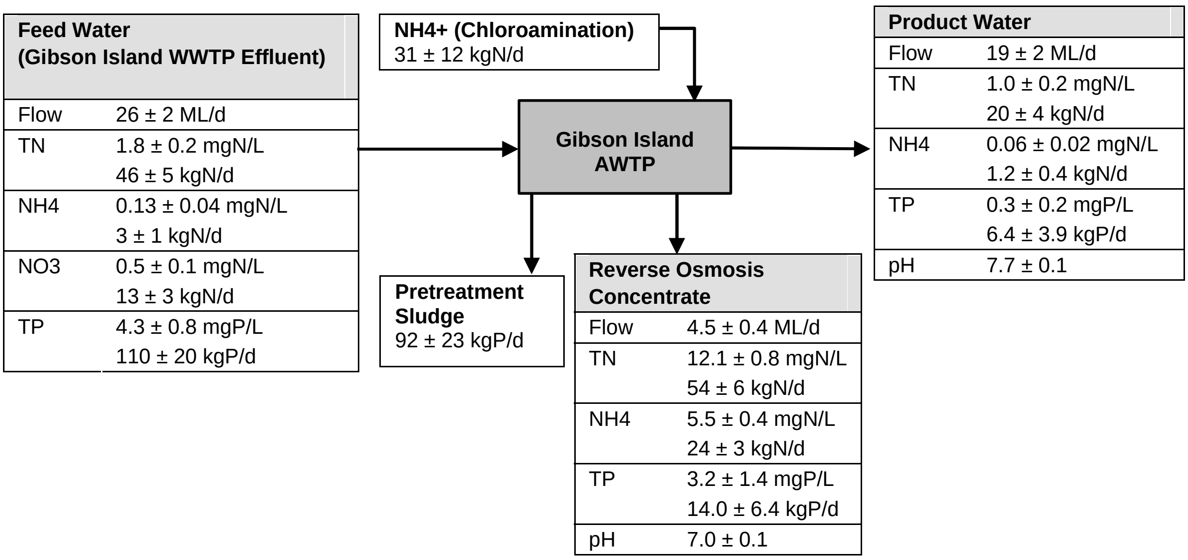

Figure 2: Nutrient mass balance for Gibson Island AWTP – August 2008 to February 2009

- About 15% of total nitrogen in feedwater remains in the AWTP treated water product and is transferred to the water supply system (Morgan 2008).
- Chloramination contributes considerable nitrogen to all three AWTPs. The added nitrogen may offset that removed with the feedwater dependant on the level of chloramine dosing. Gibson Island data shows a 17% increase between the feed and ROC load, while Luggage Point shows a 3% reduction. It should be noted that Luggage Point and Bundamba AWTPs are currently operating with chloramine dosing at near the lower limit of operation, and dosing can probably not be further reduced to lower the nitrogen load in the ROC.
- Across the Western Corridor Scheme there is approximately a 13% net reduction in nitrogen load between the treated wastewater feed and ROC discharge, which is nitrogen that would otherwise have been discharged to waterways. This is largely achieved through the nitrification/denitrification ROC treatment operating at the Bundamba AWTP.

- The ROC discharges from Bundamba and Gibson Island AWTPs meet the Healthy Waterways Strategy nitrogen target of 3 mgN/L (equivalent to 18 mgN/L in the ROC), but the Luggage Point AWTP does not.

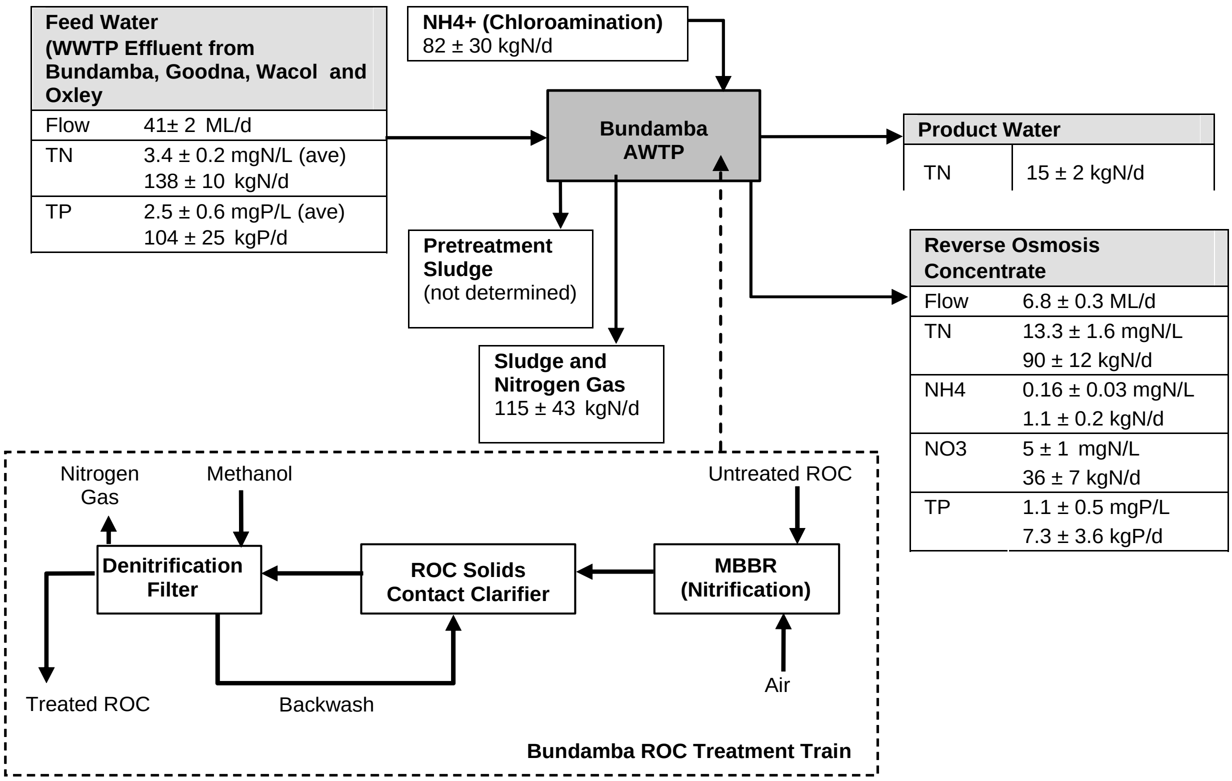

Figure 3: Nutrient mass balance for Bundamba AWTP – August 2008 to February 2009.

Toxicants

The direct toxicity assessment testing on ROC has shown that toxicity is generally quite low at Luggage Point and Bundamba, and in compliance with DA conditions. At Gibson Island, the DTA test results also comply with DA conditions, although toxicity levels were found to be higher than for the other AWTPs. Comparison of chemical analysis of ROC from Gibson Island, Luggage Point and Bundamba did not indicate any particular toxicants present in greater concentrations at Gibson Island than at the other two AWTPs.

However, toxicity assessment did identify metals, chlorine and ammonia as target contaminants. Toxicity testing data has further assisted in establishing allowable concentrations of these toxicants in the ROC discharge at each AWTP and also provided input to diffuser design to optimise near field mixing in the receiving environment.

MANAGEMENT OF CONTAMINANTS

Options for management of the target contaminants have been developed and will continue to be developed throughout the life of the Western Corridor Scheme. Already, toxicity has been addressed at all AWTPs through diffusion and through dechlorination of the ROC discharge (with sodium bisulphite dosing to the ROC).

Phosphorus

In comparison to the phosphorus loads otherwise discharged from the donor WWTPs, the ROC load is largely reduced due to phosphorus removal in all the AWTP's pre-treatment step. Phosphorus is reduced through ferric chloride dosing, flocculation/coagulation and plate clarifier solids separation upstream of MF. At Gibson Island, the Actiflo™ process is used in lieu of simple plate clarifiers.

Data given in Figures 1 to 3 shows preliminary nutrient mass balance data for each AWTP. Typical of the phosphorus removal performance is the Luggage Point AWTP trend shown in Figure 4. The data indicates about 80 to 90% phosphorus load reduction over all AWTPs that would otherwise have been released to waterways. The Healthy Waterways Strategy interim target of 1 mgP/L phosphorus (equating to 7 mgP/L in ROC) has been readily achieved at all three AWTPs.

The environmental benefits of this high level of phosphorus removal will be evaluated in relation to cost and other environmental effects of ferric chloride production and transport, waste sludge disposal, and effects of added metals through the dosing of ferric chloride and its impurities.

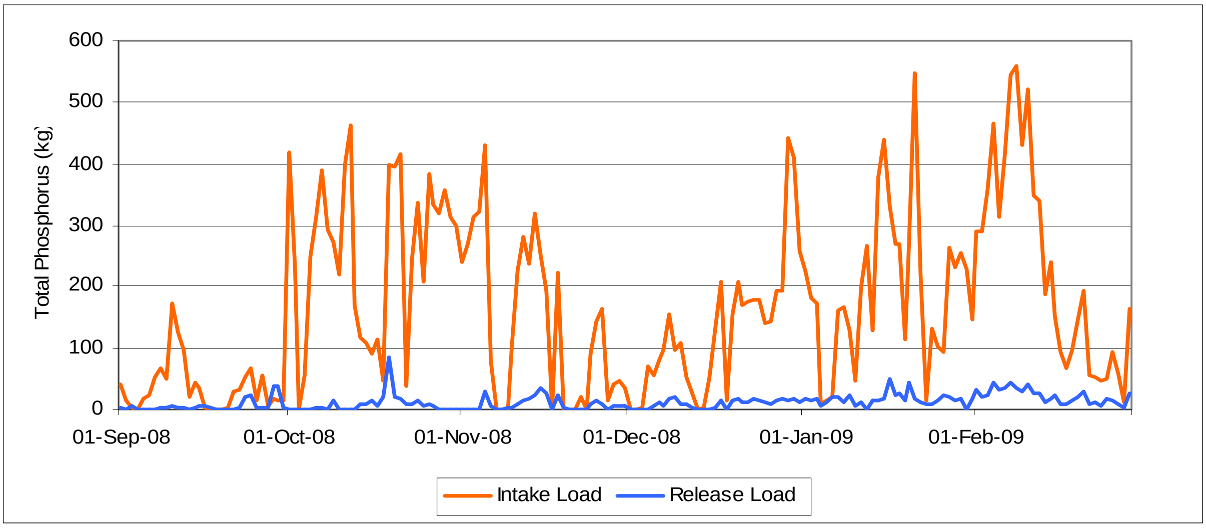

Figure 4: Luggage Point AWTP - daily intake and release loads of total phosphorus (kg).

Nitrogen

In contrast to phosphorus, there is no significant reduction in nitrogen load through the main AWTP process, and the potential exists to increase the nitrogen load due to the addition of chloramine disinfectant in the AWTP process. This effect is exacerbated by ammonia being dosed in excess of chloramine formation to ensure the absence of free chlorine in the RO feed.

Bundamba AWTP. The ROC treatment train at Bundamba is achieving substantial nitrogen removal (35% reduction for that plant) and ensuring the 3 mgN/L nitrogen Healthy Waterways Strategy target (equating to 18 mgN/L in ROC) is being achieved at this plant. Indeed, the mass balance shows that this treatment is largely responsible for the overall 13% net reduction in nitrogen load for the scheme, in spite of the nitrogen added with chloramination at all AWTPs.

The Bundamba ROC treatment process consists of the following steps in series (refer Figure 3):-

- Moving bed biofilm reactor (MBBR) nitrification process for ammonia conversion to nitrate (2 units in parallel followed by one unit in series, all aerated and using Anox/Kaldnes™ media);
- Solids contact clarification process (duty/standby units), treating flow from the upstream MBBR and the downstream filter backwash for chemical phosphorus removal and solids separation;
- Denitrification filter process for nitrate and solids reduction (3 duty/1 standby units), using sand media and with methanol dosing for carbon addition (WCRWS 2008).

The current average ROC nitrate concentration of 5 mgN/L indicates that further optimisation of the Bundamba denitrification filters may achieve lower nitrate levels and even greater nitrogen reduction at this plant and across the scheme.

Luggage Point and Gibson Island AWTPs. At present, no nitrogen reduction processes have been implemented for the Luggage Point and Gibson Island AWTPs. At Gibson Island this is due to feed nitrogen levels being lower than the Healthy Waterways target (1.8 mgN/L in the feed water versus 3 mgN/L target) and ROC concentrations meeting DA requirements without additional treatment.

For Luggage Point AWTP, uncertainty existed with the long-term total nitrogen levels in the treated wastewater feed, as the WWTP was undergoing nitrogen reduction optimisation in parallel with the Western Corridor project delivery phase. The capacity to transfer up to 40 ML/d of Luggage Point treated wastewater as feed to the Gibson Island AWTP was also implemented during this initial project phase. As a result, implementation of nitrogen reduction as part of the AWTP was deferred until greater certainty of the need and the requirements for nitrogen reduction was established.

Options for nitrogen reduction at Gibson Island and Luggage Point AWTPs include:-

- External carbon addition to the secondary anoxic zone of the Luggage Point WWTP may enhance nitrogen reduction at the WWTP.
- Options for nitrogen removal at the Luggage Point and Gibson Island AWTPs have been considered, including biological pretreatment and ROC post-treatment using such process configurations as denitrifying MBBR, wetlands (Kepke, 2008), and denitrification filters.
- As a proportion of the Gibson Island AWTP feed water will come from Luggage Point WWTP, nitrogen reduction pretreatment at Luggage Point prior to diversion to Gibson Island AWTP would reduce both Luggage Point and Gibson Island ROC nitrogen loads (refer Figure 5). If this nitrogen reduction pretreatment process was included within the AWTP, the AWTP could potentially treat water for nutrient removal independent of the demand for recycled water by directing excess pre-treated water to the existing outfall of the WWTP (albeit with appropriate sharing of costs and risks with other stakeholders such as the Luggage Point WWTP).

The magnitude of nitrogen removal benefits needs to be balanced with capital cost, particularly when the AWTPs don’t operate continuously or at capacity, as the AWTPs only remove nutrients when operating and do so only in proportion to their production rate. Due to recent rains refilling regional water storages and reduction in demand for recycled water (also due to maintenance shutdowns of industrial users), this has emerged as an important consideration.

Ammonia

As described, ammonia reduction has been included in the ROC treatment process at Bundamba AWTP using a nitrifying MBBR process. This has been included to reduce the nitrogen load, but to also reduce potential ammonia toxicity and dissolved oxygen sag effects in a more constrained receiving environment. Ammonia levels in the ROC have easily met DA requirements to date.

Ammonia reduction has not been implemented for Gibson Island or Luggage Point ROC at present, as while the results of DTA testing of the ROC indicate low to moderate toxicity, this toxicity does not necessarily appear to be linked to ammonia concentrations. Further investigation of the contribution of ammonia to toxicity at these locations will continue over the next year.

Metals

Although metals are likely to contribute to some extent to the low to moderate ROC toxicity, given the effectiveness of diffusers at each of the ROC outfalls, they are unlikely to cause acute or chronic toxic effects in the receiving environment. Work will continue to assess the source and fate of metal contaminants, as the relative contributions of ferric chloride dosing (and its metal impurities), wastewater feed contaminants and the effectiveness of metals removal in the AWTP pretreatment processes with respect to metals concentrations in the ROC, are not known.

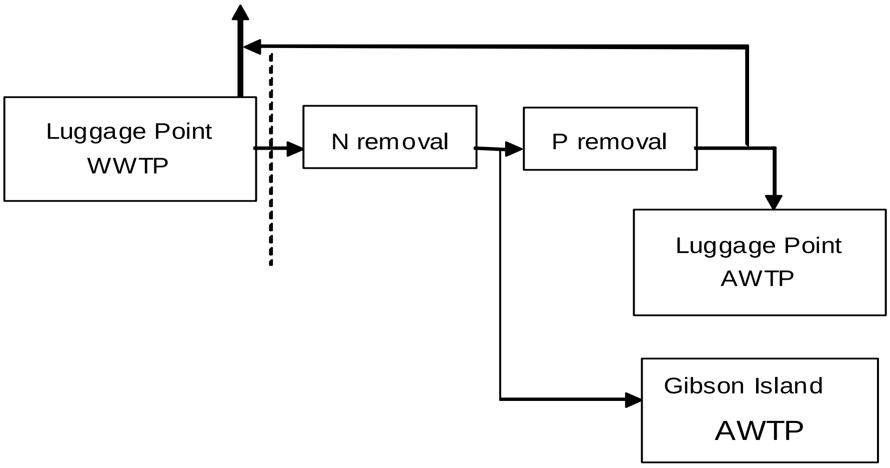

Figure 5: Option for pretreatment reduction of Luggage Point treated wastewater nitrogen loads.

Unknowns

Despite the low to moderate ROC toxicity measured to date, and although the large majority of contaminants in the ROC would have otherwise been discharged to the waterway from the WWTP (and are likely to have been doing so for many years), it is still considered important to better understand the characteristics and constituents of ROC and to continue research into emerging contaminants and those yet identified. This research work will continue over the life of the scheme.

CONCLUSIONS

This paper summarises initiatives to date with respect to contaminant reduction associated with the Western Corridor Scheme. Contaminants targeted in the initiatives include nitrogen and phosphorus for total nutrient load reduction; and ammonia, chlorine and metals for toxicity effects.

The AWTPs have shown significant load reduction of some contaminants, with 80–90% reduction in phosphorus loads across all plants and nitrogen reduction across the scheme of about 13% via the ROC treatment process at Bundamba AWTP. Potential toxicity has been effectively reduced by dechlorination and diffusion of ROC at all AWTPs and ammonia reduction at Bundamba AWTP.

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